**University of São Paulo
“Luiz de Queiroz” College of Agriculture**

**Multicriteria decision analysis applied to the spatial allocation of
crops as a planning support system for agricultural expansion in
Brazil**

Akenya Freire de Alkimim

Thesis presented to obtain the degree of Doctor in
Science. Area: Soils and Plant Nutrition

**Piracicaba
2014**

Akenya Freire de Alkimim
Geographer

**Multicriteria decision analysis applied to the spatial allocation of crops as a
planning support system for agricultural expansion in Brazil**

versão revisada de acordo com a resolução CoPGr 6018 de 2011

Advisor:
Prof. Dr. **GERD SPAROVEK**

Co-Advisor:
Prof. Dr. **KEITH CLARKE**

Thesis presented to obtain the degree of Doctor in
Science. Area: Soils and Plant Nutrition

Piracicaba
2014

Dados Internacionais de Catalogação na Publicação
DIVISÃO DE BIBLIOTECA - DIBD/ESALQ/USP

Alkimim, Akenya Freire de

Multicriteria decision analysis applied to the spatial allocation of crops as a planning support system for agricultural expansion in Brazil / Akenya Freire de Alkimim. - - versão revisada de acordo com a resolução CoPGr 6018 de 2011. - - Piracicaba, 2014.
244 p: il.

Tese (Doutorado) - - Escola Superior de Agricultura "Luiz de Queiroz", 2013.

1. Planejamento do uso da terra 2. Expansão agrícola 3. Pastagens 4. Logística
5. MCDA 6. AHP 7. SIG I. Título

CDD 631.47
A415m

"Permitida a cópia total ou parcial deste documento, desde que citada a fonte -O autor"

*I dedicate this achievement to you Father, who has
given me strength toward achieving my goals in life.*

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to all those who helped me during the research and writing process of this dissertation. I would also like to acknowledge with much appreciation and gratitude my advisor Keith C. Clarke at UCSB, whose contribution, support, patience, guidance and suggestions helped me to manage my research especially in writing this dissertation. I would also like to thank my Brazilian advisor Gerd Sparovek for introducing me to the dissertation topic as well for the support on the way.

Furthermore, I would like to acknowledge the financial support of the Coordination for the Support and Evaluation of Graduate Education (CAPES) and the National Council for Scientific and Technological Development (CNPq) in granting me a doctoral scholarship. I would also like to acknowledge the assistance and support the Fulbright scholarship (CAPES- Fulbright doctoral sandwich scholarship) has brought to the development of my studies.

CONTENTS

RESUMO	11
ABSTRACT.....	13
1 INTRODUCTION	15
References	21
2 MANAGEMENT, THE PARTICIPATORY APPROACH AND STRATEGIC PLANNING FOR AGRICULTURE	25
Abstract.....	25
2.1 Introduction	25
2.2 The role of sugarcane in the Brazilian agriculture	27
2.3 Agricultural expansion and deforestation.....	29
2.4 The role of logistics in the spatial management and strategic planning for agriculture	31
2.5 The analytic hierarchy process (AHP) as a multicriteria decision making tool for spatial planning.....	38
2.6 Conclusions	42
References	44
3 MULTICRITERIA DECISION ANALYSIS APPLIED TO THE SPATIAL ALLOCATION OF SUGARCANE AS A PLANNING SUPPORT SYSTEM FOR AGRICULTURAL EXPANSION IN BRAZIL.....	51
Abstract.....	51
3.1 Introduction	51
3.2 Materials and Methods	53
3.2.1 MCDA in sites selection for sugarcane expansion in Brazil.....	53
3.2.2 Data input	57
3.2.3 Primary data processing	59
3.2.3.1 Soils	59
3.2.3.1.1 Spatial distribution of soil data	60
3.2.3.2 Climate.....	60
3.2.3.2.1 Climate suitability for sugarcane.....	64
3.2.3.3 Topography.....	65
3.2.3.4 Physical land suitability evaluation modeling.....	66
3.2.3.5 Infrastructure.....	67
3.2.3.6 Socioeconomic data	68

3.2.4 Secondary data processing.....	70
3.2.4.1 Multicriteria evaluation for site suitability analysis	70
3.2.4.2 The decision making process.....	71
3.2.4.3 Scenario analysis	80
3.3 Results	81
3.3.1 The physical land suitability submodel.....	81
3.3.2 Geoprocessing of infrastructure accessibility	85
3.3.3 Socioeconomic data classification	95
3.3.4 Judgment synthesis of prioritization decisions	100
3.3.5 Multicriteria analysis for spatial decision support	101
3.3.6 Scenario analysis	108
3.4 Discussion and Conclusions	118
References	124
4 A COMPARATIVE ANALYSIS OF PASTURES WITH LAND SUITABILITY FOR SOYBEAN AND SUGARCANE PRODUCTION	131
Abstract	131
4.1 Introduction	131
4.2 Material and Methods.....	134
4.2.1 Soil	135
4.2.2 Climate	135
4.2.2.1 Radiation and Temperature Index.....	135
4.2.2.2 Water and Temperature Index	135
4.2.2.3 Basal Temperature Index.....	136
4.2.3 Topography	136
4.2.4 Supporting the decision making using the analytic hierarchy process (AHP)	136
4.2.5 Using multicriteria decision analysis in decision making for soybean allocation	137
4.2.6 Alternative judgments for scenario analysis.....	138
4.3 Results	139
4.3.1 Physical land suitability submodel for soybean.....	139
4.3.2 Judgment synthesis of prioritization decisions	141
4.3.3 Implementation of multicriteria decision analysis for the location of pasturelands that are best suited for soybean expansion	142

4.3.4 Implementing scenario analysis.....	145
4.3.5 Soybean versus sugarcane suitability	159
4.4 Discussions and Conclusions	162
References	165
APPENDICES.....	171

RESUMO

Análise de decisão multicritério aplicada à alocação espacial de culturas como um sistema de apoio ao planejamento da expansão agrícola no Brasil

A história do avanço da fronteira agrícola no Brasil tem sido intrinsecamente relacionada ao desmatamento. Embora perdas ambientais sejam, por vezes, inevitáveis no contexto de uma expansão agrícola, elas devem ser reduzidas sempre que possível. Tentando não seguir um padrão de desenvolvimento feito à custa de desmatamentos, e pensando numa forma mais sustentável de expansão da agricultura, nós avaliamos nesse estudo a possibilidade de expansão agrícola, para produção de alimentos e de biocombustíveis, sem o comprometimento do ecossistema natural existente no país. O Brasil tem um grande potencial agrícola atribuído à significativa quantidade de solos aptos para agricultura com clima e topografia favoráveis. Para abastecer o mercado agrícola nacional e assumir uma posição de liderança global na exportação de alimentos e biocombustíveis, ações devem ser tomadas pelo Brasil para o planejamento desse potencial de expansão. Esse planejamento seria um modelo alternativo para o avanço da fronteira agrícola, oposto aos padrões de avanço anteriores diretamente relacionados ao desmatamento. Uma forma de conseguir um padrão de desenvolvimento sustentável poderia ser pela identificação de terras agrícolas aptas à essa expansão sem estimular maiores perdas de florestas. As pastagens ocupam grandes áreas no Brasil e são consideradas recursos estratégicos para a eficácia dessa expansão, uma vez que representam áreas que já foram desmatadas e oferecem algum tipo de infraestrutura. Dado o atual potencial biofísico de produção, estima-se que as áreas de pastagem destinadas à pecuária bovina podem estar sendo subutilizadas. O objetivo desse trabalho é desenvolver um modelo de alocação espacial fundamentado numa análise de decisão multicritério e SIG com base na aptidão agrícola das terras, de forma a fornecer informações geoespaciais estratégicas aos tomadores de decisão sobre a localização das áreas potenciais para a expansão da cana-de-açúcar e soja no Brasil. A análise de decisão multicritério (MCDA) consiste na integração de dados edafoclimáticos, de infraestrutura e socioeconômicos para a identificação das áreas de pastagens aptas para a alocação dessas culturas. Para aumentar a confiabilidade do modelo, uma equipe de especialistas em cana-de-açúcar e soja foi selecionada para julgar a prioridade das variáveis no processo de análise. A combinação dos julgamentos fornece uma prioridade geral das variáveis, as quais alimentam o modelo. "E se" cenários foram também elaborados para mostrar como as mudanças nos pesos dos critérios modificariam a distribuição espacial das classes de aptidão com relação ao modelo principal. Os resultados são exibidos através de mapas que representam a distribuição das classes de aptidão agrícola para a alocação dos cultivos da cana-de-açúcar e soja. As pastagens tornam-se tanto mais adequadas para a alocação da cana ou soja de acordo com as mudanças na influência de cada critério no modelo. Os modelos projetados mostram resultados favoráveis que podem ajudar os tomadores de decisão com informações geoespaciais que identificam áreas prioritárias onde investimentos e esforços deveriam ser direcionados para estimular a expansão agrícola sustentável no Brasil.

Palavras-chave: Planejamento do uso da terra; Expansão agrícola; Pastagens; Logística; MCDA; AHP; SIG

ABSTRACT

Multicriteria decision analysis applied to the spatial allocation of crops as a planning support system for agricultural expansion in Brazil

The history of the advancement of the agricultural frontier in Brazil has been closely related to environmental losses. Although environmental losses are sometimes inevitable in the context of agricultural expansion, they should always be minimized. This study seeks to avoid the past pattern of development by proposing a more sustainable way of expanding agriculture. The research tests whether it is possible to expand the cultivation of food and fuel crops in Brazil without compromising natural ecosystems. Brazil has a great agricultural potential considering the significant amount of lands that is suitable for agriculture with a favorable climate and topography. To supply the domestic agricultural market and for Brazil to take on a global food and biofuel export leadership position, actions should be taken to plan for this potential sustainable expansion. This planning would be an alternative means of advancing the agricultural frontier, as opposed to the deforestation previously practiced. A way to accomplish a sustainable pattern of agricultural development could be by the identification of suitable areas to support the expansion without further loss of forestlands. Pasture is a type of land use that occupies large areas in Brazil, and pastures are considered strategic resources for the effectiveness of the proposed expansion, given that they represent areas that have already been deforested and offer some type of existing infrastructure. In addition, from the current biophysical potential production - pasture based beef cattle - may be underused. The goal of this dissertation is to develop a spatial allocation model based on a multicriteria decision making and geographic information systems (GIS) using land suitability analysis to support decision makers with geospatial information about where potential areas for sugarcane and soybean expansion are located in Brazil. The multicriteria decision analysis (MCDA) consists of physical land suitability, infrastructure and socioeconomic data integration to identify suitable pasturelands for crop allocation. To enhance the reliability of the model, a team of specialists in the agricultural crops was selected to establish the criteria priorities in the model for the analysis process. The combination of their judgments gives an overall priority that feeds the multicriteria model. "What if" scenarios were also built to show how changes in the criteria priority weights would modify the spatial distribution of suitability classes in relation to the main model. The results yield maps that represent the distribution of suitability classes for sugarcane and soybean expansion. Pasturelands become more or less suitable for sugarcane or soybean allocation according to shifts in the influence of each criterion in the model. The designed models show results that may assist policymakers with geospatial information about priority areas where investments and efforts should be directed for sustainable agricultural expansion in Brazil.

Keywords: Land use planning; Agricultural expansion; Pasture; Logistics; MCDA; AHP; GIS

1 INTRODUCTION

Global food prices have recently shown a major increase and the causes of these high prices are diverse, although it seems to be most likely a supply and demand issue (ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT - OECD, 2011; ABBOTT, 2009). Extensive severe weather incidents in the major food producing countries, diversification of people's diet, rises in grain and fuel prices leading to an increase of transportation costs and production inputs are some of the main factors that have contributed to the global food crisis. In this context, countries like Brazil that have shown a strong performance in the agribusiness sector can contribute to the increase in the supply of agricultural products for the international food market, alleviating the price increases.

Brazil is a leader in producing and exporting agricultural products such as soybean, sugar and ethanol (MARTINELLI et al., 2010). Agribusiness exports contributed 39.3% of Brazil's trade surplus in 2011 (BRASIL, 2012) and agricultural products account for almost 4% of the GDP (CENTRO DE ESTUDOS AVANÇADOS EM ECONOMIA APLICADA - CEPEA, 2012). The agricultural outlook for 2012-2021 predicts that among emerging countries like China and India, Brazil will grow 4.3% p.a. As reported by OECD-FAO (2012) these countries are considered the main drivers of the world economy. The projection leads us to believe that Brazil will assume an important role in the world agricultural market in the coming years, in view of the fact that it may contribute to increased exports to meet the global demand for both food (BARROS, 2009) and biofuel (OECD-FAO, 2010).

Brazil has shown significant growth in international agribusiness since 1970, becoming the first tropical agricultural country able to compete with other great food exporter countries like Canada, Australia, Argentina, the United States and the European Union. Brazilian expansion potential for agriculture compares to or exceeds the entire current U.S. agricultural area. Although the United States has widely incorporated technology, the country faces difficulty in expanding its production due to the limitation of soil and/or climate (FOREIGN AGRICULTURAL SERVICE - FAS, 2012). On the other hand, Brazil has large suitable areas for the advance of agriculture, which constitute a competitive advantage, not only compared to the U.S., but also to other countries. Good biophysical conditions are also available in other parts of the world such as in Asia and Africa. However, those areas

have more limited expansion capacities, since R&D, infrastructure, supply of agricultural technology and goods, strong domestic market essential for the expansion are also taken into account.

The outlook for increasing agricultural production in Brazil is improving (BRASIL, 2012; FEDERAÇÃO DAS INDÚSTRIAS DO ESTADO DE SÃO PAULO - INSTITUTO DE ESTUDOS DO COMÉRCIO E NEGOCIAÇÕES INTERNACIONAIS - FIESP-ICONE, 2012) while the country faces the challenge of increasing production and developing an agriculture with lower environmental impact, and that does not compromise sustainability (FERREIRA et al., 2012). The success of the agricultural sector has been related to past developments made at the expense of extensive destruction of Brazilian ecosystems, and environmental degradation had made Brazil a leader in tropical deforestation, clearing an average of 19,500 km²/year (NEPSTAD et al., 2009). However, a new tendency in agricultural development has been observed with a decrease trend in the Brazilian deforestation, mainly in the Amazon area, reaching lower rates after about 1988 (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2012).

Agriculture growth and its substantial potential for expansion are a reason for much concern about land use practices in Brazil (FAS, 2012), which can contribute to further environmental losses (FOLEY et al., 2007). This issue leads us to the following research questions: (1) How can Brazil increase agricultural production without compromising its sustainability? (2) Can the expansion of croplands in Brazil be conducted without deforestation or loss of natural resources by identifying suitable agricultural areas to support this expansion? (3) Can a suitable model be created that considers not just the land suitability for crops, but also takes into consideration the spatial pattern of infrastructure as well as socioeconomic factors?

The history of agricultural expansion in Brazil shows that the advancement of the agricultural frontier is directly related to the loss of natural ecosystems with negative impacts on biodiversity, soil and water (KLINK; MACHADO, 2005; FEARNSSIDE, 2005; MORTON et al., 2006; MARTINELLI; FILOSO, 2008; PARDINI et al., 2010; PERES et al., 2010). Even so, an advance in the rate of expansion, in the short term, is possible without an increase in pressure on the environment in the country (SPAROVEK et al., 2011; FIESP-ICONE, 2012; LIMA et al., 2012).

Therefore, this dissertation seeks to examine the means by which this goal can be achieved.

The management of changes in the pattern of Brazilian agricultural expansion requires innovative solutions to provide the stakeholders responsible for governing and planning the space with visual strategic information. One way to accomplish this, in the short term, may be through the identification of suitable cultivated pasturelands that could be converted to agricultural plantations while considering economic, social, environmental, and infrastructure criteria by using Geographic Information Systems (GIS).

By converting pastures that are potentially suitable for agriculture into croplands, we will make suitable land available in sufficient quantities for future expansion of agricultural frontier avoiding indirect land use changes in the short term in Brazil. As stated by Sparovek et al. (2011), a sustainable agricultural expansion in the country could be directed toward pasturelands with moderate and high agricultural potential in order to increase production while also minimizing environmental damage. According to a survey conducted by FAS (2012), most of the existing pasturelands in the country can easily sustain agricultural production. These lands are characterized mainly by low slope and good fertility, and are located in regions where it is possible to produce without irrigation (SPAROVEK et al., 2011).

Pasturelands occupy a large amount of land compared to other types of land use, such as soybean and sugarcane, among the many other crops in Brazil (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE, 2012; SPAROVEK et al., 2007). Those areas are considered strategic locations for the advancement of agriculture due to their easy conversion, lack of use restrictions, and low cost of deployment for infrastructure, thus avoiding additional deforestation (FAS, 2012). Besides the advantage of avoiding deforestation, agricultural products grown in these areas can become more competitive in the international market since they can satisfy environmental standards of quality that meet the current requirements of this market. Additionally, as happened in the advancement of the agricultural frontier in past decades, these areas would contribute to attracting migration to distant regions of the country, allowing their development. As reported by Graham, Gauthier and De Barro (1987) and Pereira et al. (2012), the application of new technologies in Brazilian agriculture propitiated the expansion of the agricultural frontier in the country to remote areas previously considered “unproductive”.

The Brazilian paradigm of agricultural expansion in following years will take place on pasturelands by the recuperation of degraded areas and the intensification of livestock farming (LIMA et al., 2012). This expansion tendency can be perceived spatially by the conversion of pasturelands into productive crop production through the gains in productivity and production efficiency of beef cattle and milk that reduces the area allocated for livestock (FIESP-ICONE, 2012).

Agricultural expansion in Brazil, even though profitable, may still not be suitable if it is not effectively employed through appropriate planning. Peters and Thielmann (2008) consider that for an expansion to be advantageous, it is vital that countries review the availability of sites for new plantations, and the potential for competition be inserted into the current patterns of land use. Ligtenberg et al. (2004) state that land use planning can guide the organization of the spatial environment, promoting the integration of different criteria while also meeting the demands of society.

Unplanned expansion is considered one of the most challenging problems in developing countries, as it imposes many social, economic and environmental limitations (LOTFI; HABIBI; KOOHSARI, 2009). Failure to establish sustainable agricultural expansion could instigate socioeconomic and environmental impacts that would contribute to further deforestation of intact forests, and increase the amount of CO₂ emitted to the atmosphere, as opposed to reducing it (FUJISAKA et al., 1998; FARGIONE et al., 2008; TILMAN et al., 2009; METZGER et al., 2010). In addition, it can also lead to the fragmentation of biodiversity (SCHLESINGER et al., 2008; CARVALHO; DE MARCO JÚNIOR; FERREIRA, 2009). Consequently, this would represent an important missed opportunity for the improvement of human and natural systems, one that would have global impacts (MARTINELLI et al., 2010).

A suitable allocation of croplands in Brazil is a key factor for agricultural expansion planning that considers social, economic, infrastructure and environmental characteristics. However, most national scale studies are limited to physical land suitability modeling without much concern about infrastructure availability or other socioeconomic factors that should be taken into consideration in the identification of potential sites for agricultural expansion (LAPOLA; PRIESS; BONDEAU, 2009; MANZATO et al., 2009; WORLD WILDLIFE FUND - WWF, 2008).

This study proposes to gather social, economic, infrastructure and environmental information to make a systematic model. The model shows suitable

locations for sugarcane and soybean production in areas of current pasture through the combination of those criteria and using experts opinions to judge the importance of each of the selected variables in the agricultural expansion scenario. Sugarcane and soybean were the crops selected in this study because of their importance to the Brazilian agriculture (IBGE, 2010)

The MCDA methodology was used to substantiate the model design contributing to the spatial planning of potential areas for agricultural expansion of both crops in Brazil. Geotechnology for data modeling was applied together with the MCDA through the use of GIS to simplify data presentation, which aims at providing information that assists in managing the geographic areas (KALOGIROU, 2002; MIN; ZHOU, 2002; MUNROE; SOUTHWORTH; TUCKER, 2002; DE PAZ; SANCHEZ; VISCONTI, 2006; SILVEIRA; DENTINHO, 2010). According to Seelan et al. (2003), the application of GIS facilitates more accurate intervention for attracting socioeconomic benefits and decreasing environmental impacts.

Based on the arguments presented, this study: (i) has designed and implemented a model, using MCDA, which identifies the spatial location of potential cultivated pasturelands that could be used for an agricultural expansion of sugarcane and soybean production, aiming to contribute to a more sustainable agricultural development in the country; (ii) has considered potential areas of cultivated pasture for agricultural expansion by including economic, social, environmental and infrastructure variables; (iii) has given an overview of the spatial dynamics of the logistic and transportation networks that have a substantial impact on the competitiveness of Brazilian agricultural products; and (iv) has provided information to support decision making for private and government investment in public policies by indicating areas where these actions should be focused.

In Chapter 2, we present an overview of the role of sugarcane in the Brazilian agriculture and the deforestation associated with agricultural expansion in Brazil. We attempt to combine multiple components of the environment system to develop a model that not only focuses on a physical land suitability evaluation for crops, but also assesses areas with infrastructure accessibility. Considering that, a discussion on the role of logistics in spatial management and strategic planning for agriculture is addressed, identifying the main routes of agricultural products transportation, exposing the weaknesses in the current configuration of the infrastructure and the transportation bottlenecks that exist in the country. To sustain the dynamics of the

multilayered system proposed in this study, data were analyzed from questionnaires to capture the intuitive ideas of specialists in the agricultural crops about the importance of a set of criteria in the selection of sites for sugarcane and soybean allocation. To do so, we review the application of the analytic hierarchy process (AHP) as a decision making technique for spatial planning.

Chapter 3 presents the MCDA for sugarcane allocation, which identifies areas of possible expansion for this type of crop by combining a physical land suitability submodel with infrastructure accessibility and socioeconomic criteria. Firstly, we converted all the scripting language of the factors that composed a previous physical land suitability model for the map algebra language in the GIS software ArcGIS 10 into its graphical process language ModelBuilder. The combination of different rasters (soil, climate, biome, land use and topography) resulted in the physical land suitability submodel that was the basis of our work. Secondly, submodels were created in ModelBuilder representing the socioeconomic and infrastructure criteria factors as GIS raster data layers. Thirdly, sugarcane specialists judged the importance of the factors considered in the MCDA for sugarcane allocation, by conducting a survey exercise that revealed their factor preferences. Fourthly, physical land suitability, infrastructure and socioeconomic data were processed in the GIS-based MCDA model representing the experts' knowledge with the objective of progressing toward future predictions of landscapes across Brazil. Fifthly, alternative scenarios were built, based on different combinations of weights given by the specialists in the decision making analysis. The alternative scenarios show different perspectives on the factor preferences and can provide stakeholders with information that demonstrates which measures would be most effective in moving toward better agricultural expansion planning in the country.

In Chapter 4, the same methodology is applied to the selection of sites for soybean expansion. The chosen criteria were slightly different from those previously presented in the sugarcane model. We also added overlaid maps, which compare the sugarcane and soybean models. The analysis allows an understanding of the differences between pairs of maps, concerning the spatial distribution of areas either more suitable for sugarcane or soybean allocation. Both in Chapter 3 and in Chapter 4, the data gathered show areas according to their suitability for the potential allocation of crops. The maps created may provide leaders with information on where

they can address investment in public and private policies to support sustainable agricultural expansion in Brazil. The goal of this study is to produce information that can contribute to support a sustainable land use, supplying the creation of lines of development in areas of possible expansion of agriculture.

References

ABBOTT, P. **Development dimensions of high food prices**. Paris: OECD Publ., 2009. 95 p.

BARROS, G. Brazil: the challenges in becoming an agricultural superpower. In: BRAINARD, L.; MARTINEZ-DIAZ, L. (Ed.). **Brazil as an economic superpower?: understanding Brazil's changing role in the global economy**. Virginia: R.R. Donnelley, 2009. chap. 4, p. 81-109.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. Assessoria de Gestão Estratégica. **Indicators and statistics of the Brazilian balance of trade**. Disponível em: <<http://www.agricultura.gov.br/internacional/indicadores-e-estatisticas/balanca-comercial>>. Acesso em: 02 fev. 2012.

CARVALHO, F.; DE MARCO JÚNIOR, P.; FERREIRA, L.G. The Cerrado into-pieces: Habitat fragmentation as a function of landscape use in the savannas of central Brazil. **Biological Conservation**, Edinburgh, v. 142, n. 7, p. 1392-1403, July 2009.

CENTRO DE ESTUDOS AVANÇADOS EM ECONOMIA APLICADA. **Brazilian Agribusiness GDP 1994 to 2011**. Disponível em: <<http://cepea.esalq.usp.br/pib/>>. Acesso: 01 jun. 2012.

DE PAZ, J.; SANCHEZ, J.; VISCONTI, F. Combined use of GIS and environmental indicators for assessment of chemical, physical and biological soil degradation in a Spanish Mediterranean region. **Journal of Environmental Management**, New York, v. 79, n. 2, p. 150-162, Apr. 2006.

FEARNSIDE, P.M. Deforestation in Brazilian Amazonia: history, rates, and consequences. **Conservation Biology**, New York, v. 19, n. 3, p. 680-688, June 2005.

FEDERAÇÃO DAS INDÚSTRIAS DO ESTADO DE SÃO PAULO - INSTITUTO DE ESTUDOS DO COMÉRCIO E NEGOCIAÇÕES INTERNACIONAIS. **Outlook Brazil 2022: agribusiness projections**. São Paulo, 2012. 132 p.

FERREIRA, J.; PARDINI, R.; METZGER, J.P.; FONSECA, C.R.; POMPEU, P.S.; SPAROVEK, G.; LOUZADA, J. Towards environmentally sustainable agriculture in Brazil: challenges and opportunities for applied ecological research. **Journal of Applied Ecology**, Oxford, v. 49, n. 3, p. 535-541, Apr. 2012.

FOLEY, J.A.; ASNER, G.P.; COSTA, M.H.; COE, M.T.; DEFRIES, R.; GIBBS, H.K.; HOWARD, E.A.; OLSON, S.; PATZ, J.; RAMANKUTTY, N.; SNYDER, P. Amazonia revealed: forest degradation and loss of ecosystem goods and services in the Amazon Basin. **Frontiers in Ecology and the Environment**, Washington, v. 5, n. 1, p. 25-32, Feb. 2007.

FOREIGN AGRICULTURAL SERVICE. **Brazil**: future agricultural expansion potential underrated. 2003. Disponível em: <http://www.fas.usda.gov/pecad2/highlights/2003/01/ag_expansion/>. Access: 18 abr. 2012.

GRAHAM, D.H.; GAUTHIER, H.; DE BARROS, J.R.M. Thirty years of agricultural growth in Brazil: crop performance, regional profile, and recent policy review. **Economic Development and Cultural Change**, Chicago, v. 36, n. 1, p. 1-34, Oct. 1987.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Censo agropecuário 2006**: segunda apuração. Rio de Janeiro, 2012. 774 p.

_____. **Produção agrícola municipal**. Rio de Janeiro, 2010. 91 p.

INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS. **PRODES Project**: Program for Deforestation Assessment in the Brazilian Legal Amazon. 2012. Disponível em: <<http://www.obt.inpe.br/prodes/>>. Acesso: 01 nov. 2012.

KALOGIROU, S. Expert systems and GIS: an application of land suitability evaluation. **Computers, Environment and Urban Systems**, New York, v. 26, n. 2, p. 89-112, Mar./May 2002.

KLINK, C.A.; MACHADO, R.B. Conservation of the Brazilian cerrado. **Conservation Biology**, Boston, v. 19, n. 3, p. 707-713, June 2005.

LAPOLA, D.; PRIESS, J.; BONDEAU, A. Modeling the land requirements and potential productivity of sugarcane and jatropha in Brazil and India using the LPJmL dynamic global vegetation model. **Biomass & Bioenergy**, New York, v. 33, n. 8, p. 1087-1095, Aug. 2009.

LIGTENBERG, A.; WAXHOWICZ, M.; BREGT, A.K.; BEULENS, A.; KETTENIS, D.L. A design and application of a multi-agent system for simulation of multi-actor spatial planning. **Journal of Environmental Management**, New York, v. 72, n. 1/2, p. 43-55, Aug. 2004.

LIMA, R.C.A.; NASSAR, A.; HARFUCH, L.; CHIODI, L. ANTONIAZZI, L.; MOREIRA, M. **Low impact agriculture**: building the Brazilian green economy. São Paulo: ICONE, 2012. 29 p.

LOTFI, S.; HABIBI, K.; KOOHSARI, M.J. An analysis of urban land development using multi-criteria decision model and geographical information system (a case study of Babolsar City). **American Journal of Environmental Sciences**, New York, v. 5, n. 1, p. 87, Sept. 2009.

MANZATO, C.V.; ASSAD, E.D.; BACCA, J.F.M.; ZARONI, M.J.; PEREIRA, S.E.M. **Zoneamento agroecológico da cana-de-açúcar**. Rio de Janeiro: Embrapa Solos, 2009. 55 p.

MARTINELLI, L.; NAYLOR, R.; VITOUSEK, P.M.; MOUTINHO, P. Agriculture in Brazil: impacts, costs, and opportunities for a sustainable future. **Current Opinion in Environmental Sustainability**, Maryland Heights, v. 2, n. 5/6, p. 431-438, Dec. 2010.

MARTINELLI, L.A.; FILOSO, S. Expansion of sugarcane ethanol production in Brazil: environmental and social challenges. **Ecological Applications**, Arizona, v. 18, n. 4, p. 885-898, 2008.

MIN, H.; ZHOU, G. Supply chain modeling: past, present and future. **Computers & Industrial Engineering**, Amsterdam, v. 43, n. 1/2, p. 231-249, July 2002.

MORTON, D.C.; DEFRIES, R.S.; SHIMABUKURO, Y.E.; ANDERSON, L.O.; ARAI, E.; DEL BON ESPIRITO-SANTO, F.; FREITAS, R.; MORISETTE, J. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. **Proceedings of the National Academy of Sciences of the USA**, Washington, v. 103, n. 39, p. 14637-14641, July 2006.

MUNROE, D.; SOUTHWORTH, J.; TUCKER, C. The dynamics of land-cover change in western Honduras: exploring spatial and temporal complexity. **Agricultural Economics**, New York, v. 27, n. 3, p. 355-369, Nov. 2002.

NEPSTAD, D.; SOARES-FILHO, B.S.; MERRY, F.; LIMA, A.; MOUTINHO, P.; CARTER, J.; BOWMAN, M.; CATTANEO, A.; RODRIGUES, H.; SCHWARTZMAN, S.; MCGRATH, D.G.; STICKLER, C.M.; LUBOWSKI, R.; PIRIS-CABEZAS, P.; RIVERO, S.; ALENCAR, A.; ALMEIDA, O.; STELLA, O. The end of deforestation in the Brazilian Amazon. **Science**, Washington, v. 326, n. 5958, p. 1350-1351, Feb. 2009.

ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT. **Rising food prices: causes and consequences**. 2008. Disponível em: <<http://www.oecd.org/trade/agricultural-trade/40847088.pdf>>. Acesso: 15 abr. 2011.

ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT - FAO. **Agricultural outlook 2010-2019**. Rome: FAO, 2010. 247 p.

_____. **Organization for Economic Co-Operation and Development, Food and Agricultural Organization of the United Nations: agricultural outlook 2012-2021**. Rome, 2012. 281 p.

PARDINI, R.; DE ARRUDA BUENO, A.; GARDNER, T.A.; PRADO, P.I.; METZGER, J.P. Beyond the fragmentation threshold hypothesis: regime shifts in biodiversity across fragmented landscapes. **Plos One**, San Francisco, v. 5, n. 10, p. e13666, Oct. 2010.

PEREIRA, P.A.A.; MARTHA JUNIOR, G.B.; SANTANA, C.A.M.; ALVES, E. The development of Brazilian agriculture: future technological challenges and opportunities. **Agriculture & Food Security**, London, v. 1, n. 4, p. 1-12, 2012.

PERES, C.A.; GARDNER, T.A.; BARLOW, J.; ZUANON, J.; MICHALSKI, F.; LEES, A.C.; VIEIRA, I.C.G.; MOREIRA, F.M.S.; FEELEY, K.J. Biodiversity conservation in human-modified Amazonian forest landscapes. **Biological Conservation**, Barking, v. 143, n. 10, p. 2314-2327, Oct. 2010.

PETERS, J.; THIELMANN, S. Promoting biofuels: Implications for developing countries. **Energy Policy**, Guildford, v. 36, n. 4, p. 1538-1544, Apr. 2008.

SCHLESINGER, S.; ORTIZ, L.; MORENO, C.; BERMANN, C.; TEIXEIRA ASSIS, W.F. **Novos caminhos para o mesmo lugar: a falsa solução dos agrocombustíveis**. Porto Alegre: Núcleo Amigos da Terra/Brasil, 2008. 36 p.

SEELAN, S.; LAGUETTE, S.; CASADY, G.M.; SEIELSTAD, G.A. Remote sensing applications for precision agriculture: a learning community approach. **Remote Sensing of Environment**, New York, v. 88, n. 1/2, p. 157-169, Nov. 2003.

SILVEIRA, P.; DENTINHO, T. Spatial interaction model of land use: an application to Corvo Island from the 16th, 19th and 20th centuries. **Computers, Environment and Urban Systems**, New York, v. 34, n. 2, p. 91-103, Mar. 2010.

SPAROVEK, G.; BARRETTO, A.; KLUG, I.; PAPP, L.; LINO, J. A revisão do código florestal brasileiro. **Novos Estudos-CEBRAP**, São Paulo, n. 89, p. 111-135, Mar. 2011.

SPAROVEK, G.; BERNDES, G.; EGESKOG, A.; DE FREITAS, F.L.M.; GUSTAFSSON, S.; HANSSON, J. Sugarcane ethanol production in Brazil: an expansion model sensitive to socioeconomic and environmental concerns. **Biofuels, Bioproducts and Biorefining**, Hoboken, v. 1, n. 4, p. 270-282, Dec. 2007.

WORLD WILDLIFE FUND. **O impacto do mercado mundial de biocombustíveis na expansão da agricultura brasileira e suas consequências para as mudanças climáticas**. Brasília: Programa de Agricultura e Meio Ambiente, 2009. 66 p.

2 MANAGEMENT, THE PARTICIPATORY APPROACH AND STRATEGIC PLANNING FOR AGRICULTURE

Abstract

The objective of this chapter is to present an overview of the role of sugarcane in the Brazilian agriculture and the deforestation associated with agricultural expansion in Brazil. The role of logistics in the spatial management and strategic planning for agriculture are examined, including the configuration of transportation routes in geographic space and the infrastructure bottlenecks that exist in Brazil. A literature review, regarding the analytic hierarchy process (AHP) as a decision making technique for spatial planning, is introduced to provide sufficient information about the methodology that was used to derive weights for a multicriteria decision model of possible sustainable future crop distribution. In the transportation logistics analysis, it was found that the most critical problem is the overuse of Brazil's roads for the transportation of agricultural products and the lack of good transport systems, which compromise the competitiveness of Brazilian agribusiness. The AHP technique was proven to be practical and convenient to obtain quantitative data from subjective judgments to feed the multicriteria model for the allocation of crops. The maps produced in this analysis can provide useful guidance to agricultural management and planning in the future.

Keywords: Agricultural expansion potential; Agricultural production; Logistics; AHP

2.1 Introduction

Meeting the growing global demand for food and biofuels is one of the greatest challenges of modern agriculture. The food insecurity of populations and nations, and problems arising from this question have a global dimension, and can further increase if measures are not taken to solve or at least minimize them, so that food security is achieved (FAO, 1998). Among the actions that could be taken to achieve food security, there are: increases in government subsidies (VORLEY, 2001; ROSEGRANT; CLINE, 2003); investment in social programs, including different agronomic practices, and improvement of infrastructure aimed at reducing the price of food (MALONI; BROWN, 2006; GODFRAY et al., 2010); efforts to supply the global demand for food in a socially and environmentally responsible way, through investment in science and technology (VON BRAUN, 2007); and the creation of suitable conditions for agricultural expansion without causing negative effects on the environment (SPAROVEK et al., 2009; WWF, 2009).

Increasing productivity and/or expanding sustainable agricultural activities are efficient ways to produce food, in adequate quantity and sufficient quality, to supply the demand for food without having to increase the pressure on natural resources. On the other hand, it can also be considered only as a palliative measure. This is because agricultural expansion is not directly related to a reduction in social inequality and to an increase in the capacity of the individual to have access to good food. It is also necessary to have an expansion of purchasing power. To Hoffmann (2006), economic growth generated by agricultural production rarely benefits everyone equally. Thus, actions - besides the food security of populations - should be well planned and executed.

The goal of meeting the needs of the growing world population will prevail in the coming years (TROSTLE, 2008). Therefore, execution and planning of effective actions should be well addressed in order to promote a sustainable agriculture, not only in the environmental aspect, but also socioeconomic to support a population that will go, as projected by United Nations, Department of Economic and Social Affairs - ESA (2007), from the current 7.1 billion to 9.2 billion by 2050. At this juncture, Brazil stands out as one of the countries with the greatest amount of farmland in the world, capable of a major contribution to the increase in not just domestic but world production of foodstuffs (PEREIRA et al., 2012) and also sustainable energy (LEITE et al., 2009).

With an agriculture expansion rate among the highest in the world, it is projected that Brazil will achieve growth in agriculture lands over 40% to 2019 when compared to a 2007-2009 base period (OECD-FAO, 2010). Driven by the necessity to adjust to demand modifications and pressures, Brazilian agriculture has improved its agricultural production capacity, showing a strong performance in the growth of this sector.

The physical land suitability integrated with the scientific-technological transformations that have taken place in the country have allowed the modernization of rural activities through the insertion of modern equipment and methods, and by training labor in the field. The adoption of quality monitoring programs for agricultural products has ensured the production of healthy food, helping the country to achieve more credibility in the international market. Government's agricultural policies and the application of scientific research also sum to this success. These are some of the

characteristics that have added to the development of a new facet of agriculture in Brazil. Not only that, they have contributed to the economy and growth of available jobs in the country.

The objective of this chapter is to explore the role of sugarcane in the Brazilian agriculture, the deforestation associated with agricultural expansion in Brazil, how the current logistics system is organized in the country to better allocate new agricultural areas depending on their accessibility to infrastructure, and the infrastructure bottlenecks that exist in the country. A literature review is presented to provide enough information about the decision making technique used to derive weights for the multicriteria decision analysis model.

2.2 The role of sugarcane in the Brazilian agriculture

The 1970s oil crisis favored the establishment of a national program (Proálcool) created in 1975 with the aim of stimulating domestic fuel ethanol supply obtained from sugarcane. This program was established by the government to respond to the high prices of petroleum derivatives in the international market (SHIKIDA, 1997). At that time, the mix substantially favored ethanol instead of sugar production (BRASIL, 2010).

In the late 1980s, there was a slowdown in productivity growth stimulated by the decrease in the world price of oil, intensified by the departure of state control in this sector (BELIK; RAMOS; VIAN, 1998), which led to aging cane fields and reduction of cultivation, resulting in the decline of agricultural and industrial productivity (UNIÃO DAS INDÚSTRIAS DE CANA-DE-AÇÚCAR - UNICA, 2013). To Alves (2002), deregulating public sector intervention favored self-regulation, increasing the competitiveness of this sector, which resulted in changes in the mix over time.

Farmers started shifting to sugar production in the late 1990s, decreasing the ethanol production in the country (MAPA, 2010). This mix adjusted in the 2000s (Figure 1). The mix was better balanced between the seasons 03/04 and 06/07. Between 07/08 and 08/09, more sugarcane was used toward the production of ethanol instead of sugar. From the season 08/09, the mix had started to become balanced again.

Figure 1 - Mix of sugarcane production during the 2003-2004 to the 2012-2013 seasons in the South-Central region

Source: UNICA (2013)

The economic growth rebound, in the early 2000s, was driven by the insertion of flex fuel cars (MARTINES-FILHO; BURNQUIST; VIAN, 2006), and it was interrupted in 2009 by a slowdown in the growth of sugarcane production (Figure 2), reflecting the economic crisis of 2008, which led the industry to rethink its investments. The global financial crisis directly affected sugarcane productivity. In consequence of it, sugarcane fields over-aged, followed by a poor agricultural yields on top of poor weather conditions, diseases and pests (UNICA, 2013). After being severely impacted by the 2008 global financial crisis, an economic recovery is observed in 2011.

Figure 2 – Development of agricultural productivity (Tons of sugarcane per hectare – TC/Ha) of the South-Central region from 1990 to 2013

Source: IBGE (2013)

Despite the crisis faced by the sugarcane industry, ethanol production in Brazil is expected to represent 28% of global production by 2021 (OECD-FAO, 2012). This trend is the result of a growing demand for renewable energy sources, and as stated by OECD-FAO (2010), Brazil is considered one of the few countries with potential to produce enough to supply both domestic and external demand, being the fastest growing nation in terms of the production of agricultural surpluses.

Biofuel production has acquired great importance in Brazil and in the world (ESCOBAR et al., 2009; BALAT; BALAT, 2009). The country is in a strong position thanks to the favorable edaphoclimatic suitability particularly for sugarcane cultivation, and advantages in biofuels production technology that have contributed significantly to the renewable share within the Brazilian energy matrix. Products derived from sugarcane already represent the second largest source of energy in the country (Figure 3).

Figure 3 - Brazilian energy matrix and supply structure in 2012

Source: SugarCane.org (2013) - Balanço Energético Nacional (2013) and International Energy Agency: World Energy Outlook 2012 and Key World Energy Statistics 2012. Compiled by UNICA

2.3 Agricultural expansion and deforestation

The favorable outcome of agriculture and all other related agribusiness activities have increased the overall competitiveness of Brazil, which is now among the major world producers of high demand agricultural products such as soybean

(FAO, 2011). This puts Brazil in the limelight as the country with the most favorable characteristics to expand production and to meet the increasing demand for food and biofuels. But, at the same time that Brazil attracts attention due to its agricultural expansion potential (BARROS, 2009; OECD-FAO, 2010), the country also draws attention to the deforestation rates that are associated with agricultural expansion, especially in the Amazon (SKOLE; TUCKER, 1993; MORTON et al., 2006).

Between 1995 and 2008, the commodity prices were the main responsible for changes in the deforestation rates. As can be seen from Figure 4, the deforestation rates in the Amazon fluctuate mainly due to changes in commodity prices. Between 2001 and 2004, the deforestation rate rose from 18,165 square kilometers to 27,772 square kilometers. After reaching its peak in 2004, the deforestation rates began to decline and were interrupted by another increase in 2008. As reported by Barreto and Araújo (2012), in 2008, 15% of the deforested areas, nearly 11 million hectares were underused.

Figure 4 - The influence of soybean and cattle prices on the annual deforestation rates in the Amazon
Source: Barreto; Araújo (2012)

Despite fluctuations in deforestation rates, a new tendency in agricultural development has been observed with a decrease trend in the Brazilian deforestation rates that coincides with international policy discussions on climate change, which

have resulted in new policies against deforestation in Brazil (BARRETO; ARAÚJO, 2012). According to the projections of agricultural expansion presented by Lima et al. (2012), the agricultural expansion scenario for 2030 reveals that the Brazilian agriculture will not significantly rely on the conversion of new areas and the deforestation rates will tend to reduce over time.

2.4 The role of logistics in the spatial management and strategic planning for agriculture

To meet the growing global demand for food, logistics have become more and more important, especially in terms of increasing the competitiveness of agricultural products allowing them to reach consumers more quickly and with greater flexibility, and lower cost. Logistics include not just transportation, but the entire workflow chain from planting, growing, sustaining, harvesting and processing of an agricultural crop.

In this dissertation, infrastructure is addressed and not logistics as a whole. To FAO (1976), the location of land for cultivation and the suitability (or existence) of transport services should be taken into consideration in land evaluation wherever is possible. Therefore, the infrastructure and transport conditions of food, such as the availability of a good road network, railroads, waterways and ports for the movement of crops for domestic and foreign markets, plus the distribution of processing facilities and the availability of labor, water and fertilizers, ensure greater competitiveness and profitability for the agricultural sector (BRASIL, 2008).

The spatial patterns of logistics are the underlying factors critical for understanding agricultural spatial dynamics, and are considered a key element at all levels of strategic planning, both operational and tactical, aiming to increase efficiency and decrease operating costs (CAIXETA FILHO, 2010). For this, the circulation routes and means of transportation, and other variables that may influence a certain area are often studied (RENTING; MARSDEN; BANKS, 2003; KOPCZAK; JOHNSON, 2003; BARAT et al., 2007). Thus, the benefits arising from logistics is an optimization of space, which reduces the estimated costs from the place of production to the consumer (WIT et al., 2010; ARAMYAN et al., 2011).

Adequate logistics services reduce the costs and improve the competitiveness of a country, but this has been considered a challenge for Brazil. High operating costs have substantial impacts on the competitiveness of Brazilian products in the

international market (FAS, 2012). The challenges that Brazil faces with its logistics are related to obsolete systems and a low level of efficiency; the quality of railroads; frequent potholes and unpaved roads; lack of operational capability and queues of ships in the ports due to a lack of dock capacity, the number of trucks waiting to unload products in the docks, while the products remain stored in them for a long period of time causing economic loss to the farmers (KAWANO et al., 2012).

Brazil's infrastructure has not kept pace with the growing economy. The transportation costs and storage of agricultural production are considered the main restrictions for sustaining Brazilian competitiveness in the world market (VALDES, 2006; FAS, 2012). Despite the fact that Brazil has had great technological advances in its agribusiness sector in recent years, which contributed to a more competitive cost of Brazilian products in the international market, the country still has set backs due to the cost of the transportation of agricultural products (Figure 5).

Figure 5 - Soybean transport costs to Shanghai (China) according to the main productive states in Brazil and the USA

Source: FAS (2012)

The performance of the supply chain is limited by the poor transportation system in Brazil, which has formed an infrastructure bottleneck, in particular with reference to the quality of the infrastructure. FAS (2012) states that, even though Brazil has, in general, lower labor costs, lower land values and a favorable topography and climate, the competitive advantage of its products is compromised in the international market because of the high costs of production.

The combination and administration of transport modes are inefficient in Brazil. As reported by IBGE (2012), the country has more than 29,000 km of navigable rivers, of which only 5% is used to transport grain harvested in the country, while 67% is shipped by trucks. Also, according to the same source, during the period of 1990 and 2000, transport by roads accounted for about 70% of the total shipping in the country, in contrast to the United States (26%) and China (8%). These data show an over-dependence on road transportation (LICIO; CORUCCI, 1996). Railroads are more appropriate than roads for transporting high volumes of crop yields over long distances at low cost. However, they are not an effective mode of transport in Brazil, as a result trucks do the transport of the greater part of the agricultural production.

Railroads are intrinsically linked to the economic and political history of agriculture in Brazil, counting on the investment of large farmers in the past. The material used in their construction came to Brazil, generally, as scrap. Besides, the use of different types of gauges, and the poor technology employed in their construction, which does not meet current standards of transportation, complicates the operational integration between railroads. In some areas, railroads connect one place to nowhere, which causes the railroads to be dispersed and isolated, hindering the integration between markets (DEPARTAMENTO NACIONAL DE INFRAESTRUTURA DE TRANSPORTE – DNTI, 2013).

The logistics in Brazil are distributed in zones designated as transport corridors (FINANCIADORA DE ESTUDOS E PROJETOS - FINEP, 2007). They constitute areas that have homogenous characteristics such as transport flow grouped into a common area (corridors). Considering the existent transport infrastructure, the corridors integrate the main agricultural areas of the Brazilian territory. The influence of the corridors extends beyond their boundaries, determining certain areas to be influenced by more than one corridor. The corridors are as follows:

Northwest Corridor. The north of Mato Grosso and east of Rondônia are part of this corridor (Figure 6). The main modes of transportation are road, accessed by BR 364, BR 163, and the Madeira and Amazonas rivers. There are two alternative routes to transport agricultural production in the Northwest Corridor. One route is to transport the agricultural production of Mato Grosso (MT) and Rondônia (RO) toward BR 364 to Porto Velho (RO) through the north of the country by the Madeira Waterway. The

production goes from there to Port of Itacoatiara in Amazonas (AM), which is connected to the Atlantic by the Amazon River. The other alternative route is toward BR 163 between Cuiabá and Santarém to the Port of Santarém. The Ferronorte Railroad located in the area is not used to transport agricultural production toward this Corridor but instead to the Southeast region.

Figure 6 - Influence area of the Northwest Corridor

North Central Corridor. The North Central Corridor incorporates areas of the states of Tocantins, Goiás, Mato Grosso, Pará, Maranhão, Bahia and Piauí (Figure 7). The transportation is multimodal and the Port of Itaqui in São Luís (MA) is the main maritime port where the production is directed to the export of grains. The logistics system is as follows:

- 1,230 navigable km in the Araguaia River;
- 580 km of the Rio das Mortes in Mato Grosso;
- Tocantins River 420 navigable km;

- 1,500 km of road BR 010;
- 230 km of the North-South Railroad, between Estreito (MA) and Açailândia (MA);
- 600 km of Carajás Railroad between Açailândia (MA) and the Port of Ponta da Madeira in São Luís (MA).

Figure 7 - Influence area of the North Central Corridor

Northeast Corridor. The Northeast Corridor includes Bahia, Pernambuco, Sergipe, Alagoas, Paraíba, Ceará, north of Minas Gerais, south of Piauí and south of Maranhão (Figure 8). The transport system is carried by roads (BR101, BR230, BR242, BR222, BR020 and BR407), waterways (São Francisco River - navigable between Pirapora - MG and Petrolina - PE) and railroads (Centro-Atlântica S.A, Transnordestina and West-East).

Figure 8 - Influence area of the Northeast Corridor

Midwest Corridor. This Corridor incorporates the regions of Midwest, Southeast and South Brazil (Figure 9). The transportation system is multimodal and the railroads are a very important mode of transport for agricultural products in this Corridor. América Latina Logística Malha Norte S.A. - ALL (Ferro Norte Railroad) from Alto Araguaia (MT) to the state of São Paulo is connected to Ferrobán Railroad and then to the ports of Itaguaí, Santos, Paranaguá and São Francisco. The main waterway is Tietê-Paraná with 2,400 navigable kilometers, and the road BR 163, which takes up the agricultural production from Mato Grosso to the southeast and south ports.

Figure 9 - Influence area of the Midwest Corridor

The spatial organization of logistics systems is a key feature in strategic land planning in Brazil. Knowing the limitations and exploring the organizational distribution of infrastructure in the country is one of the identifying marks for suitable areas that enable the expansion of agriculture. To establish an integrated approach in land use planning, it is important to devise a desirable land use model, substantiated by the balance of different criteria.

The identification of areas with greater accessibility to infrastructure, and their combination with socioeconomic and physical land suitability factors, allows a better analysis and, consequently, optimization of space, which contributes to minimize the pressure that infrastructure imposes on the agricultural sector. To establish an integrated approach in the land use planning, it is of utmost importance to come up with a desirable land use model, substantiated by the balance of different criteria, to support public and private initiatives, in order to direct efforts and investments to suitable areas for the expansion of agriculture in Brazil.

2.5 The analytic hierarchy process (AHP) as a multicriteria decision making tool for spatial planning

Land use planning is normally a complex and multifaceted process, involving the strategic integration of different elements of the physical environment to achieve a reasonable use of it and to promote socioeconomic growth (PATEL; KOK; ROTHMAN, 2007). Many of the complex decisions about “what” and “where” to allocate resources require multiple considerations. The complexity of the problem becomes more manageable when we integrate priorities and ideas to formulate and evaluate environmental policies through a systematic decision making process.

The problems involved in land use planning reflect the realities of spatial organization to support decision making processes over time, which requires extensive data management. It is a dynamic process, but can be simplified by a multicriteria decision analysis considering the feasibility of factors and their constraints (KIKER et al., 2005). Hence, the role of AHP in this context is to help structure the problem to support the planning and decision making process, using the knowledge of experts to evaluate the relative importance of each criterion in an overall ranking of criteria to achieve the main goal (Figure 10). The weights derived from this process feed the multicriteria model.

A lack of sufficient quantitative information in the land use planning process leads to a dependency on the intuition, experience and judgment of experts (BHUSHAN; RAI, 2004). Therefore, decision processes commonly offer guidance on how to integrate or judge the relative importance of information. Multidisciplinary knowledge, consisting of intuitive or heuristic approaches, is taken into consideration for multicriteria assessment in relation to a total number of factors involved in an analysis.

Saaty introduced the AHP method in the 1970s to help in the decision making process (SAATY, 1980). To Bhushan and Rai (2004), this method structures and organizes the decision-makers' thoughts in a manner that is simple to follow and analyze. It refers to the principle of hierarchic composition to derive composite priorities or preferences of a set of alternatives related to multiple criteria, which are subject to a numerical ranking that indicates an order of preference among the alternatives (SAATY, 2003).

Figure 10 - AHP is a comprehensive and integrated way based on a cost benefit relationship among criteria that supports, facilitates and provides prioritizations in optimal site selections

Saaty (1990) affirmed that the arrangement of the elements in a hierarchy serves two purposes:

- It offers an overall view of the complex relationship that is inherent, and the relative importance of the elements in each level of the hierarchy;
- It helps the decision maker judge whether the issues at each level are of the same order of magnitude, so they can compare homogeneous elements.

The AHP method is very popular, particularly due to its ability to structure complex decision making problems. The complexity of each decision is reduced to comparison matrices between pair of alternatives, and stakeholders make judgments about the relative importance of the alternatives on the overall goal out of a numerical scale. Its popularity has been criticized by some authors concerning its inconsistency (GASS; RAPCSAK, 2004; KWIESIELEWICZ; VAN UDEN (2004); OCAMPO-DUQUE

et al., 2006; CHO; CHO, 2006; JASKOWSKI; BIRUK; BUON, 2010) and aggregation of individual judgments necessary for group decision making, and also the complexity of numerous pairwise comparisons (CHAMODRAKAS et al., 2010). Besides, its implementation can be quite inconvenient, considering the fact that it may require a large number of evaluations by the user, especially for problems with many criteria and options. Even though it has its pros and cons, the method is very useful (OELTJENBRUNS; KOLARIK; SCHNADTKIRSCHNER, 1995; CARLSSON; FULLER, 1996) and can easily be applied (MURALIDHAR; SANTHANAM; WILSON, 1990; KURTTILA et al., 2000; HANDFIELD et al., 2002; NGAI; CHAN, 2005), since every single evaluation is very simple to use and to understand.

AHP has been widely used to help in the decision making process in different areas of the science. To determine the weights and rating values representing the relative importance of factors and their categories, Hosseinali and Alesheikh (2008) used two main methods: *data-driven* - Weight of Evidence (WOE), Logistic Regression (LR) and Artificial Neural Networks (ANN); and *knowledge-driven* - AHP, Delphi and Ratio Estimation (RE) to produce Mineral Potential Maps (MPM). Among the *knowledge driven* models used to solve this problem, the authors found out that the AHP offered the best results for their study in Iran. According to them, analyzing the system in a hierarchic structure, step by step, helps the decision making process to be systematic, numerical and model based.

Carrion et al. (2008) combined AHP and multicriteria analysis by using GIS to select optimal sites for grid-connected photovoltaic power plants (GPPPs). The model presented by the authors defined the structure and the principal phases of an environmental decision-support system geared to facilitate site selection for GPPPs installations.

An integration of AHP and the quantifier-guided Ordered Weighted Averaging procedure (OWA) was used to simplify the definition of decision strategies (BOROUSHAKI; MALCZEWSKI, 2008). The objective was to facilitate an exploratory analysis of multiple criteria through the inclusion of qualitative information within the analysis. This model proposed a GIS-multicriteria evaluation system through the improvement of the conventional AHP by combining the fuzzy linguistic OWA operators.

Rahman and Saha (2008) suggested an optimal cropping pattern planning for a flood prone area to combat the adverse effects of floods. The study integrated analysis of land suitability for crops derived by spatial multicriteria evaluation and the AHP. A 0-1 scale and pairwise comparison technique along with AHP was used for standardization of criterion maps. The authors considered that the integration of spatial data and a decision maker's preferences are of critical importance for spatial multicriteria evaluation.

The AHP combined with the fuzzy set theory of Zadeh (1965) was applied by Vahidnia, Alesheikh and Alimohammadi (2009) to achieve more flexibility in judgment and decision making in the selection of an optimum site for hospital construction in the Tehran urban area. Important weights of the components of land planning (travel times, distance from arterial routes, population density, land cost, and air pollution) were assessed by pairwise comparisons provided by an expert. The traditional AHP was applied first in the model, and posteriorly, three fuzzy analytic hierarchy process (FAHP) methods were compared to each other. The expert rated the various alternatives and criteria based first on the traditional AHP and after, on the standard linguistic variables and their corresponding triangular fuzzy numbers. They concluded that the fuzzy extent approach was the most convenient method for estimating the weights in comparison to center-of-area and α -cut methods.

AHP and GIS were combined to provide decision makers with a model determining optimal site locations for fire stations in Istanbul (ERDEN; COSKUN, 2010). The authors considered six groups of major factors or criteria to determine the best location for a fire station: high population density, proximity to main roads, distance from existing fire stations, distance from hazardous material facilities, wooden building density, and distance from the areas subjected to earthquake risk. A total of 10 decision makers, academic-related emergency management specialists, participated in the study. The study had the objective to allow the Fire Brigade to reduce the average response time that was approximately 7 min in 2009 to 5 min or less. As reported by them, the integration of AHP and GIS was very useful and can benefit the population, reducing human and property losses.

De Feo and De Gisi (2010) proposed an innovative criteria weighting tool ("priority scale") to be used for stakeholders involvement to rank a list of suitable municipal solid waste facility sites in Italy with the AHP. Ten criteria were selected for the evaluation of composting plant sites. The authors verified that the "priority scale"

showed the same behavior with both technical and non-technical decision makers, and presented the same good AHP inconsistency ratio due to the utilization of that tool.

The method presented by Chamodrakas et al. (2010) was a synthesis of a satisficing approach with fuzzy AHP to support effective supplier selection in electronic market places. Their argument is that the method facilitates an easier elicitation of user preferences through the reduction of necessary user input and computational complexity. This model also was able to deal with the inconsistency and uncertainty of the preference models of the decision makers using Fuzzy Preference Programming (FPP).

Chandio et al. (2011) proposed a systematic way to evaluate the location of public parks in Larkana, Pakistan using AHP. The analysis considered the land availability, accessibility and socioeconomic criteria. AHP was applied to help calculate the weights for three alternative scenarios (land availability, land value and population density) to produce suitability maps, and it was considered very useful to determine suitable land for urban development.

As can be seen, AHP can be widely applicable in numerous fields to derive criteria weighting and so delineate a practical strategic planning. The idea behind the AHP is to transform the comparison between pairs of criteria into numeric values. This capability to convert empirical into mathematical data is a significant contribution to the decision making process, which helps in comprehending and defining a problem in detail.

2.6 Conclusions

Brazil attracts attention due to its agricultural expansion potential. The country has shown a strong performance in the growth of the agricultural sector and it is considered the fastest growing nation in terms of agricultural surpluses. It is also characterized as one of the few countries able to produce enough to supply both domestic and external demand for food and biofuel.

To understand the spatial dynamics of the infrastructure available in the country, an overview of the infrastructure system in Brazil was provided. It found an absolute supremacy of roads over all other modes of transport for the agricultural

products, and in some cases this mode of transportation is the only access to some agricultural places. Further operational difficulties are observed such as high transportation costs; potholes and unpaved roads; obsolete, low efficiency and low quality of railroads; lack of port capacity; inefficient use of multimodal transport.

Finding weights in the literature to define the relative importance of the criteria in the model is a hard task. Hence a participatory approach is chosen instead, one that counts on the intuition, experience and knowledge of specialists. The AHP was selected as a decision making tool to convert qualitative judgments into weights to feed the MCDA model, considering that this technique is a systematic evaluation method, practical and convenient to obtain quantitative data from subjective judgments. Its application in the model will be further discussed in Chapter 3 and some additional information about the participatory approach is available in Appendix A.

References

- ALVES, L.R.A. **Transmissão de preços entre produtores do setor sucroalcooleiro do Estado de São Paulo**. 2013. Thesis (Master in Applied Economy) – Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo, Piracicaba, 2002.
- ARAMYAN, L.H.; BROEK, W.; GROOT, J.; SOETHOUDT, H.; NGUYEN, T.L.T.; HERMANSEN, J.E.; VORSTG. A.J. Towards sustainable food production: a scenario study of the European pork sector. **Journal on Chain and Network Science**, Wageningen, v. 11, n. 2, p. 177-189, Sept. 2011.
- BALAT, M.; BALAT, H. Recent trends in global production and utilization of bio-ethanol fuel. **Applied Energy**, Burlington, v. 86, n. 11, p. 2273-2282, Nov. 2009.
- BARAT, J. **Logística e transporte no processo de globalização: oportunidades para o Brasil**. São Paulo: UNESP, 2007. 256 p.
- BARRETO, P.; ARAÚJO, E. **O Brasil atingirá sua meta de redução do desmatamento?** Belém: Imazon, 2012. 52 p.
- BARROS, G. Brazil: the challenges in becoming an agricultural superpower. In: BRAINARD, L.; MARTINEZ-DIAZ, L. (Ed.). **Brazil as an economic superpower?: understanding Brazil's changing role in the global economy**. Virginia: R.R. Donnelley, 2009. chap. 4, p. 81-109.
- BHUSHAN, N.; RAI, K. **Strategic decision making: applying the analytic hierarchy process**. Kent: Springer, 2004. 172 p.
- BOROUSHAKI, S.; MALCZEWSKI, J. Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS. **Computers & Geosciences**, New York, v. 34, n. 4, p. 399-410, Apr. 2008.
- BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. Assessoria de Gestão Estratégica. **Plano agrícola e pecuário 2008-2009**. Brasília, 2008. 36 p.
- _____. Ministério da Agricultura, Pecuária e Abastecimento. **Anuário estatístico da agroenergia 2010**. Disponível em: <http://www.agricultura.gov.br/arq_editor/file/Desenvolvimento_Sustentavel/Agroenergia/estatisticas/Book_Anuario_Portugues.pdf>. Acesso em: 10 nov. 2013.
- CAIXETA FILHO, J.V. Logística para a agricultura brasileira. **Revista Brasileira de Comércio Exterior**, Rio de Janeiro, v. 103, n. 1, p. 18-30, apr./june 2010.
- CARLSSON, C.; FULLER, R. Fuzzy multiple criteria decision making: recent developments. **Fuzzy Sets and Systems**, Cambridge, v. 78, n. 2, p. 139-153, Mar. 1996.

CARRION, J.A.; ESTRELLA, A.E.; DOLS, F.A.; TORO, M.Z.; RODRIGUES, M. RIDAO, A.R. Environmental decision-support systems for evaluating the carrying capacity of land areas: optimal site selection for grid-connected photovoltaic power plants. **Renewable & Sustainable Energy Reviews**, Amsterdam, v. 12, n. 9, p. 2358-2380, Dec. 2008.

CHAMODRAKAS, I.; BATIS, D.; MARTAKOS, D. Supplier selection in electronic marketplaces using satisficing and fuzzy AHP. **Expert Systems With Applications**, New York, v. 37, n. 1, p. 490-498, Jan. 2010.

CHANDIO, I.A.; MATORI, A.N.; LAWAL, D.U.; SABRI, S. GIS-based land suitability analysis using AHP for public parks planning in Larkana City. **Modern Applied Science**, Washington, v. 5, n. 4, p. 177, Aug. 2011.

CHO, Y.; CHO, K. A loss function approach to group preference aggregation in the AHP. **Computers & Operations Research**, Amsterdam, v. 35, n. 3, p. 884-892, Mar. 2008.

DE FEO, G.; DE GISI, S. Using an innovative criteria weighting tool for stakeholders involvement to rank MSW facility sites with the AHP. **Waste Management**, New York, v. 30, n. 11, p. 2370-2382, Nov. 2010.

DE WIT, M.; JUNGINGER, M.; LENSINK, S.; LONDO, M.; FAAIJ, A. Competition between biofuels: modeling technological learning and cost reductions over time. **Biomass & Bioenergy**, New York, v. 34, n. 2, p. 203-217, Feb. 2010.

DEPARTAMENTO NACIONAL DE INFRAESTRUTURA DE TRANSPORTE. **Ferroviário**. Disponível em: <<http://www1.dnit.gov.br/ferrovias/historico.asp>>. Acesso em: 05 nov. 2013.

ERDEN, T.; COSKUN, M. Multi-criteria site selection for fire services: the interaction with analytic hierarchy process and geographic information systems. **Natural Hazards and Earth System Sciences**, Katienburg-Lindau, v. 10, n. 10, p. 2127-2134, Oct. 2010.

ESCOBAR, J.C.; LORA, E.S.; VENTURINI, O.J.; YÁÑEZ, E.E.; CASTILLO, E.F.; ALMAZAN, O. Biofuels: environment, technology and food security. **Renewable and Sustainable Energy Reviews**, Amsterdam, v. 13, n. 6, p. 1275-1287, Aug./Sept. 2009.

FAO. **A framework for land evaluation**. Rome, 1976. 94 p.

_____. **Declaração de Roma sobre a segurança alimentar mundial**. 1998. Disponível em: <<http://www.fao.org/DOCREP/003/W3613P/W3613P00.HTM>>. Acesso em: 18 abr. 2011.

_____. **Top production: soybean 2011**. Disponível em: <<http://faostat.fao.org/site/339/default.aspx>>. Acesso: 02 jun. 2012.

FARGIONE, J.; HILL, J.; TILMAN, D.; POLASKY, S.; HAWTHORNE, P. Land clearing and the biofuel carbon debt. **Science**, Washington, v. 319, n. 5867, p. 1235-1238, Feb. 2008.

FINANCIADORA DE ESTUDOS E PROJETOS. **Ação transversal**: logística de transporte. Disponível em: <http://www.finep.gov.br/fundos_setoriais/acao_transversal/editais/Chamada_Publica_Acao_Transversal_Transportes_02_2007.pdf>. Acesso em: 03 set. 2012.

FOREIGN AGRICULTURAL SERVICE. **Brazilian agricultural exports face growing constraints**. Disponível em: <<http://www.fas.usda.gov/data/brazilian-agricultural-exports-face-growing-constraints>>. Acesso em: 18 abr. 2012.

FUJISAKA, S.; CASTILLA, C.; ESCOBAR, G.; RODRIGUES, V.; VENEKLAAS, E.J.; THOMAS, R.; FISHER, M. The effects of forest conversion on annual crops and pastures: estimates of carbon emissions and plant species loss in a Brazilian Amazon colony. **Agriculture, Ecosystems & Environment**, Washington, v. 69, n. 1, p. 17-26, May 1998.

GASS, S.; RAPCSAK, T. Singular value decomposition in AHP. **European Journal of Operational Research**, Amsterdam, v. 154, n. 3, p. 573-584, May 2004.

GODFRAY, H.C.J.; BEDDINGTON, J.R.; CRUTE, I.R.; HADDAD, L.; LAWRENCE, D.; MUIR, J.F.; PRETTY, J.; ROBINSON, S.; THOMAS, S.M.; TOULMIN, C. Food security: the challenge of feeding 9 billion people. **Science**, Washington, v. 327, n. 5967, p. 812-818, Feb. 2010.

HANDFIELD, R.; WALTON, S.V.; SROUFE, R.; MELNYK, S.A. Applying environmental criteria to supplier assessment: A study in the application of the analytical hierarchy process. **European Journal of Operational Research**, Amsterdam, v. 141, n. 1, p. 70-87, Aug. 2002.

HOFFMANN, R. Segurança alimentar e produção de etanol no Brasil. **Segurança Alimentar e Nutricional**, Campinas, v. 13, n. 2, p. 1-5, 2006.

HOSSEINALI, F.; ALESHEIKH, A.A. Weighting spatial information in GIS for copper mining exploration. **American Journal of Applied Sciences**, New York, v. 5, n. 9, p. 1187, 2008.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Retratos do Brasil rural**: modernização da agropecuária contrasta com baixa escolaridade. Disponível em: <<http://saladeimprensa.ibge.gov.br/pt/noticias?view=noticia&id=1&busca=1&idnoticia=2242>>. Acesso em: 21 nov. 2012.

_____. **Sistema IBGE de recuperação automática**. Disponível em: <<http://sidraibge.gov.br>>. Acesso em 05 nov. 2013.

JASKOWSKI, P.; BIRUK, S.; BUCON, R. Assessing contractor selection criteria weights with fuzzy AHP method application in group decision environment. **Automation in Construction**, Amsterdam, v. 19, n. 2, p. 120-126, Mar. 2010.

KAWANO, B.R.; VARGAS MORES, G.; DA SILVA, R.F.; CUGNASCA, C.E. Estratégias para resolução dos principais desafios da logística de produtos agrícolas exportados pelo Brasil. **Revista de Economia e Agronegócio**, Viçosa, v. 10, n. 1, p. 71-88, May 2012.

KIKER, G.A.; BRIDGES, T.S.; VARGHESE, A.; SEAGER, T.P.; LINKOV, I. Application of multicriteria decision analysis in environmental decision making. **Integrated Environmental Assessment and Management**, Hoboken, v. 1, n. 2, p. 95-108, 2005.

KOPCZAK, L.R.; JOHNSON, M.E. The supply-chain management effect. **MIT Sloan Management Review**, Cambridge, v. 44, n. 3, p. 27-34, Spring 2003.

KURTTILA, M.; PESONEN, M.; KANGAS, J.; KAJANUS, M. Utilizing the analytic hierarchy process (AHP) in SWOT analysis - a hybrid method and its application to a forest-certification case. **Forest Policy and Economics**, Amsterdam, v. 1, n. 1, p. 41-52, May 2000.

KWIESIELEWICZ, M.; VAN UDEN, E. Inconsistent and contradictory judgments in pairwise comparison method in the AHP. **Computers & Operations Research**, Amsterdam, v. 31, n. 5, p. 713-719, Apr. 2004.

LEITE, R.C.C.; LEAL, M.R.L.V.; CORTEZ, L.A.B.; GRIFFIN, W.M.; SCANDIFFIO, M.I.G. Can Brazil replace 5% of the 2025 gasoline world demand with ethanol? **Energy**, New York, v. 34, n. 5, p. 655-661, May 2009.

LÍCIO, A.; CORBUCCI, R. A agricultura e os corredores de transporte multimodais. **Revista de Política Agrícola**, Brasília, ano 5, n. 2, p. 22-36, 1996.

LIMA, R.C.A.; NASSAR, A.; HARFUCH, L.; CHIODI, L. ANTONIAZZI, L.; MOREIRA, M. **Low impact agriculture: building the Brazilian green economy**. São Paulo: Ícone, 2012. 29 p.

MALONI, M.J.; BROWN, M.E. Corporate social responsibility in the supply chain: an application in the food industry. **Journal of Business Ethics**, Dordrecht, v. 68, n. 1, p. 35-52, Sept. 2006.

METZGER, J.P.; LEWINSOHN, T.M.; JOLY, C.A.; VERDADE, L.M.; MARTINELLI, L.A.; RODRIGUES, R.R. Brazilian law: full speed in reverse? **Science**, Washington, v. 329, n. 5989, p. 276-277, July 2010.

MORTON, D.C.; DEFRIES, R.S.; SHIMABUKURO, Y.E.; ANDERSON, L.O.; ARAI, E.; DEL BON ESPIRITO-SANTO, F.; FREITAS, R.; MORISETTE, J. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. **Proceedings of the National Academy of Sciences**, Washington, v. 103, n. 39, p. 14637-14641, Sept. 2006.

MURALIDHAR, K.; SANTHANAM, R.; WILSON, R. Using the analytic hierarchy process for information-system project selection. **Information & Management**, Amsterdam, v. 18, n. 2, p. 87-95, Feb. 1990.

NGAI, E.; CHAN, E. Evaluation of knowledge management tools using AHP. **Expert Systems with Applications**, Elmsford, v. 29, n. 4, p. 889-899, Nov. 2005.

OCAMPO-DUQUE, W.; FERRE-HUGUET, N.; DOMINGO, J.L.; SCHUHMACHER, M. Assessing water quality in rivers with fuzzy inference systems: a case study. **Environment International**, New York, v. 32, n. 6, p. 733-742, Aug. 2006.

ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT - FAO. **Agricultural outlook 2010-2019**. Rome: FAO, 2010. 247 p.

_____. **Organization for Economic Co-Operation and Development, Food and Agricultural Organization of the United Nations: agricultural outlook 2012-2021**. Rome, 2012. 281 p.

OELTJENBRUNS, H.; KOLARIK, E.; SCHNADTKIRSCHNER, R. Strategic-planning in manufacturing systems - AHP application to an equipment replacement decision. **International Journal of Production Economics**, New York, v. 38, n. 2/3, p. 189-197, Mar. 1995.

PATEL, M.; KOK, K.; ROTHMAN, D.S. Participatory scenario construction in land use analysis: an insight into the experiences created by stakeholder involvement in the Northern Mediterranean. **Land Use Policy**, Amsterdam, v. 24, n. 3, p. 546-561, 2007.

RAHMAN, M.; SAHA, S. Remote Sensing, Spatial Multi Criteria Evaluation (SMCE) and Analytical Hierarchy Process (AHP) in optimal cropping pattern planning for a flood prone area. **Journal of Spatial Science**, Philadelphia, v. 53, n. 2, p. 161-177, Dec. 2008.

RENTING, H.; MARSDEN, T.K.; BANKS, J. Understanding alternative food networks: exploring the role of short food supply chains in rural development. **Environment and Planning A**, London, v. 35, n. 3, p. 393-412, 2003.

ROSEGRANT, M.; CLINE, S. Global food security: challenges and policies. **Science**, Washington, v. 302, n. 5652, p. 1917-1919, Dec. 2003.

SAATY, T.L. **The Analytical Hierarchy Process: planning, priority, resource allocation**. New York: McGraw Hill, 1980. 287 p.

_____. How to make a decision: the analytic hierarchy process. **European Journal of Operational Research**, Amsterdam, v. 48, n. 1, p. 9-26, Sept. 1990.

_____. Decision-making with the AHP: Why is the principal eigenvector necessary. **European Journal of Operational Research**, Amsterdam, v. 145, n. 1, p. 85-91, Feb. 2003.

SKOLE, D.; TUCKER, C. Tropical deforestation and habitat fragmentation in the Amazon. Satellite data from 1978 to 1988. **Science**, Washington, v. 260, n. 5116, p.1905-1910, 1993.

SHIKIDA, P.F.A. **A evolução diferenciada da agroindústria canavieira no Brasil de 1975 a 1995**. Dissertation (Doctor in Applied Economy) – Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo, Piracicaba, 2013.

SPAROVEK, G.; BERNDES, G.; BARRETO, A.; MARTINS, S.P.; MAULE, R.F.; BURGI, R.; SMORIGO, J.N. **Polos de produção de energia, alimento e cidadania: conceito e aplicação em políticas públicas**. Piracicaba: GAJ Editora e Comunicação, 2009. 109 p.

SUGARCANE.ORG. **Brazil diverse energy matrix**. Disponível em: <<http://sugarcane.org/the-brazilian-experience/brazils-diverse-energy-matrix>>. Acesso em: 02 set. 2013.

TILMAN, D.; SOCOLOW, R.; FOLEY, J.A.; JASON, H.; LARSON, E.; LYND, L.; PACALA, S.; REILLY, J.; SEARCHINGER, T.; SOMERVILLE, C.; WILLIAMS, R. Beneficial biofuels: the food, energy, and environment trilemma. **Science**, Washington, v. 325, n. 5938, p. 270, July 2009.

TROSTLE, R. **Global agricultural supply and demand: stakeholders contributing to the recent increase in food commodity price (USDA)**. 2008. Disponível em: <<http://www.ers.usda.gov/Publications/WRS0801/WRS0801.pdf>>. Acesso em: 01 jun. 2011.

UNIÃO DAS INDÚSTRIAS DE CANA-DE-AÇÚCAR. **Unicadata**. Disponível em: <<http://www.unicadata.com.br>>. Acesso em: 10 nov. 2013.

UNITED NATIONS, DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS. Population Division. **World Population Prospects: the 2006 revision**. 2007. Disponível em: <<http://www.gceholdings.com/pdf/GoldmanReportFoodFeedFuel.pdf>>. Acesso: 01 jun. 2011.

VAHIDNIA, M.; ALESHEIKH, A.; ALIMOHAMMADI, A. Hospital site selection using fuzzy AHP and its derivatives. **Journal of Environmental Management**, New York, v. 90, n. 10, p. 3048-3056, July 2009.

VALDES, C. Brazil's booming agriculture faces obstacles. **Amber Waves**, Washington, v. 4, n. 5, p. 28-35, Nov. 2006.

VON BRAUN, J. **The world food situation: new driving forces and required actions**. Washington: International Food Policy Research Institute, 2007. 18 p.

VORLEY, B. **The chains of agriculture: sustainability and the restructuring of agri-food markets**. London: IIED, 2001. 8 p.

WORLD WILDLIFE FUND. **Analysis of sugar cane agriculture industry expansion in Brazil**. 2008. Disponível em: <assets.panda.org/downloads/report_sugarcane_wwf_brasil_jun2008.pdf>. Acesso em: 30 maio 2013.

ZADEH, L.A. Fuzzy sets. **Information and Control**, New York, v. 8, n. 3, p. 338-353, June 1965.

3 MULTICRITERIA DECISION ANALYSIS APPLIED TO THE SPATIAL ALLOCATION OF SUGARCANE AS A PLANNING SUPPORT SYSTEM FOR AGRICULTURAL EXPANSION IN BRAZIL

Abstract

This research project is embedded in the logic of a sustainable expansion of agriculture in Brazil and has as its main objective the identification of cultivated pasturelands for sugarcane expansion at a national scale that satisfies criteria such as accessibility to existing transportation and logistics facilities, production potential, social needs, and environmental conditions necessary for a supportable agricultural exploration. Such a system will provide leaders with strategic visual information for land planning in Brazil. The research therefore has an interest in developing a study that was able to deal with the dimensionality of different criteria by integrating them into the process of spatial modeling, and by including experts' knowledge to evaluate the priorities that each criterion plays in a multicriteria decision analysis (MCDA) model. The AHP was the method selected to convert the experts' subjective judgments into quantitative data during the participatory approach. The criteria derived from the participatory approach were used to feed the MCDA model. The MCDA integrated with Geographic Information System (GIS) tools, enables stakeholders to obtain important information, particularly with regard to support for decision making. Our study showed that Brazil has 66 million hectares of cultivated pasturelands, varying from moderate to high suitability lands that could support a sustainable sugarcane production expansion. In general, those lands are mostly located in the South-Central region in the country in traditional pasturelands. Information generated in this study can contribute to public decisions related to the direction of public investments and private strategies, by indicating potential areas for future sugarcane farming in which actions may have positive effects both environmentally and socioeconomically.

Keywords: Land-use planning; Spatial modeling; GIS; ModelBuilder; Participatory approach; AHP

3.1 Introduction

Global biofuel production has grown significantly, and it is projected that its demand will continue to increase in the coming years. World concerns about general issues such as reducing the dependency on fossil fuels due to their scarcity, increasing price of fuel and food in the international market, and adverse impacts on the environment are considered the driving forces for the prognosis. This growing trend toward the use of clean energy sources provides several benefits to the countries that produce biofuels and make use of them, especially in relation to global warming, through a reduction of greenhouse gases emitted in the atmosphere, and the fact that the fuels are a renewable resource (GOLDEMBERG, 2007). On the

other hand, biofuels produced on lands already occupied by agriculture may force the agricultural frontier to go somewhere else, which would lead to increasing greenhouse gases through emissions from land use change (SEARCHINGER et al., 2008; FARGIONE et al., 2008).

In the renewable energy production context ethanol has been the focus of attention among the biofuels (MACEDO; SEABRA; SILVA, 2008). Ethanol produced from sugarcane is a renewable energy source and has great advantages over gasoline, especially with regard to reducing greenhouse gas emissions, thus improving air quality in urban areas (GOLDEMBERG, 2008; GOLDEMBERG; COELHO; GUARDABASSI, 2008). Its lower air pollution is due to its more complete combustion in comparison to petroleum products. Moreover, sugarcane biomass retains a considerable part of the carbon dioxide produced in its manufacture and consumption (DE CARVALHO MACEDO, 1992; SEABRA et al., 2010).

Most of the world's biofuels are produced in Brazil and the United States (88% of production), and the remaining 12% is produced mostly in China, Canada and a few countries in Europe (F.O. LICHT, 2010). The ethanol production in Brazil has one of the highest percentages of market share of total world production. In 2012, world ethanol production reached 107 million cubic meters, of which Brazil contributed 20% from sugarcane (F.O. LICHT, 2013).

Brazil is a major producer of ethanol biofuel derived from sugarcane. The crop has been cultivated since the colonial period, and its production is intrinsically related to the social, political and economic history of Brazil. Characterized by socioeconomic cycles of greater and lesser importance, sugarcane promoted the establishment and consolidation of the settlement of much of the northeast coast and São Paulo. Considering its long experience with sugarcane cultivation, the country has shown an ability to decrease the dependency on petroleum-based fuels, reducing its vulnerability through the improvement of energy security.

Pioneer ethanol fuel programs have been implemented over the years by the government to insulate Brazil from the global oil crisis. The first experience in using ethanol as a fuel occurred in the 1920's with not much success. Between 1930's and the early 1970's, the mixture of ethanol with petroleum was an average of 7.5%. In the 1970's, the Proálcool Program regulated the mixture of ethanol with petroleum up to 25%. This Program had its glory days, but eventually showed a decreasing use

trend at the beginning of the 1990's. Since 2003, we have been observing again an increase in the production of sugarcane, strongly related to the insertion of flex fuels cars that can use either gasoline or pure ethanol into the national market (MARTINES-FILHO; BURNQUIST; VIAN, 2006).

Brazil is well-known as one of the leading world exporters of agricultural products, and one of the most advanced countries in innovative technologies and energy policies in the production of biofuel (BANCO NACIONAL DE DESENVOLVIMENTO ECONÔMICO E SOCIAL - BNDES, 2008; GELLER et al., 2004). The significant amount of areas available for crop expansion, favorable climate and topography are considered important characteristics that enhance its competitiveness in relation to the international market and allow the country to follow the global trend of clean energy production (biofuels).

The advantages of producing ethanol, as a substitute for petroleum, may be further maximized through an informed planning of sugarcane expansion in Brazil, resulting in better utilization of its agricultural regions. The needs for (1) large and continuous suitable lands for extended usage of mechanization, especially for ethanol production, (2) proximity to modes of transportation and other types of infrastructures and (3) qualified and skilled laborers are strategic factors that support productivity and farmland growth. Thus, considering these factors, this study has the objective to identify suitable cultivated pasturelands substantiated by a multicriteria approach for sugarcane expansion planning that considers physical land suitability, infrastructure and socioeconomic criteria. The study results provide stakeholders with visual information and insights to help the agricultural planning process in Brazil. Such information may contribute to public decision making and to private strategies to allocate new investments toward the most suitable pasturelands to prevent forest losses in the short term in the country.

3.2 Materials and Methods

3.2.1 MCDA in sites selection for sugarcane expansion in Brazil

The modeling is based on public data that contain different sources of information about the national territory of Brazil. A preexisting physical land suitability model was also part of our database (BARRETTO, 2013). Soil and climate indexes

obtained from this previous model form the basis of the MCDA model for sugarcane expansion.

Sugarcane was the crop selected for the MCDA model because of its importance among the croplands. As can be seen in Figure 11, sugarcane and soybean are the main crops that make a major contribution to the value of agricultural production in Brazil. Their importance is not just related to value, but also to the planted area that sugarcane and soybean occupy in Brazil (14% and 36% of total croplands, respectively) (IBGE, 2010).

Figure 11 - Proportions of the agricultural products by value of agricultural production in Brazil
Source: Adapted from IBGE (2010)

Variables were selected to create the MCDA model for sugarcane and the methodology of mapping process is described in the following sections. Soil and climate indexes were added to ESRI ArcGIS 10 ModelBuilder as a starting point for the MCDA model. The scripting language used in the prior model to create the physical land suitability for sugarcane was converted to the ArcGIS ModelBuilder graphical format. From there several other processes were chained together to define the infrastructure accessibility and socioeconomic factors associated with the MCDA model. The choice of converting the script language and rerunning the geoprocessing in the ArcGIS platform, instead of simply using the datasets in their ready-to-use format, was because any changes in a parameter value or the addition or deletion of any inputs in the ModelBuilder could then alter the whole process

simply by rerunning it, which would make it very easy to use for any adjustment in the future.

All ESRI format shapefiles were converted to a raster format to perform the map algebra operations. The workflow chart shown in Figure 12 presents the stages that our model has followed. The steps for running the MCDA model are:

Physical land suitability evaluation. This step required the processing of the soil, climate, biome, land use and topography layers through map algebra expressions. The procedure involved the combination of layers based on the map algebra by the conversion to a Boolean map turning the set of all operation to false and true (binary suitability model) for every possible allocation. The operational procedure was processed using the ESRI ArcGIS 10 Raster Calculator tool. The final result was a map of suitability for sugarcane with an evaluation scale from 1 (least suitable) to 5 (most suitable).

Establishing rating scale values. A Euclidean Distance transformation was carried out as an operation to identify areas surrounding the infrastructure related variables, with the purpose of classifying the values of each criterion according to their importance. This included roads, railroads, ports, pipelines and sugarcane mills. A high suitability (5) was assigned to the ranking of values with closer access to infrastructure in order to prioritize areas with minimum distance between suitable agricultural locations for sugarcane and its accessibility to infrastructure. The socioeconomic variables were joined to a preexisting attribute table linked to the country shapefile. Subsequently, each variable was converted to a raster format. A reclassification of the socioeconomic variables was processed in accordance with their values from a quantile interval method. All the layer values on this stage were classified into a common scale set at 1 (least suitable) to 5 (most suitable).

Assigning weights. Weights were assigned as a percentage of influence of each raster according to its importance in the agricultural expansion scenario. The weights were acquired from the AHP during the decision making process. The Expert Choice 2000 was the software that handled this operation. The weights derived from this stage were used in ArcGIS 10 Weighted Overlay tool for the MCDA. The suitability

map was overlain with the areas of existing pasture and the values were reclassified in a range of 1 to 5.

Figure 12 - Workflow showing the stages involved in the MCDA model for sugarcane sites selection

Validation procedure and sensitivity testing. The final step was to analyze the effect of altering the weights in the model through a scenario analysis. The goal was to verify how the model would respond to any change in the weights obtained from the experts' judgments of sugarcane production environments. In each scenario, shifts in the priority of each of the factors were made to verify the robustness of the spatial changes. A pixel-by-pixel analysis was applied to each scenario to find out where the dominant changes occurred in geographic space.

3.2.2 Data input

The modeling of agricultural expansion was based on the selection of those factors that play an important role in spatial land use planning. The selected variables are related to agricultural suitability (soil, climate, biome, land use and slope) for sustainable land use; proximity and accessibility to transport networks; infrastructure (mills); people to be employed in agriculture (workforce); and value of output (proxy of added value). These variables were modeled in order to make reflect reality, and subsequently were represented across space, with the aim of ensuring consistency of data in the decision support system.

Land suitability plays an important role in the allocation expansion model due to its importance in sustaining various forms of agricultural use for sugarcane cultivation. Seeking a balance between land use and conservation, evaluation scales were set to represent the greater or lesser potential of the physical environment to support crop production. The sources of information and data to create the physical land suitability submodel (represented in this by the edaphoclimatic variable) are described in Table 1 and Table B1.

Data on infrastructure (the location of mills and the transportation network) determined the most suitable areas closer to sugarcane mills and with the best accessibility to transportation. Socioeconomic variables identify suitable areas for agricultural expansion considering people's age structure, their level of education, the value of production, and the proportion of people employed in agriculture. Evaluation weights for the suitability analysis of those variables are specified in Table B2.

Model Builder in ArcGIS 10 was used to manage, organize and visualize the relationships among these variables, which is possible because the application creates a workflow that shows the sequence of tools used in the geoprocessing,

including their inputs and outputs. This is very advantageous, since it allows the reproduction and reuse of the model. The linear sequence of tools and variables used make it simple to follow. A report, which contains all the data processing involved in the analysis, can also be exported.

Table 1 - Geodatabase used to determine the land suitability for sugarcane allocation in relation to the main variables in the model (Soil, climate and topography)

Variables	Data Source	Date	Type of feature, Scale or Spatial resolution	Format
Soil	IBGE – Soil Map of Brazil < http://www.dpi.inpe.br/Ambdata/English/soil_map.php >	2001	1:5.000.000	Shapefile
	ESALQ – Project soil profile database of RADAM-BRASIL < http://www.esalq.usp.br/gerd/ >	2005	Point	Database
Climate	FAO - FAOCLIM precipitation and monthly average temperature database (1025 stations) < http://www.fao.org/nr/climpag/public/en1102_en.asp >	2001	Point	Database
	INMET and DAAE - Database of precipitation and monthly average temperature (283 stations)	Not published	Point	Database
	ANA - Hidroweb precipitation database (2676 stations) < http://hidroweb.ana.gov.br/ >	2005	Point	Database
Topography	EMBRAPA - Brazil in Relief – Digital Elevation Model (DEM) < http://www.relevobr.cnpem.embrapa.br >	2009	90m x 90m	Geotiff

In the Model Builder the overall model is simplified into a group of linear submodels where it is possible to review all the steps, orientate, locate and so communicate the potential areas for the development of agricultural production,

which facilitates the review of information by stakeholders, making it an important planning tool. This allows actions to be formulated and positioned with logical and consistent trends, with the perspective of assisting with better planning of the geographic space, looking for a balance between contradictory variables, i.e., maximizing economic and social benefits and the sustainable use of the environment.

3.2.3 Primary data processing

In this stage vector data were converted to raster data and projected to the South America Lambert Conformal Conic Projection, so that all the layers had a common geographic map projection and scale in kilometers. In the Euclidian Distance geoprocessing a cell size of 90 m x 90 m was employed. Each raster was submitted to a different type of data processing. Soil, climate, topography, biome and land use were the input data layers as rasters. The outputs of this stage were combined through map algebra operations to produce the physical land suitability.

The model was broken down into linear submodels to simplify the data processing for analysis. Each raster participating in the analysis defined a variable that the submodel was assessing, and contributed to the objectives of the submodel. In the primary data processing, each submodel then contributes to the final model.

3.2.3.1 Soils

Soil suitability analysis was evaluated using a range of values from 0 to 9 representing the soil attributes (drainage, fertility and rooting conditions), which are related to the soil's agricultural suitability. The evaluation scale was associated with the importance of those attributes to the cultivation of sugarcane, 0 (restricted suitability) and 9 (highly suitable).

Soil Drainage. Soil drainage is related to the availability of oxygen to a plant root system and the risk of salinization. Permanent flooding - resulting from a deficiency of soil drainage due to upwelling groundwater - and temporary waterlogging of the soil sub-surface were the factors used in the soil suitability analysis.

Soil Fertility. Soil fertility refers to the natural ability of soil to provide nutrients to plants and to keep this supply over time, thus defining the production potential of soils without the use of fertilizers and correctives.

Rooting Conditions. Rooting conditions indicate the development capacity of plant root systems, ensuring root support and water absorption. Restrictions imply a difficulty of deep-rooting plants to settle and develop. Low values (evaluation scale) show the difficulty of growth and nutrient fixing for crops, increased susceptibility to water stress and restrictions for the absorption of nutrients.

3.2.3.1.1 Spatial distribution of soil data

A soil map legend was interpreted by a qualitative methodology proceeding from the general characteristics of the map units (drainage, fertility and rooting conditions), combining soil profile data points (COOPER et al., 2005) and experts' opinion. The soil information enclosed in the map legend was ranked according to the capacity of the selected parameters (drainage, fertility and rooting conditions) to provide nutrients for crop growth and phenology. Each map unit was classified according to their suitability for drainage, fertility and rooting conditions into classes that express the degrees of suitability varying from maximum restriction (0) to highly suitable (9) (Figure 13). The geometric mean of drainage, fertility and rooting conditions was used as a proxy for the attainable yields.

3.2.3.2 Climate

Climatic conditions are a major determinant of crop production, and indicate the necessity of irrigation to reduce the risk of harvest loss. To evaluate the climate suitability for sugarcane, the climate components - precipitation and temperature - were grouped into zones, ranging from 1 to 6, representing different aspects of climate related to crop yield.

Weather station databases were used to complete a dense coverage of Brazil: FAOCLIM (1025 stations) and São Paulo (DAAE + INMET - 283 stations) (Figure

14A), and National Water Agency (ANA) database containing the precipitation data for 2076 stations (Table 1) (Figure 14B).

Figure 13 - Soil suitability map for sugarcane production. The soil suitability classification ranges from 0 (maximum restriction) to 9 (highly suitable)

Figure 14 - A. FAOCLIM and São Paulo (DAAE + INMET) databases. B. National Water Agency (ANA) database

Air Temperature Estimation. Data from the hydro-meteorological network of the National Water Agency (ANA) were obtained to expand the meteorological data used in the analysis of climate suitability. However, stations that collect this information do not also collect temperature data. Thus a literature review was conducted to select papers that have offered consistent estimates of minimum, maximum and average monthly temperature (Figure 15). Multiple linear regression equations in which the independent variables were longitude, latitude and altitude of the stations were then used to interpolate these data within zones (Table B3).

The criteria used to include data in the regression equations and the climate databases were a minimum of 10 years to calculate the mean, and no absence of data for temperature, radiation and precipitation. In this sense, data were excluded from 298 stations, equivalent to 11% of the ANA hydrometeorological stations.

Precipitation and temperature data points were interpolated using the Voronoi algorithm to produce a continuous surface for further map analysis (Figure 16). The interpolation method assigns values to areas where there is no data by taking the value of the nearest sample (neighbor). Each sample point was used to predict values at locations that lack sample points.

Figure 15 - Spatial distribution of temperature data into zones of minimum and maximum temperature according to latitude and longitude

Figure 16 - Voronoi interpolation applied to the spatial distribution of weather station's data

3.2.3.2.1 Climate suitability for sugarcane

In the climate suitability analysis, the annual water deficit was taken into consideration, as were annual average temperature and average temperature in July, since the cultivation of sugarcane has very specific physiology and cultivation cycles. Six suitability zones were defined for the cultivation of sugarcane, according to the criteria described by Camargo et al. (1977) and Alfonsi et al. (1987), and 4 suitability classes were generated in this process (Table 2).

Table 2 - Evaluation scale representing zones that define the climate suitability

Suitability Classes	Annual Average Temperature (Ta)	Annual Water Deficit (Def)	Description	Suitability Scale	Reclassification (Values)
6	Ta $\geq$ 20°C	Def $\leq$ 200 mm	Satisfactory thermic and water conditions.	Suitable	High (4)
5	18°C < Ta < 20°C T _{jul} >14°C	Def $\leq$ 200 mm	Thermic Restriction.	Moderate	Moderate (3)
4	Ta>18°C	200 mm Def < 400 mm	Water restriction, Irrigation recommended.	Moderate	Moderate (3)
3	Ta>26°C	Def < 5 mm	Absence of a rest season due to cold or dry.	Moderate to unsuitable	Low (2)
2	-	Def > 400 mm	Excessive water deficit. Suitable with irrigation.	Unsuitable	Very Low (1)
1	Ta < 18°C or T _{jul} <14°C	-	Thermal insufficiency and severe frosts.	Unsuitable	Very Low (1)

3.2.3.3 Topography

Topographic suitability for sugarcane was evaluated regarding its feasibility for mechanization. It was considered that the lower the feasibility for mechanization, the lesser would be the pressure on crop cultivation. The data used in this procedure were the digital elevation model of the terrain (Shuttle Radar Topography Mission - SRTM).

The digital elevation model (DEM) used as the input to process the slope had a resolution of 90 m x 90 m. The slope was classified into an evaluation scale according to the criteria adopted by Levy (1995) and Lepsch (1991). Areas with slopes up to 12% were classified as highly suitable, 12-16% were considered moderately suitable and above 16% unsuitable because of the difficulty or impossibility of using machines for farming operations.

3.2.3.4 Physical land suitability evaluation modeling

An integration procedure was adopted to associate climate, soil, biome, land use and topography. They were combined using Boolean logical operators and mathematical operations to generate a final matrix with a scale of 5 values (Figure 17), representing the physical land suitability for sugarcane (Table 3). Due to the use of machinery in contemporary agriculture, the limitation imposed by the topography is greater than that imposed by soil and climate. The analysis tried to capture this constraint by including the limitation imposed by topography.

Figure 17 - Example showing how the overlay operation works. In the process new elements are created based on the multiple input maps

Table 3 - Factor and evaluation scale used in the physical land suitability analysis for sugarcane

Soil and Climate Suitability	Topography	Biome	Land Use
Not evaluated = NoData	0-6 = 1	Amazon = 1	Water
Unsuitable = 0	6-12 = 2	Savannas (Cerrado) = 2	Urban
Low = 1	12-16 = 3	Caatinga = 3	Natural
Medium = 2	16-25 = 4	Pantanal = 4	vegetation
High = 3	25-46 = 5	Atlantic Forest = 5	Pasture
Very high = 4	46-100 = 6	Pampas = 6	
	>100 = 7		

The land use and biome maps were also used in the map algebra to filter the effect of flattening that the rainforest canopy had in the slope calculation (SHORTRIDGE; MESSINA, 2011), and to avoid misinterpretation of the Pantanal flood plain area as being of high agricultural potential. Additionally, a land use map served to identify rivers, lakes, dams, flooded areas and urban land use that were omitted in the calculation of suitability for sugarcane.

Another spatial analysis operation combined the physical land suitability map with the existing cultivated pasturelands in Brazil. The physical land suitability raster was then overlain with the pasturelands raster to classify the areas of pasture suitable for sugarcane expansion in the country.

3.2.3.5 Infrastructure

The sugarcane allocation map also reflects a minimum distance location of infrastructure to determine the optimal location for the production of sugarcane, considering the current infrastructure in Brazil. Potential agricultural areas were identified according to their accessibility to infrastructure depending on distance calculations. Thus, infrastructure was one of the key variables considered, since it is essential in the strategic interconnections between potential expansion areas and locations where the infrastructure is already accessible. Hence, the land suitability for crops itself is not feasible for agricultural expansion in this model if there is no association with infrastructure, especially, transportation.

Transportation facilitates the movement of agricultural products to processing and to market, contributing to the better use of the productive potential of the regions. Therefore, railroads, roads, pipelines, ports and mills were the infrastructure

elements used to compose the database. They were obtained through the georeferenced database Plano Nacional de Logística e Transporte - PNLT (2010). A Euclidean distance operator was executed for each infrastructure factor based on the average distance to the means of transport, whether road, railroads, ports or mills, aiming toward finding the greatest accessibility to them.

The Euclidean Distance was computed as a geometric distance in a multidimensional space, where the distance to each source cell is determined by calculating the hypotenuse for each cell (eq. 1). A straight line distance establishes how far each cell is from the nearest source.

$$\text{Distance (x,y)} = \{(x_{\max}^2 + y_{\max}^2)\}^{\frac{1}{2}} \quad (1)$$

The calculation in ArcGIS derived the Euclidean Distance in kilometers. The output was a raster where each cell had a distance value. Those values were reclassified into a suitable range of distance (1 to 5). Areas with close proximity to infrastructure were given higher values and considered the most suitable locations in the modeling.

Ports included in the analysis were considered the most important in the transportation scenario. The pipelines used for infrastructure evaluation represent future and existing pipelines related to the transport of ethanol. Pipelines that move other types of product other than ethanol were not included in the suitability analysis for sugarcane allocation.

3.2.3.6 Socioeconomic data

In this research socioeconomic variables have an objective of analyzing the feasibility and requirements of important elements in the agricultural development. Data were obtained by the reorganization of information acquired from the Brazilian Institute of Geography and Statistics (IBGE) - Agricultural Census (IBGE, 2006), Demographic Census and Municipal Agricultural Production 2010 (IBGE, 2012). Note that the difference in years among censuses is a limitation in these data. The variables were selected based on aspects that could support the development of

agriculture such as people's age structure, level of education and employment (SELF; GRABOWSKI, 2007).

The agricultural production variable was used as a proxy of added value. People's age structure and level of education were normalized for the total population represented by the population age structure between 18 and 49. This interval was chosen based on the minimum labor age and not necessarily on the reality of Brazilian labor. People between the ages 16 and 17 are considered apprentices, and the type of work performed is very specific in accordance with Brazilian law. Therefore, the universe selected covers people already available and able to work in this type of activity. On the other hand, the employed people in temporary crops considered those with ages above 14, because it was not possible to determine a specific interval for this variable.

The socioeconomic variables were added to the geodatabase through a shared common city code field with the country feature (join tables option). People's age structure, level of education and employment variables were normalized by the population so we could have the data converted to a common scale of percent. The normalization procedure was carried out in the field calculator within ArcGIS 10. The next step was transforming the data into a raster format.

A quantile method was employed to rank the socioeconomic variables. This method was chosen because it was considered the most appropriate data classification in reference to the visual pattern, and because absolute numbers will vary over time. The quantile processing involved polygon feature datasets that were collectively defined by a categorization of break points located in the attribute values. This type of classification processes the datasets into ranges of attribute values, from maximum to minimum, into unequal sized intervals but with proportionate number of features within classes. The following procedure was a reclassification of each layer scale value ranging from 1 to 5. The higher value (5) was considered most suitable, while the lower value (1) least suitable.

3.2.4 Secondary data processing

3.2.4.1 Multicriteria evaluation for site suitability analysis

Multicriteria decision analysis has gained widespread acceptance for solving multicriteria decision making problems (HAYASHI, 2000; KIKER et al., 2005; LINKOV et al., 2006; MALCZEWSKI, 2006; KOSCHKE et al., 2012). Its intrinsic characteristics make it an appropriate tool for analyzing complex problems (BELTON; STEWART, 2002). The capability to deal with different datasets (quantitative and qualitative), to provide structure methods for the intervention of individuals or group of people that participate in decision making, and to help filling gaps in data, makes the MCDA a valuable method for the consideration of multiple criteria in decision making (MENDOZA; MARTINS, 2006).

The MCDA aims to balance the various interests of the stakeholders - environment, society and economy - involved in the systematic spatial distribution. This proposal is complex, since the principles of sustainable development seek to achieve a balance between nature conservation and economic growth. To Joerin, Theriault and Musy (2001), MCDA integrated with GIS for decision making can help manage the space in order to deal with this complexity of working with different criteria.

Strategic analysis to support decision making is connected with the dialectics of territorial planning. In this planning, criteria are used, measured and assessed, and that is the basis for the decision. Eastman (2006) states that the criteria consist of factors and restraints. The factors, also known as decision variables, are criteria that enhance or decrease the suitability of an alternative to an activity under consideration.

A multicriteria decision analysis approach involves a group of variables *criteria* $(1, 2, \dots, n)$ (eq. 2) evaluated in relation to a set of criteria values *weights* $(1, 2, \dots, n)$ (eq. 3).

$$X = (X_1, X_2, \dots, X_n) \quad (2)$$

$$W = (w_1, w_2, \dots, w_n) \quad (3)$$

The weights assigned to each of the variables participating in the analysis were gathered from the AHP. The relative importance of the selected criteria is determined multiplying the criteria (X) by the weights (W), given as follows (eq. 4):

$$Z = \begin{bmatrix} X_1 w_1 \\ X_2 w_2 \\ \dots \\ X_n w_n \end{bmatrix} \quad (4)$$

The MCDA was carried out in a map overlay operation using differential weight assignments aiming to combine the information belonging to different criteria to create a scale of evaluation. The weights were derived from the AHP with the assistance of specialists' knowledge of sugarcane production environments.

3.2.4.2 The decision making process

AHP is a multicriteria decision making tool, and it was used to process the judgment of sugarcane experts (Figure 18). Relevant variables were selected to represent the problem thoroughly but not as much as to include the whole set of variables into the decision process. When composing hierarchies, the variables that would have direct influence on the model were categorized. Once the variables were selected, it was time to identify the participants that would provide consistent judgment on them.

Specialists who worked in universities, resource management agencies, sugarcane mills and rural banks made up a team of 10 appraisers, who provided subjective judgments by choosing among the selected criteria used to identify potential areas for sugarcane expansion in Brazil. As the AHP is a non-probabilistic evaluation, a minimum number of participants were not required in the performance assessment of the combined set of criteria.

Figure 18 – To help the decision making process in deriving weights necessary for the MCDA, specialists give their opinion regarding their personal experiences in relation to a set of criteria. Qualitative judgments are evaluated and processed for the priorities outcomes.

No prior meeting was held with the specialists to discuss the variables that should participate as design criteria for the expansion of sugarcane areas in Brazil. Instead, due to the difficulty of working at a country level scale, the criteria were chosen according to data availability for the whole country, and the importance in the design of the study supported by FAO (1976). For these reasons, an analysis of the relevance of the variables was made in relation to the data accessibility to select those variables that could effective contribute to the objective of this research. This explains why there is not an immense list of relevant criteria in the analysis, however the chosen criteria are expected to be critical criteria applicable to the sugarcane expansion context (Table 4).

Table 4 - Criteria evaluation included in the decision making process to support the MCDA

General Criteria	Subcriteria	Normalized Evaluation
Physical land suitability	Soil	-
	Climate	-
	Topography	-
	Biome	-
	Land use	-
Infrastructure	Roads	kilometers
	Railroads	kilometers
	Ports	kilometers
	Pipelines	kilometers
	Mills	kilometers
Economic	Value of production	R\$ 1,000 ha ⁻¹
Social	Ages between 18 and 44	Ages between 18 and 44 / population ages between 18 and 49 in the municipality
	Ages between 44 and 49	Ages between 44 and 49 / population ages between 18 and 49 in the municipality
	Population with elementary education	Population with elementary education / population ages between 18 and 49 in the municipality
	Population with high school education	Population with high school education / population ages between 18 and 49 in the municipality
	Population with university education	Population with university education / population ages between 18 and 49 in the municipality
	Population with no education	Population with no education / population ages between 18 and 49 in the municipality
	Agricultural labor	Population employed in the temporary crop / total population in the municipality

The decision making problem was decomposed into a hierarchy that reduced the complexity of decision to a series of pairwise comparison choices represented by row/column pairing in matrices, establishing the importance among the elements in the hierarchy. The criteria were broken down into subcriteria by further

decomposition. An ideal scenario would be that where all the participants meet to discuss the decision and to get into a consensus among all the pairwise comparisons. However it was impossible to accomplish that because of the participants' schedules and availability. Considering that, each participant made judgments separately. A questionnaire survey was then conducted to assess the experts' judgments reflecting the relative importance of a criterion on a specific criterion for all possible pairs.

Questionnaires were built based on the pairwise comparison matrices and sent to the participants, so that they could examine them before the interview took place (see Appendix A). The questionnaire contained instructions about how to complete the pairwise comparisons and other additional guidance. During the interview the participants were asked if they had any questions about completing the questionnaire. The author conducted the interview, and provided supplementary assistance to the participants who were asked to give their opinion in regard to their knowledge about the importance of a set of chosen criteria in the comparison matrices.

The pairwise comparisons provided by the experts were used to average the values at each level to get the corresponding rating. A weight was generated for each evaluation criterion according to the experts' pairwise comparisons. The weight vector expresses the relative importance of the different elements in the hierarchy. The experts' judgments evaluated the importance of each element in the pairwise comparison matrix using a scale from 1 (equal importance) to 9 (extreme importance). The higher numbers mean that the chosen factor is considered more important and to a greater degree than other factor being compared with (Table 5).

Table 5 - Comparison scale for each pair of criteria

Numerical Rating	Degree of Preference	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate Importance	Slightly favors one activity over another
5	Strong Importance	Strongly favors one activity over another
7	Very Strong Importance	Dominance of an activity demonstrated in the practice
9	Extreme Importance	The evidence favoring one activity absolutely and clearly
2,4,6,8	Intermediate values	When compromise is needed
Reciprocals of above	When comparing elements i and j if i is a number different of zero, then j has a reciprocal value ($a_{ij} = 1/a_{ji}$)	For inverse comparison

The AHP processing was done using the Expert Choice 2000 software. Each participant's judgment was entered into the program with an identification number. A verification procedure of each participant's rating was performed to check for consistency among the judgments before calculating the weights for the criteria. Once an individual's judgment was verified, the next step was to determine the consensus among the specialists using statistics. With the consensus checked, the qualitative judgments of each expert were combined into a single matrix representing the group's judgment.

The logic of the AHP processing consisted of a matrix A that is built out of the results obtained from the judgments. The matrix is an $n \times n$ matrix, where n is the number of evaluation criteria considered. Each entry a_{ij} of the matrix represents the element of row i and the column j , and the importance of the i^{th} criterion in comparison to the j^{th} criterion. When $a_{ij} > 1$, then the i^{th} criterion is considered more important than the j^{th} criterion, although when $a_{ij} < 1$, then the i^{th} criterion is considered less important than the j^{th} criterion. When two criteria have the same importance, then the entry a_{ij} is 1. The entries a_{ij} satisfy the following constraint (eq. 5):

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{21}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \frac{1}{a_{n1}} & a_{n2} & \cdots & 1 \end{bmatrix} \quad (5)$$

$a_{ij} > 0 \rightarrow$ positive
 If $a_{ij} = 1$ then $a_{ji} = 1 \rightarrow$ equal intensity
 $a_{ij} = 1/a_{ji} \rightarrow$ reciprocal
 $a_{ik} = a_{ij} \times a_{jk} \rightarrow$ consistency

The entries in each column of the pairwise matrix are then summed (eq. 6):

$$a_{ij} = \sum_{i=1}^n a_{ij} \quad (6)$$

The next step is the normalization of the matrix by making sum of the entries on each column equal to 1 (eq. 7):

$$C_{ij} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}} \quad (7)$$

The weight vector W is then built by averaging the entries in each row (eq. 8):

$$W_{ij} = \frac{\sum_{j=1}^n C_{ij}}{n} \quad (8)$$

The consistency index (CI), a deviation or a degree of consistency, can be calculated as (eq. 9):

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (9)$$

Where n is the number of criteria and λ_{max} is the maximum eigenvalue (average score).

The consistency of the expert judgments is then determined by a consistency ratio (CR) (eq. 10):

$$CR = \frac{CI}{RI} \quad (10)$$

Where the random index (RI) reflects the consistency index of a pairwise comparison matrix for n criteria (Table 6).

Table 6 - Random consistency index (RI) for a certain number of criteria

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

When the CR value is smaller than or equal to 0.1 the inconsistency of the judgments are within acceptable limits because the judgments are considered coherent for the decision making process. Although when this value is greater than 0.1, the comparison process has to be verified to find out where the inconsistency is located in the comparison matrix and brought to a level smaller than or equal to 0.1.

The individual responses were converted to a scale of 100 instead of a scale of 1 given by the Expert Choice because the total influence of all rasters must equal 100 percent in the ArcGIS Weighted Overlay tool. An attribute agreement analysis worksheet was then created with those responses to be used in the agreement analysis in Minitab 16 statistical program. The objective of this type of analysis was to verify whether any consensus had been reached among the participants, and the degree of this agreement. The variation observed shows how similar the individuals' judgments were when assigned by the participants in completing the questionnaire.

Kendall's coefficient of concordance, a nonparametric test, was used in the attribute agreement analysis to validate the existence of significant agreement in ranking criteria at each level of the hierarchy. To Schmidt (1997), Kendall's W is the most popular method to verify a consensus group because of its simplicity of application. Kendall's coefficient ranges between 0, when there is no pattern agreement between the appraisers, and +1, when there is a perfect agreement among them (Table 7).

Table 7 - Interpretation of the agreement level among groups according to Kendall's W

Scale of agreement of Kendall's W		
W	Interpretation	Confidence in Ranks
0.1	Very weak agreement	None
0.3	Weak agreement	Low
0.5	Moderate agreement	Fair
0.7	Strong agreement	High
0.9	Unusually strong agreement	Very High

Source: Schmidt (1997)

The data gathered from the respondents are theoretically arranged into a $k \times N$ table with each row representing the rates assigned by the participants to the N criteria. Supposedly, each participant makes single rating on each criterion, and there are k participants per criterion in the analysis. The null hypothesis in this method considers no statistically significant difference in the criteria rating among the participants. If the null hypothesis is not rejected that means that there is a statistically significant agreement among the participants.

After verifying that the null hypothesis had been rejected, at a 0.05 significance level, which shows an acceptable consensus among the specialists when rating the criteria, the individual responses were combined in the Expert Choice. The aggregation of individual judgments of each respondent was obtained using the geometric mean. To Aczel and Saaty (1983) the geometric mean preserves the reciprocal property of the judgment matrix being the most appropriate rule to combine judgments. The formula to aggregate the individual priority weights is as follows (eq. 11):

$$w_j = \sqrt[n]{\prod_{i=1}^n w_{ij}} \quad (11)$$

Where W is the aggregated comparison matrix of geometric means calculated from the individual (ij) comparison matrices, and n represents the number of decision makers.

The normalization of the individual assessments is calculated using the geometric mean (eq. 12):

$$N_j = \frac{w_j}{\sum_j w_j} \quad (12)$$

To verify if there were more or less variations of judgments within the group of experts than variation among them, two groups of experts that had the same percentage of matched judgments, in accordance with the average, were selected for comparison. Two experts composed each group, and the percentage of matched responses was the same for all the individuals. Although they had the same percentage of matched responses, the individuals were grouped in relation to the importance that they gave to each of the main criteria. The first group was composed of specialists (P2 and P10), who had more similar judgments. The same idea was applied when choosing the second group composed of P6 and P8.

Each individual response was used to create a map representing the potential areas for sugarcane expansion. Maps that were built in the previous step were then subtracted from each other within each group. The performed arithmetic operation resulted in a map that shows the changes between the individuals' responses within the groups that is the spatial robustness of the forecast areas across experts' choices. Subsequently, the difference between the two rasters was quantified at each cell location. In the next step, the absolute value from the rasters representing each group was obtained and then subtracted to verify the changes between the groups, and the difference between them was also quantified. Figure 19 represents the arithmetic operations involved in this process.

Figure 19 - Diagram of the geoprocessing analysis employed to the rasters to verify the variation of judgments within the group of experts and between them. The illustration shows the arithmetic operations involved in this process

3.2.4.3 Scenario analysis

A model is a simplified version of reality. Thinking about a consistent representation of a real system, the issue is whether a model is reliable or not. So, how does one make a reliable model? To Qureshi, Harrison and Wegener (1999), validation is a very important procedure to ensure that a model is correctly developed. However, as stated by these authors, the validation process in multicriteria analysis models is difficult, since it considers different parameters, which affect the model's reliability for policy analysis in comparison to the real system. To overcome this problem, the inclusion of different specialists' opinions in the planning process can be used for model validation (COLORNI; LANIADO; MURATORI, 1999).

A sensitivity analysis can additionally be an alternative way to explore further confidence and stability in the modeling process (HYDE; MAIER; COLBY, 2005; CHEN; YU; KHAN, 2010). That is because the results of a sensitivity analysis will indicate areas for improvement in case the model needs to be adjusted. Accordingly, a scenario analysis (a variant of sensitivity analysis) was performed in the MCDA model for sugarcane to evaluate the impact of the changes of an individual criterion weight obtained in the pairwise comparisons, taking into consideration the judgments of the experts. Modifying the influence percentages set to the criteria in the model will produce different results? To answer that, scenario analysis was used to determine how the changes in each criterion influenced the final model given by the design of seven “what if” scenarios.

The analysis consisted of reproducing different values by increasing the percentage of a factor while keeping constant the proportionality among the others. The new assigned weights were entered in the Weighted Overlay tool and new maps were generated. The map with the weights given by the experts was the basis for the comparison. A pixel-by-pixel analysis was used to verify the changes.

The map resulting from the experts' judgments (main model) was used as a predictor input raster to determine which values were logically different from the values of the other predicted input scenarios (cane allocation alternative scenario – CAAS) on a pixel-by-pixel analysis. When the cell values on the predicted raster were distinct from those of the main model (predictor), the values on the predicted input (scenarios) were considered the output. A value of zero was given to the cells with the same values in both inputs.

3.3 Results

3.3.1 The physical land suitability submodel

With the combination of data it was possible to create a general soil suitability map for sugarcane cultivation. A soil suitability index was the output of this process. Soil raster was reclassified to a measurement scale of 1 to 3 (reclassified values: $\leq 2 = 1$; $\leq 6 = 2$ and $\leq 9 = 3$) (Figure 20) and combined with the climate raster (reclassified values: zone 6 = 4; zone 5 = 3; zone 4 = 3; zone 3 = 2; zone 2 = 1 and zone 1 = 1) (Figure 21).

Figure 20 - Soil suitability classification for sugarcane: low suitability (1), moderate suitability (2) and high suitability (3)

Figure 21 - Climate suitability classification for sugarcane: (1 = very low suitability; 2 = low suitability; 3 = moderate suitability; 4 = high suitability)

The two intermediate maps that were the product of the map algebra processing are present in Figure 22 and Figure 23. The multiple operators and tools used in the statements to build them are accessible through a model report in ModelBuilder (Contact the author to request the model report). The suitability classes show areas of very low to high suitability for sugarcane expansion. The areas in grey represent water bodies and urban sites.

The most suitable areas with moderate to high soil and climate suitability are located for the most part in São Paulo, Minas Gerais, Espírito Santo, Rio de Janeiro, Mato Grosso do Sul, south of Goiás, north of Paraná and south of Bahia (Figure 22). A moderate suitability zone, sparsely distributed, can be observed in some other areas such as Mato Grosso and Pará.

When the topography variable was added to the physical land suitability submodel, it was observed that areas that thus far had moderate to high land suitability (particularly in Minas Gerais) became less suitable because of the relief that was not appropriate for mechanization (Figure 23). This is due to the fact that with the prioritization evaluation scale in the map algebra analysis, areas with slope over 16% were considered unsuitable. Areas that belong to the Pantanal biome also became less suitable.

Figure 22 - Spatial distribution of soil and climate suitability for sugarcane

Figure 23 - Soil and climate suitability for sugarcane with environmental land use restrictions, biome and topography integration limiting feasible areas for mechanization

Physical constraints were established in the model to avoid the integration of areas with slopes over 16%, which were considered restrictive for mechanized agriculture. Restricted areas assumed a value of “0” after the weighted overlay procedure, which were eliminated from the analysis when overlapped onto the pastureland raster. In the suitability classification, the areas categorized as unsuitable do not necessarily represent unsuitable agricultural zones. They were classified as such according to the logical framework that does not classify suitable areas other than cultivated pastureland.

3.3.2 Geoprocessing of infrastructure accessibility

Areas that have the most suitable transportation infrastructure in the country are located in the Southeast region where the transportation network is denser. As can be seen through Figure 24 to Figure 28, distances increase away from the infrastructure elements. The difference in transportation accessibility across the country is perceptible, and this variability shows an unbalanced logistic/transportation cost throughout the Brazilian regions. In great agricultural producer states such as Mato Grosso and Mato Grosso do Sul the logistic/transportation system presents difficulties to the producers, mostly due to the insufficient infrastructure available.

Roads are the main Brazilian transportation mode, and are responsible for the integration of the economic regions (Figure 24), playing an important role in the movement of agricultural products. This type of transportation accounts for most part of the agricultural production in the country, and the producers are, in general, situated near to them. Because of the high demand, and due to the lack of investment, the roads are, generally, overloaded and worn out.

A.

B.

Figure 24 - A. Spatial distribution of roads network in the country. B. Distance to roads (km) based on the roads network. The prioritized values represent: (1) the least suitable and (5) the most suitable areas with high accessibility to roads

Railroads and waterways are insufficient and under-used, even though they are characterized as cheap and safe modes of transport. Instead, the road network system is used for transporting the larger part of the agricultural production even over long distances. As can be observed in Figure 25, the amount of railroads linking long distances in the country is very scarce. Therefore, in many cases, the only alternative is the road to transport the agricultural products.

A.

B.

Figure 25 - A. Spatial distribution of railroad infrastructure in the country. B. Distance to the nearest rail station (km) for each location. The prioritized values represent: (1) the least suitable and (5) the most suitable areas with high accessibility to rail station

Brazil has easy ocean access (Figure 26), and port is considered a key component of the logistics system in terms of reducing the transportation costs in the country, especially when it comes to load capacity that enables significant reductions in per unit cost price. Additionally, the ships transport large volumes over long distances besides the higher energy efficiency, more safety features and the reduction of maintenance cost of roads (decrease in the number of trucks transporting goods). Although the maritime transport presents great advantage over other modes, the ports face logistical problems.

A.

B.

Figure 26 - A. Spatial distribution of the cabotage system and main ports in the country. B. Distance to the main ports (km). The prioritized values represent: (1) the least suitable and (5) the most suitable areas with high accessibility to ports

The major reasons for failure in the maritime transport are the lack of proper connectivity of other modes of transportation in the Brazilian territory, which causes traffic jam in the loading docks (instigated by the great number of trucks), and the fact that most part of the agricultural production in the country goes directly to the South-Central ports, which contributes to the traffic jam in the ocean (lines of ships waiting to be loaded). Such issues erode the country's farming gains because farmers have faced difficulties in delivering products to consumers in the time established, causing production volume and credibility losses. In relation to the international transportation, the choices of routes are restricted to the limited number of ports and customs offices.

In order to become more competitive, the country is now investing in a more reliable mean of transport that aggregates financial, logistics and environmental efficiency (BRASIL, 2013), reducing cost and pollution. Pipelines will be the mean of transport to promote this development, connecting distant regions and aggregating other means of transport. Thus, this connection will allow more efficiency in the transportation of ethanol.

The ethanol pipeline is still not a part of the transportation reality in Brazil. However, private and public investments have been made in this sense. The pipelines are a project of the Federal Government as part of the Accelerate Growth Program (PAC) in the country (BRASIL, 2013). This project envisages the construction of pipelines for 2013 and next years linking areas in the Midwest (Senador Canedo – GO) overpassing Minas Gerais toward São Paulo (Ribeirão Preto - which is one of the major ethanol producing zones) to Paulínia (the largest refinery in the country) to Port of São Sebastião (Figure 27). The second project, which is not included in the mapping, will connect Cuiabá (MT) to Corumbá to Port of Paranaguá (PR). With the improvement of another mean of transportation, it is expected that the cost of producing biofuel will reduce significantly, allowing the country to become more competitive in the market.

A.

B.

Figure 27 - A. Spatial distribution of pipelines infrastructure in the country. B. Distance to pipelines (km) based on future and existing ones. The prioritized values represent: (1) the least suitable and (5) the most suitable areas with high accessibility to pipelines

Most of the sugarcane mills existent in the country are located in the Southeast region, predominantly in the São Paulo state (Figure 28). The Northeast is the second region with significant number of mills followed by the Midwest, which are, in general, installed where there is logistical infrastructure to ensure the production. The Midwest region reflects the extension of the advance of the agricultural frontier coming from the South-Central.

A.

B.

Figure 28 - A. Spatial distribution of sugarcane mills in the country. B. Distance to the nearest mill (km) for each location. The prioritized values represent: (1) the least suitable and (5) the most suitable areas with high accessibility to sugarcane mills

3.3.3 Socioeconomic data classification

The quantile classification method for the socioeconomic criteria describes the break values that have been established for each variable. The break values were categorized into 5 classes, which define the socioeconomic rasters that along with the other rasters create the MCDA model. In the socioeconomic rasters, each value class in each input raster is assigned a new reclassified value that represents the lowest suitability (1) and the highest suitability (5). The parameters for the evaluation of each variable are presented in Figure 29 to Figure 36.

Figure 29 - Data classification of the population with no education (%)

Figure 30 - Data classification of the population with elementary school education (%)

Figure 31 - Data classification of the population with high school education (%)

Figure 32 - Data classification of the population with university education (%)

Figure 33 - Data classification of the population age structure between 18 and 44 (%)

Figure 34 - Data classification of the population age structure between 44 and 49 (%)

Figure 35 - Sugarcane production data classification (Thousand Reais/ha)

Figure 36 - Employed people in annual crops data classification (%)

3.3.4 Judgment synthesis of prioritization decisions

Kendall's coefficient of concordance assessed the relative agreement between the specialists' ratings. Kendall's coefficient was 0.53, which indicates that the level of association between the specialists was fair. The null hypothesis, which implies that the agreements among the specialist rating were unrelated to each other, was rejected at a 5% significance level. Based on these results, it was concluded that the consistency of the ratings among specialists was within acceptable limits, indicating that the group average weights describe individual opinions satisfactorily. That means there was a fair agreement among the specialists' ratings. Table B2 compares the consistency of the ratings among the experts.

The specialist versus average (combined judgments) assessment agreement graph shows the accuracy of each specialist's ratings in relation to the average (Figure 37). P4 was the specialist assessment agreement with the closest match to the average, a match score above 60%. P2, P3, P6, P8 and P10 had the same number of matched variables compared to the combined judgments. The same thing could be observed between P1 and P9, but with less percentage of agreement.

Figure 37 - Specialists assessment agreement graph. The circle indicates the percent matched and the line a 95% confidence interval for the percent matched of each specialist versus the combined opinion

The level of agreement among experts was not very high, although the aggregate judgments represent an acceptable individual expert's response. The influence that each criterion plays in the sugarcane expansion context is a qualitative decision, so we benefit from the AHP to make a valid decision, since this technique involves a process that counted on the knowledge of the experts on sugarcane. The results obtained from the pairwise comparison in the decision making analysis were thus used to feed the sugarcane spatial modeling.

3.3.5 Multicriteria analysis for spatial decision support

Land covered by cultivated pastures represents, approximately, 112 million hectares (Mha) in Brazil. Overlaying the soil and climate suitability raster (that includes land use restrictions and topography limitations) with the pastureland raster, 108 Mha are the remaining pasturelands available that could be evaluated for the allocation of sugarcane. From those 108 Mha, 15 Mha were of very low suitability, 27 million of low suitability, 31 Mha of moderate suitability and 35 Mha of high suitability for sugarcane allocation. The most suitable areas of pasture were predominantly concentrated in Goiás, Mato Grosso, Pará, Paraná, São Paulo, Mato Grosso do Sul and Minas Gerais. The last two were the states with more highly suitable areas of pasture for agricultural expansion (Figure 38).

Figure 38 - Histogram graph showing cultivated pasturelands with different suitability for sugarcane cultivation in each Brazilian state

The results of the participatory modeling process, considering the combination of weights derived from the decision making analysis, show that the most suitable pasturelands for sugarcane allocation in the main model were clearly most concentrated in São Paulo, Minas Gerais, Goiás, Paraná and Mato Grosso do Sul (Figure 39). Very low to moderate suitable areas for sugarcane cultivation were more numerous than highly suitable lands as can be verified in the pixel-by-pixel analysis (Figure 40). It is important to note that due to the combination of the criteria weights, areas with limited and high suitability hardly occurred on the mapped areas.

Figure 39 – Suitability map for sugarcane expansion over pasturelands according to the judgments of the experts

Figure 40 - Area of cultivated pasturelands by land suitability classes for sugarcane

The large quantity of highly suitable pasturelands for sugarcane allocation is clustered in space in some states in Brazil as observed in Figure 38. However, those areas become less apparent when the weights derived from the experts' opinion are incorporated into the model as can be seen in Figure 39. This has to do with the fact that the model was not only dependent on the geospatial distribution of the physical land suitability, but also on the overall weights that considered the geometric mean of all the experts' judgment for all criteria involved in the analysis.

To show how the divergence in the experts' opinion would interfere in the spatial distribution of suitable classes, four experts were selected and grouped considering their similarity judgments. The judgments' variation between groups and within groups of experts is shown in more detail through maps representing the combination of criteria relative to the importance that each criterion assumes in the MCDA model.

Spatial patterns in the experts' judgments distribution reveal the similarity between the opinions of P2 and P10, unlike P6 and P8 who showed a more dissimilar distribution (Figure 41 to Figure 44). The disparity in the suitability classes' distribution between the two groups has, basically, to do with the fact that they weighed the importance of the criteria in the model differently. To P6 and P8, for example, the physical land suitability are more important than the economic criterion, contrasting with P2 and P10, who considered the physical variable as important as the economic variable.

Figure 41 - Suitability map for sugarcane expansion over pasturelands according to the judgments of sugarcane expert P2

Figure 42 – Suitability map for sugarcane expansion over pasturelands according to the judgments of sugarcane expert P10

Figure 43 - Suitability map for sugarcane expansion over pasturelands according to the judgments of sugarcane expert P6

Figure 44 - Suitability map for sugarcane expansion over pasturelands according to the judgments of sugarcane expert P8

P2 and P10 did not agree with each other's judgments mainly in areas of Mato Grosso do Sul, São Paulo, Paraná, Minas Gerais, Goiás, Mato Grosso and Pará (Figure 45). The number of times their judgments did not agree with each other was 2% of the total number of pixels in the raster. When comparing their judgments, it is visible that on the P10 map there are more areas of higher suitability for sugarcane allocation than for P2.

Figure 45 - Variation in judgments between P2 and P10. The red color in the map means that P10 had higher suitability classes' distribution over space when compared to P2. The blue color means the opposite

P6 disclosed more areas of higher suitability for sugarcane allocation than did P8 (Figure 46). Comparing the individuals in this group with the others, it is noticeable that the variation between their judgments was higher than between P2 and P10. The quantification analysis shows that a total of 4% represent the number of unmatched judgments between P6 and P8.

Figure 46 - Variation in judgments between P6 and P8. The blue color in the map means that P6 had higher suitability classes' distribution over space when compared to P8. The red color means the opposite

The variation between the groups of experts was higher than the variation within the groups (Figure 47). Unmatched judgments were 5% between the two groups. Although they all presented the same percentage of matched judgments, the maps show that the opinion in relation to the importance of each criterion in the MCDA model had more similarity within the groups of experts, which had similar judgments between them, than between the groups.

Figure 47 - Variation in judgments between the two groups of experts. The red color in the map means that the group composed by P6 and P8 had higher suitability classes' distribution over space when compared to P2 and P10. The blue color means the opposite

3.3.6 Scenario analysis

The overall results obtained from the MCDA show that the most suitable areas of pasture were mostly located in the South-Central economic region in Brazil, according to the main model and to the scenarios. This area is already part of the main sugarcane producing zones in the country. Mato Grosso do Sul, Triângulo Mineiro, south of Goiás and west of São Paulo constitute predominantly traditional pasturelands, and, in fact, in agreement with Nassar et al. (2008) they represent areas where the sugarcane cultivation has already been advancing, substituting for livestock, a trend that will prevail for the following years.

The suitability classes for sugarcane allocation varied for all seven scenarios, considering the different combination of the main factors (physical land suitability, infrastructure and socioeconomic criteria), as did the areas of high suitability. Major frameworks shifts for the scenarios reflected primarily general changes in the relative importance of each of the main criteria. The spatial changes in the distribution of land suitability classes for each of the seven scenarios are shown through maps and the variation in the number of hectares for each suitability class is presented in Table 8.

Table 8 - Distribution of cultivated pasturelands by land suitability classes for each of the seven scenarios and the main model

	Main Model	CAAS						
		1	2	3	4	5	6	7
Land Suitability	Area (thousand hectares)							
Limited	6	0	16,600	28,100	0	60	0	1,458
Very Low	41,600	15,500	71,000	56,000	15,497	49,045	36,100	61,890
Low	51,677	27,100	19,600	7,880	32,600	51,695	48,505	29,800
Moderate	14,700	30,500	800	9,390	48,828	7,200	22,505	13,970
High	17	34,900	0	6,630	11,075	0	890	882

In the CAAS1, the physical land suitability influence increases to a limit of 90% and 10% is set to the other criteria. The proportionality was kept constant among criteria (Table B5). It is noteworthy that these changes stimulate more movement of high suitable classes toward Mato Grosso do Sul, west and center of São Paulo,

predominantly in Triângulo Mineiro, south of Goiás, eastern of Pará, northwestern of Paraná and some random areas in Mato Grosso (Figure 48).

Figure 48 - Suitability map for sugarcane expansion over pasturelands in the CAAS1

The frequency distribution of pixel values is higher in the mentioned states (Figure 49). CAAS1 showed a dissimilar pattern of class distribution in comparison to the main model. The first one had a higher frequency distribution of pixel values for the high suitability class, while the second one for the low. Similar scenario analysis was implemented for the infrastructure and socioeconomic criteria.

Figure 49 - Frequency distribution of pixel values. The graph shows the differences between the CAAS1 and the main model in the distribution of suitability classes for sugarcane expansion in each state

CAAS2 disclosed major changes in the spatial distribution of the suitability classes when there is an increase in the infrastructure priority to 90%, keeping the remaining criteria weights constant (Figure 50). The significant outcome of this scenario is the limited suitability areas derived from the combination of the priorities weights.

Figure 50 - Suitability map for sugarcane expansion over pasturelands in the CAAS2

Rondônia, Pará and Mato Grosso had the highest frequency distribution of pixel values for the limited suitability class when the infrastructure had higher priority than the other criteria in the model (Figure 51). Likewise very low suitability areas were widespread. Only a very small area in São Paulo and Minas Gerais was covered by moderate suitability.

Figure 51 - Frequency distribution of the number of pixel. The graph shows the differences between the CAAS2 and the main model in the distribution of suitability classes for sugarcane expansion in each state

Considering an increase of the economic criterion to 90% in CAAS3, Mato Grosso, Mato Grosso do Sul, Goiás, Tocantins and Pará showed a noteworthy expansion in the direction of the limited suitability areas (Figure 52). Although Mato Grosso and Goiás showed significant areas of limited suitability, they also had some areas of high suitability. Minas Gerais, Mato Grosso do Sul and São Paulo stand out with more areas of high suitability.

Figure 52 - Suitability map for sugarcane expansion over pasturelands in the CAAS3

Mato Grosso do Sul, Minas Gerais and São Paulo had the highest frequency distribution of pixel values for the high suitability class compared to Mato Grosso, Goiás, Tocantins and Pará (Figure 53). The increment in the importance of the economic criterion reveals the maximization of the discrepancies between classes. As the classification method separates the classes into the same number of features, a high number of pixels fell into the limited suitability class that identify areas with a value of sugarcane production of 0 to approximately 10 million Reais.

Figure 53 - Frequency distribution of the number of pixel. The graph shows the differences between the CAAS3 and the main model in the distribution of suitability classes for sugarcane expansion in each state

In the CAAS4, 0% influence is given to the social criterion in the selection of sites for sugarcane allocation. Edaphoclimatic criterion has an 80% influence, infrastructure has a 10% influence and economic criterion has a 10% influence. Moderate and high suitability areas concentrated in great part of Mato Grosso do Sul, northwestern of Paraná, south and center of Goiás, eastern of Pará, Triângulo Mineiro and west and center of São Paulo (Figure 54).

Figure 54 - Suitability map for sugarcane expansion over pasturelands in the CAAS4

This scenario significantly differs from the main model, showing higher frequency of pixel values, particularly, for the moderate and high suitability classes (Figure 55). The zones with the highest frequency distribution of pixel values for the high suitability class are located in Minas Gerais, Mato Grosso do Sul, Goiás and São Paulo.

Figure 55 - Frequency distribution of the number of pixel. The graph shows the differences between the CAAS4 and the main model in the distribution of suitability classes for sugarcane expansion in each state

In the CAAS5 each criterion received equal importance (25%). This scenario presents less variation in the frequency distribution of pixel values in relation to the main model. A market difference in this scenario was the absence of the high suitability class. Areas of low and very low suitability were the most noticeable changes (Figure 56).

Figure 56 - Suitability map for sugarcane expansion over pasturelands in the CAAS5

The moderate suitability class was rarely located, and the distribution of pixels in the high suitability class was non-existent (Figure 57). Minas Gerais, Mato Grosso do Sul, Goiás, Pará and São Paulo were the states where the changes were more apparent.

Figure 57 - Frequency distribution of the number of pixel. The graph shows the differences between the CAAS5 and the main model in the distribution of suitability classes for sugarcane expansion in each state

In the CAAS6, the edaphoclimatic criterion had a 50% influence, infrastructure had a 25% influence, economic had a 25% influence and social had a 0% influence on the analysis. Compared to the main model, shifts in the moderate suitability lands in this scenario are more concentrated in Minas Gerais, Goiás and Mato Grosso do Sul (Figure 58).

Figure 58 - Suitability map for sugarcane expansion over pasturelands in the CAAS6

A higher frequency distribution of pixel values for the high suitability class was found in São Paulo, however it was not so significant (Figure 59). This scenario and the CAAS5 had less variation in the frequency distribution of pixel values in relation to the main model than did the others.

Figure 59 - Frequency distribution of the number of pixel. The graph shows the differences between the CAAS6 and the main model in the distribution of suitability classes for sugarcane expansion in each state

Fewer changes arose in the CAAS7 when increasing to 50% the influence of the economic criterion and assigning 25% to the infrastructure and 25% to the edaphoclimatic (Figure 60). The main variations took place, considerably, in the very low suitability class.

Figure 60 - Suitability map for sugarcane expansion over pasturelands in the CAAS7

A higher distribution of pixel values fell into the very low suitability class in Goiás, Minas Gerais, Mato Grosso do Sul, Mato Grosso and Pará (Figure 61). The other classes did not show substantial difference from the main model.

Figure 61 - Frequency distribution of the number of pixel. The graph shows the differences between the CAAS7 and the main model in the distribution of suitability classes for sugarcane expansion in each state

3.4 Discussion and Conclusions

Attention has been driven to countries able to expand their agricultural production in order to meet the increasing world demand for food and biofuel. However, expanding agricultural lands without compromising sustainability is a severe challenge for the countries. To follow the trend of more sustainable agricultural expansion, this study focus on the identification of suitable cultivated pasturelands that could be used for conversion to sugarcane.

According to the Agricultural Census (IBGE, 2006), the total area of pasture is approximately 160 Mha of which 92 Mha are considered cultivated pasturelands in good conditions and 10 Mha are of degraded pasturelands. The disparity between the number of cultivated pasturelands provided by IBGE and the number estimated in this study has to do with the fact that the IBGE does not have the areas devoted to pasture mapped. Because of that, this study had to depend on the only data

available, which was based on the combination of different sources on Brazilian land use (Table B1).

The information provided by the IBGE was acquired from questionnaires answered by farmers, which means that the pasture data may vary, and the amount of pasture could be misleading, since the area was not measured. As was highlighted by Braz et al. (2013), classification of pasturelands considering the farmers' perception point of view is not always accurate. Besides, the census tracts do not cover the whole territory of Brazil.

In accordance with our database (Table B1), Brazil has 112 Mha of cultivated pasturelands that, in part, could be used to support a sustainable agricultural expansion in the country. From the total area of cultivated pasturelands estimated in this study, 31 Mha are considered moderately suitable and 35 Mha highly suitable. We believe that if new technologies were inserted into such lands to improve their productivity and efficiency, more areas of pasture would be made available for conversion to croplands as way to meet the demand for agricultural products.

Agricultural projections presented by Goes, Marra and Silva (2008) indicate that the expansion of areas covered by sugarcane in coming years will focus mainly on ethanol not on sugar production, and will primarily arise in response to increasing demand for ethanol and to improvements in the profitability of the sugarcane industries due to technological advances in this sector. To meet future needs for additional agricultural lands, pasture with moderate and high land suitability, estimated at 66 Mha, will be sufficient to supply that demand in the short term in Brazil.

The area of cultivated pasturelands (moderately and highly suitable lands) is much higher than the total area covered by sugarcane, currently estimated at 9 Mha (IBGE, 2012). If part of such lands would be made available and accessible through a more effective pasture use and livestock management employable in such areas, it would contribute to an expansion of the agricultural land for sugarcane cultivation without compromising the environmental sustainability in the country.

As has been stated by Cerri et al. (2010), a more efficient pasture use and livestock management would result in more available lands for agriculture and consequently avoid indirect land use changes (LAPOLA et al., 2010). Improving cattle management, through mechanisms that increase the number of cattle per hectare without negatively impacting the environment, could make the conversion of

pasture to croplands feasible to satisfy that condition (LEITE et al., 2009). However, a sustainable livestock pattern would be one that does not allow cattle operation movement northward in the direction of forestlands.

The expansion of croplands for sugarcane production would also be more practicable in pasture mainly because of its general accessibility to infrastructure to support an agricultural production system. Hence, additional infrastructure costs associated with the deployment of necessary transportation systems, for more mobility of the agricultural products, would be lower. To take advantage of the existing infrastructure and that under development, to explore the export market opportunity and to meet the demand of the domestic market, attention should be directed to pasturelands to allocate sugarcane cultivation in the most suitable pasture zones presented in this work.

The results obtained in this study confirm the spatial trend of sugarcane expansion presented by Goes, Marra and Silva (2008), which shows that Minas Gerais, Paraná, São Paulo, Goiás and Mato Grosso do Sul and also Mato Grosso and Pará are the priority states for the expansion of sugarcane in Brazil. Such areas have a large amount of pastures with moderate and high agricultural potential that could be used for future expansion of sugarcane.

The main MCDA model relies on physical land suitability, infrastructure and socioeconomic data to assess potential areas for sugarcane expansion by combining weights obtained through AHP, which was supported with the systematization of experts' knowledge. The inclusion of experts in the modeling process generates more confidence in the results, which may allow policymakers to make more informed decisions based on the model results. Model validation resulted in the projection of different scenarios showing how the distribution of suitability classes would differ from the main model. Scenarios were built to explore divergent views on the potential for sugarcane expansion considering the combinations of variables in the spatial allocation process. Each scenario was compared to the main model to verify the changes.

Considering the results obtained from the MCDA, decreases in the priority of the edaphoclimatic criterion in the model lead to increases in the distribution of the low, very low and unlimited suitability classes. The most suitable areas of pasture are

predominantly located in the South-Central region, even when changing in the criteria priorities for each of the “what if” scenarios are made.

Infrastructure directly affects the MCDA when that criterion had high percentages in the model. The suitability of pasture was really influenced by the variation in the infrastructure criterion, even in states like São Paulo that has greater access to transportation than some others in the country. The results show that when the infrastructure criterion has a higher priority in the model more areas of lower suitability become evident. Due to the combination of different infrastructure elements (roads, pipelines, rail stations, mills and ports), areas with low accessibility to infrastructure turn into lands with a lower degree of suitability for sugarcane.

Transportation is essential to link Brazil's main sugarcane producing regions, and is a major issue in reducing the agricultural products costs to make the country more competitive in the world market. Transporting products from the producing areas to the markets is still very expensive because trucks transport a great part of the agricultural production in Brazil. In areas far from the central part of the territory, the cost is even higher. In others, particularly in leading agricultural producing states such as Mato Grosso and Mato Grosso do Sul the road networks are insufficient. Consequently, the cost of transportation constitutes a limitation to the agricultural sector, which is also embedded in the inputs, influencing the cost of production and affecting the final price of products.

Problems arising from the transportation and logistics limitations in Brazil, as partially expounded in this research, have tremendous impact on the competitiveness of the agricultural products in the market. The relative lower production cost is, in general, not so competitive when the cost of transportation is included in the analysis. It was not the objective of this study to develop a model able to measure the impact of the logistics system on the Brazilian agriculture competitiveness, although a more specific study has pointed out that the cost of shipping does interfere in the country competitiveness in the international market (CRAGO et al., 2010). This shows that whereas it is possible to allocate more suitable areas for agricultural expansion, agriculture will still face issues in relation to the infrastructure efficiency available in the country if this issue is not addressed. As noted by Fuller et al. (2003), an improvement in the transportation system would allow an increase in production followed by an expansion of exports and a more attractive price in the world market.

The overview on the Brazilian infrastructure makes evident that although it is possible to increase the amount of suitable lands for agriculture, the logistical limitations in the country will still be a disadvantage to be faced by the producers that have to deal with the high shipping costs and other issues related to the available infrastructure in the country. This demonstrates that efficient modes of transportation are also essential to competitiveness. Thus, it is not just enough to invest in equipment, people and technology if progress is not made to improve the flow of agricultural and industrial production to expand trade performance through the efficient connection of all modes of transport in the country.

When it comes to accessibility of multimodal transport in areas of cultivated pasturelands, most states in the country has some limitations, considering the variation in access to infrastructure. Although infrastructure has tremendous impact on the competitiveness of the agricultural products in the market, its limitation does not make the lands unsuitable for agricultural expansion, considering that infrastructure can always be built. According to the general consensus among specialists, it is the physical land suitability that actually defines the ability of a land to support agricultural expansion and that is the variable that has the most impact on a model.

The MCDA model proposed for sugarcane allocation has the advantage of presenting the spatial distribution of the land suitability classes that result from the combination of a physical land suitability submodel with infrastructure and socioeconomic criteria for the entire country, and also covers important land use restrictions such as biome, areas of natural vegetation and slopes too steep for mechanization. In addition, it overcomes the limitation of many other studies on land use planning that are limited to the local and regional scales (NEPSTAD et al., 2008; BERNARD; BARBOSA; CARVALHO, 2011; MARTINELLI et al., 2011; LORZ et al., 2012; MONTENEGRO; RAGAB, 2012; DUARTE et al., 2013).

To be sustainable, a model should not point out suitable lands for the expansion of crops in areas occupied by forest, otherwise it will lose its value for sustainability. This was the reason why this model was set up in a way to identify suitable areas of pasture where sugarcane could replace this type of land use because they represent areas already occupied, so as to avoid more deforestation in the short term in Brazil.

Data combination on land suitability for sugarcane and cultivated pasturelands from public databases allowed us to develop a model for geographic location of suitable areas for sugarcane expansion over pasturelands, as an alternative pathway for agricultural expansion in Brazil. The model not just identifies such areas, but disclose important information about spatial differences in the distribution of the most suitability classes in each Brazilian state. It also shows that the sum of the total area of pasture with moderate and high suitable lands for sugarcane expansion is almost equivalent to the total area of croplands in Brazil, which makes those lands priority regions for sustainable development of Brazilian agriculture.

The study intended to develop a model that was a suitable representation of the real world and to make it practical. The model was developed in a way that it was not too complex, making it suitable to be able to communicate the idea of this work. It is acknowledged that there is no single precise approach to land planning modeling. As a representation of a real complex system, the model does present limitations, but these do not make it impractical.

The results of this study could be used for future applications for land planning in Brazil. The different scenarios enable policymakers to judge the best scenario for the Brazilian agricultural context. Besides, the construction of workflow in ModelBuilder allows other researchers to replicate the model, to define different priorities for the set of criteria employed in the MCDA and to add or substitute criteria of which can be guided by the modeling report that facilitates further applications.

References

- ACZEL, J.; SAATY, T. Procedures for synthesizing ratio judgments. **Journal of Mathematical Psychology**, New York, v. 27, n. 1, p. 93-102, Mar. 1983.
- ALFONSI, R.R.; PEDRO JÚNIOR, M.J.; BRUNINI, O.; BARBIERI, V. Condições climáticas para a cana-de-açúcar. In: PARANHOS, S.B. (Ed.). **Cana-de-açúcar: cultivo e utilização**. Campinas: Fundação Cargill, 1987. p. 42-87.
- BANCO NACIONAL DE DESENVOLVIMENTO ECONÔMICO E SOCIAL. **Sugarcane-based bioethanol: energy for sustainable development**. Rio de Janeiro: 2008. 304 p.
- BARRETTO, A.G.O.P. **Agricultural land-use expansion dynamics in Brazil**. 2013. 147 p. Dissertation (Doctor in Science: Soils and Plant Nutrition) – Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo, Piracicaba, 2013.
- BELTON, S.; STEWART, T.S. **Multiple Criteria Decision Analysis: an integrated approach**. Massachusetts: Kluwer Academic Publishers, 2002. 372 p.
- BERNARD, E.; BARBOSA, L.; CARVALHO, R. Participatory GIS in a sustainable use reserve in Brazilian Amazonia: implications for management and conservation. **Applied Geography**, Sevenoaks, v. 31, n. 2, p. 564-572, Apr. 2011.
- BRASIL. Ministério do Planejamento. **Programa de Aceleração do Crescimento: etanol duto**. Disponível em: <<http://www.pac.gov.br/noticia/6eacdcfdf>>. Acesso em: 10 nov. 2013.
- BRAZ, S.P.; URQUIAGA, S.; ALVES, B.J.R.; JANTALIA, C.P.; GUIMARÃES, P.P.; SANTOS, C.A.; SANTOS, S.C.; PINHEIRO, E.F.M.; BODDEY, R.M. Soil carbon stocks under productive and degraded *Brachiaria* pastures in the Brazilian Cerrado. **Soil Science Society of America Journal**, Madison, v. 77, n. 3, p. 914-928, May 2013.
- CAMARGO, A.P.; ALFONSI, R.R.; PINTO, H.S.; CHIARINI, J.V. Zoneamento da aptidão climática para culturas comerciais em zonas de cerrado. In: SIMPÓSIO SOBRE O CERRADO, 6., 1977, São Paulo. **Anais...** São Paulo: Editora USP, 1977. p. 89-105.
- CERRI, C.C.; BERNOUX, M.; MAIA, S.M.F.; CERRI, C.E.P.; COSTA JUNIOR, C.; FEIGL, B.J.; FRAZÃO, L.A.; MELLO, F.F.C.; GALDOS, M.V.; MOREIRA, C.S.; CARVALHO, J.L.N. Greenhouse gas mitigation options in Brazil for land-use change, livestock and agriculture. **Scientia Agricola**, Piracicaba, v. 67, n. 1, p. 102-116, Jan./Feb. 2010.
- CHEN, Y.; YU, J.; KHAN, S. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. **Environmental Modelling & Software**, Oxford, v. 25, n. 12, p. 1582-1591, Dec. 2010.

COELHO, D.T.; SEDIYAMA, G.C.; VIEIRA, M. Estimativas das temperaturas médias mensais e anuais no estado de Minas Gerais. **Revista Ceres**, Viçosa, v. 20, n. 112, p. 455-459, 1973.

COLORNI, A.; LANIADO, E.; MURATORI, S. Decision support systems for environmental impact assessment of transport infrastructures. **Transportation Research Part D: Transport and Environment**, Amsterdam, v. 4, n. 1, p. 1-11, Jan. 1999.

COOPER, M.; MENDES, L.M.S.; SILVA, W.L.C.; SPAROVEK, G. A national soil profile database for Brazil available to international scientists. **Soil Science Society of America Journal**, Madison, v. 69, n. 3, 649-652, May 2005.

CRAGO, C.; KHANNA, M.; BARTON, J.; GIULIANI, E.; AMARAL, W. Competitiveness of Brazilian sugarcane ethanol compared to US corn ethanol. **Energy Policy**, Guildford, v. 38, n. 11, p. 7404-7415, Nov. 2010.

DE CARVALHO MACEDO, I. The sugar cane agro-industry: its contribution to reducing CO₂ emissions in Brazil. **Biomass and Bioenergy**, New York, v. 3, n. 2, p. 77-80, 1992.

DUARTE, C.; GAUDREAU, K.; GIBSON, R.; MALHEIROS, T.F. Sustainability assessment of sugarcane-ethanol production in Brazil: a case study of a sugarcane mill in Sao Paulo state. **Ecological Indicators**, New York, v. 30, p. 119-129, July 2013.

EASTMAN, J.R. **IDRISI Andes**: guide to GIS and image processing. Worcester: Clark University, 2006. 322 p.

F.O. LICHT. Fuel ethanol production in ten leading countries and the world, 2010. **World Ethanol and Biofuels Report**, Kent, v. 8, n. 16, p. 328, Apr. 2010.

_____. **World fuel ethanol production**. Disponível em: <<http://ethanolrfa.org/pages/World-Fuel-Ethanol-Production>>. Acesso em: 30 nov. 2013.

FAO. **A framework for land evaluation**. Rome, 1976. 94 p.

FEITOZA, L.R.; SCÁRDUA, J.A.; SEDIYAMA, G.C.; OLIVEIRA, L.M.; VALLE, S.S. Estimativas das temperaturas médias mensais e anual do estado do Espírito Santo. **Revista Centro de Ciências Rurais**, Santa Maria, v. 9, n. 3, p. 279-291, 1979.

FERREIRA, M.; BURIOL, G.A.; ESTEFANEL, V.; PINTO, H.S. Estimativas das temperaturas médias mensais e anuais do estado do Rio Grande do Sul. **Revista Centro de Ciências Rurais**, Santa Maria, v. 1, n. 4, p. 21-52, 1971.

_____. Estimativas das temperaturas médias mensais e anuais do estado de Santa Catarina. **Revista Centro de Ciências Rurais**, Santa Maria, v. 4, n. 1, p. 19-38, 1974.

FARGIONE, J.; HILL, J.; TILMAN, D.; POLASKY, S.; HAWTHORNE, P. Land clearing and the biofuel carbon debt. **Science**, Washington, v. 319, n. 5867, p. 1235-1238, 2008.

FERREIRA, W.P.M.; VALLADARES, G.S.; HOTT, M.C. Estimativa da temperatura média mensal do ar para os estados de Minas Gerais e do Pará, utilizando-se Modelos Digitais de Elevação. **Engenharia na Agricultura**, Viçosa, v. 14, n. 4, p. 293-303, 2006.

FULLER, S.; YU, T.H.; FELLIN, L.; LALOR, A.; KRAJEWSKI, R. Effects of Improving Transportation Infrastructure on competitiveness in world grain markets. **Journal of International Food & Agribusiness Marketing**, New York, v. 13, n. 4, p. 61-85, 2003.

GELLER, H.; SCHAEFFER, R.; SZKLO, A.; TOLMASQUIM, M. Policies for advancing energy efficiency and renewable energy use in Brazil. **Energy Policy**, Guildford, v. 32, n. 12, p. 1437-1450, Aug. 2004.

GOES, T.; MARRA, R.; SILVA, G.S. Setor sucroalcooleiro no Brasil: situação atual e perspectivas. **Revista de Política Agrícola**, Brasília, ano XVII, n. 2, abr., 2008. p. 39-51.

GOLDEMBERG, J. The Brazilian biofuels industry. **Biotechnology For Biofuels**, London, v. 1, n.6, p. 1-7, May 2008.

_____. Ethanol for a sustainable energy future. **Science**, Washington, vol. 315, n. 5813, p. 808-810, 2007.

GOLDEMBERG, J.; COELHO, S.; GUARDABASSI, P. The sustainability of ethanol production from sugarcane. **Energy Policy**, Guildford, v. 36, n. 6, p. 2086-2097, June 2008.

HAYASHI, K. Multi-criteria analysis for agricultural resource management: a critical survey and future perspectives. **European Journal of Operational Research**, Amsterdam, v. 122, n. 2, p. 486-500, 2000.

HYDE, K.; MAIER, H.; COLBY, C. A distance-based uncertainty analysis approach to multi-criteria decision analysis for water resource decision making. **Journal of Environmental Management**, New York, v. 77, n. 4, p. 278-290, Dec. 2005.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Censo agropecuário 2006**. Disponível em: <<http://sidraibge.gov.br>>. Acesso em: 05 out. 2011.

_____. **Produção agrícola municipal**. Rio de Janeiro, 2010. 91 p.

_____. **Sistema IBGE de recuperação automática**. Disponível em: <<http://sidraibge.gov.br>>. Acesso em: 03 fev. 2012.

JOERIN, F.; THERIAULT, M.; MUSY, A. Using GIS and outranking multicriteria analysis for land-use suitability assessment. **International Journal of Geographical Information Science**, London, v. 15, n. 2, p. 153-174, Mar. 2001.

KIKER, G. A.; BRIDGES, T.S.; VARGHESE, A.; SEAGER, T.P.; LINKOV, I. Application of multicriteria decision analysis in environmental decision making. **Integrated Environmental Assessment and Management**, Hoboken, v. 1, n. 2, p. 95-108, 2005.

KOSCHKE, L.; FÜRST, C.; FRANK, S.; MAKESCHIN, F. A multi-criteria approach for an integrated land-cover-based assessment of ecosystem services provision to support landscape planning. **Ecological Indicators**, Amsterdam, v. 21, n. 1, p. 54-66, 2012.

LAPOLA, D.M.; SCHALDACH, R.; ALCAMO, J.; BONDEAU, A.; KOCH, J.; KOELKING, C.; PRIESS, J.A. Indirect land-use changes can overcome carbon savings from biofuels in Brazil. **Proceedings of the National Academy of Sciences of the United States of America**, Washington, v. 107, n. 8, p. 3388-3393, Feb. 2010.

LEITE, R.C.C.; LEAL, M.R.L.V.; CORTEZ, L.A.B.; GRIFFIN, W.M.; SCANDIFFIO, M.I.G. Can Brazil replace 5% of the 2025 gasoline world demand with ethanol? **Energy**, New York, v. 34, n. 5, p. 655-661, May 2009.

LEPSCH, I.F. **Manual para levantamento utilitário do meio físico e classificação de terras no sistema de capacidade de uso: 4ª aproximação**. Campinas: SBCS, 1991. 175 p.

LEVY, M.C.T.C. **Avaliação de cenários da produção agrícola visando a sustentabilidade do uso das terras de Piracicaba, SP**. 1995. 104 p. Dissertação (Mestrado em Solos e Nutrição de Plantas) - Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba, 1995.

LINKOV, I.; SATTERSTROM, F.K.; KIKER, G.; BATCHELOR, C.; BRIDGES, T.; FERGUSON, E. From comparative risk assessment to multi-criteria decision analysis and adaptive management: recent developments and applications. **Environment International**, New York, v. 32, n. 8, p. 1072-1093, 2006.

LORZ, C.; ABBT-BRAUN, G.; BAKKER, F.; BORGES, P.; BÖRNICK, H.; FORTES, L.; FRIMMEL, F.; GAFFRON, A.; HEBBEN, N.; HÖFER, R.; MAKESCHIN, F.; NEDER, K.; ROIG, H.L.; STEINIGER, B.; STRAUCH, M.; WALDE, D.H.; WEIB, H.; WORCH, E.; WUMMEL, J. Challenges of an integrated water resource management for the Distrito Federal, Western Central Brazil: climate, land-use and water resources. **Environmental Earth Sciences**, Berlin, v. 65, n. 5, p. 1575-1586, Mar. 2012.

MACEDO, I.; SEABRA, J.; SILVA, J. Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: the 2005/2006 averages and a prediction for 2020. **Biomass & Bioenergy**, New York, v. 32, n. 7, p. 582-595, July 2008.

MALCZEWSKI, J. GIS-based multicriteria decision analysis: a survey of the literature. **International Journal of Geographical Information Science**, London, v. 20, n. 7, p. 703-726, 2006.

MARTINELLI, L.A.; GARRETT, R.; FERRAZ, S.; NAYLOR, R. Sugar and ethanol production as a rural development strategy in Brazil: evidence from the state of Sao Paulo. **Agricultural Systems**, England, v. 104, n. 5, p. 419-428, Jun 2011.

MARTINES-FILHO, J.; BURNQUIST, H.L.; VIAN, C.E. Bioenergy and the rise of sugarcane-based ethanol in Brazil. **Choices**, New York, v. 21, n. 2, p. 91-96, 2006.

MEDEIROS, S.E.; CECÍLIO, R.A.; MELO JUNIOR, J.C.F.; SILVA JUNIOR, J.L.C. Estimativa e espacialização das temperaturas do ar mínimas, médias e máximas na região Nordeste do Brasil. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 9, n. 2, p. 247-255, 2005.

MENDOZA, G.A.; MARTINS, H. Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. **Forest Ecology and Management**, Amsterdam, v. 230, n. 1, p. 1-22, 2006.

MONTENEGRO, S.; RAGAB, R. Impact of possible climate and land use changes in the semi arid regions: A case study from North Eastern Brazil. **Journal of Hydrology**, New York, v. 434, p. 55-68, Apr. 2012.

NASSAR, M.; RUDORFF, B.F.T.; ANTONIAZZI, L.B.; AGUIAR, D.A.; BACCHI, M.R. P.; ADAMI, M. Prospects of the sugarcane expansion in Brazil: impacts on direct and indirect land use changes. In: ZUURBIER, P.; VAN DER VOOREN, J. (Ed.). **Sugarcane ethanol: contributions to climate change mitigation and the environment**. Wageningen: Academic Publishers, 2008. p. 63-93.

NEPSTAD, D.C.; STICKLER, C.M.; SOARES-FILHO, B.; MERRY, F. Interactions among Amazon land use, forests and climate: prospects for a near-term forest tipping point. **Philosophical Transactions of the Royal Society B-Biological Sciences**, London, v. 363, n. 1498, p. 1737-1746, May 2008.

OLIVEIRA NETO, S.N.; REIS, G.G.; REIS, M.G.F.; LEITE, H.G.; COSTA, J.M.N. Estimativa de temperaturas mínima, média e máxima do território brasileiro situado entre 16 e 24 latitude sul e 48 e 60 longitude oeste. **Engenharia na Agricultura**, Viçosa, v. 10, p. 8-18, 2002.

PLANO NACIONAL DE LOGÍSTICA E TRANSPORTE. **Base de dados georreferenciados 2010**. Disponível em: <<http://www.transportes.gov.br/index/conteudo/id/36604>>. Acesso em: 07 nov. 2011.

QURESHI, M.E.; HARRISON, S.; WEGENER, M. Validation of multicriteria analysis models. **Agricultural Systems**, Barking, v. 62, n. 2, p. 105-116, 1999.

SCHMIDT, R.C. Managing delphi surveys using nonparametric statistical techniques. **Decision Sciences**, Atlanta, v. 28, n. 3, p. 763-774, July 1997.

SEABRA, J.; TAO, L.; CHUM, H.L.; MACEDO, I.C. A techno-economic evaluation of the effects of centralized cellulosic ethanol and co-products refinery options with sugarcane mill clustering. **Biomass & Bioenergy**, New York, v. 34, n. 8, p. 1065-1078, Aug. 2010.

SEARCHINGER, T.; HEIMLICH, R.; HOUGHTON, R. A.; DONG, F.; ELOBEID, A.; FABIOSA, J.; TOKGOZ, S.; HAYES, D.; YU, T. H. Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. **Science**, Washington, v. 319, n. 5867, p.1238-1240, 2008.

SELF, S.; GRABOWSKI, R. Economic development and the role of agricultural technology. **Agricultural Economics**, Amsterdam, v. 36, n. 3, p. 395-404, May 2007.

SHORTRIDGE, A.; MESSINA, J. Spatial structure and landscape associations of SRTM error. **Remote Sensing of Environment**, New York, v. 115, n. 6, p. 1576-1587, June 2011.

4 A COMPARATIVE ANALYSIS OF PASTURES WITH LAND SUITABILITY FOR SOYBEAN AND SUGARCANE PRODUCTION

Abstract

Increasing food and biofuel production without compromising sustainability is a reason of much concern for land use practices in Brazil. A way to expand the agriculture in the country, and at the same time avoid further environmental losses would be the conversion of suitable cultivated pastures to croplands, given that a more efficient use of pasturelands, which occupy large areas in Brazil, would release a substantial area for agricultural expansion. The purpose of this study is to identify suitable cultivated pasturelands for soybean allocation, and to compare its results with the findings obtained from the sugarcane model to locate the most suitable areas for soybean or sugarcane production, making available information that may assist decision makers about priority areas where investment should be directed. To do so, this study uses multicriteria decision analysis (MCDA) for land suitability analysis regarding the combination of physical land suitability, infrastructure and socioeconomic criteria. The criteria used in the modeling were chosen based on the data availability for the whole country. The chosen criteria are slightly different from those previously presented in the sugarcane model. Both quantitative and qualitative criteria were analyzed with no need for conversion to the same unit in the multicriteria analysis. The relative importance of the variables in the MCDA model was set using a participatory approach. Their importance was determined with the help of the analytic hierarchy process (AHP) technique, which was a useful tool for decision making analysis. In this stage a team of soybean specialists was selected to establish the importance of each variable in the model. Individual judgments were aggregated into an overall result. A scenario analysis was performed, and seven scenarios were built to examine the impact of modifications of the parameters in the main model. The maps show areas according to the land suitability for soybean production. A series of contrasting views were obtained from shifts in the criteria priorities. Minas Gerais, São Paulo, Paraná, Goiás, Mato Grosso do Sul, Mato Grosso and Pará were the states that had the largest areas of cultivated pasture with moderate and high agricultural potential in both sugarcane and soybean models. The information created in this study may provide leaders with information relating to where they can address investment in public and private policies to support a sustainable agricultural expansion in Brazil.

Keywords: Land-use planning; Spatial modeling; GIS; ModelBuilder; Participatory approach; AHP

4.1 Introduction

The growing investments in the use of biofuels (FAAIJ, 2006; HIMMEL et al., 2007; MATHEWS, 2007; NASS; PEREIRA; ELLIS, 2007; HEADEY; FAN, 2008; RATHMANN; SZKLO; SCHAEFFER, 2010) and changes in eating habits (GUO et

al., 2000; BLISARD et al., 2002) are the major factors that contribute to the increase in global consumption of soybean. The global trend to find replacements to petroleum and the concern about global warming have led the effort to take the world into a promising future based on clean energy production (HILL et al., 2006; HUO et al., 2008; DEMIRBAS, 2009).

Also considered one of the alternatives to biodiesel production, soybean enters in this scenario thanks to its feasibility for generating energy (SHEEHAN et al., 1998). However, it is not only in the renewable energy production conjecture that soybean finds its future promising. The socioeconomic changes related to the increase in the purchasing power in some countries boosted the population to increase the direct (oil, juices, milk, etc.) and indirect consumption (feeding animals, particularly pork and poultry) of soybean derivatives (MARCHANT; FANG; SONG, 2003; MEADE et al., 2011).

Soybean has become an advantageous crop in the agribusiness world. The capacity to produce a diversity of products, the high oil content and protein in the grain has made it a very profitable agricultural product (HERTEL; TYNER; BIRUR, 2010; UNITED STATES SOYBEAN EXPORT COUNCIL - USSEC, 2011). Its high demand makes it a very attractive product in the market, especially for countries like China where soybean is very important in the diet, and the European Union that had to substitute meal flour for soy flour to feed animals because of mad cow disease (YEN; FANG; SU, 2004; NEPSTAD; STICKLER; ALMEIDA, 2006; LAMBIN; MEYFROIDT, 2011).

The largest soybean producers in the world are found in America (FAO, 2011; UNITED STATES DEPARTMENT OF AGRICULTURE - USDA, 2012). Brazil, Argentina and the United States are the main producers, and great competitors in the soybean international market. The production of this type of crop is very important for the Brazilian agriculture and for its balance of trade (BRASIL, 2012).

Soybean production is strongly related to the expansion of agricultural frontier in Brazil (GRAHAM; GAUTHIER; DE BARROS, 1987). The Cerrado Ecosystem was the foundation for this advance, supporting the establishment of large farming areas and urban clusters through the installation of agricultural industries, improvements in logistics planning, and employment. The growth was also stimulated by the transference of the Brazilian capital to the Midwest to motivate the expansion and

development to more remote areas of the country. Brasilia's construction was responsible for improvements in infrastructure, such as roads, communications and urbanization.

Soybean production has changed the history of Brazil not only in the agricultural and socioeconomic aspect, but also in its spatial relationships (MAHAR et al., 1981). It stimulated the migration of population and economic activities previously concentrated in the northeast coast, south and southeast of the country, and pushed the development to the Central region of Brazil, promoting a national integration through the growth and expansion of depopulated and isolated areas.

Agronomic technical changes and the development of a successful set of technologies for soybean production in tropical areas, transformed the Cerrado with millions of hectares previously considered unproductive into suitable areas for the cultivation of soybean (SPEHAR, 1995). Some other characteristics such as low land value, tax incentives, knowledge of the producers, who occupied the region mainly from the south where the crop was successfully cultivated, climate and topography very favorable to mechanization, transformed the central part of the country into a favorable region for the development of agriculture (FREIRE DE SOUSA; BUSCH, 1998).

To meet increasing demand for food and biofuels, attention has been driven toward countries that have arable land for agricultural production expansion (GRAU; AIDE, 2008). The majority of the world's lands with crop production potential are located in developing countries, and Brazil stands out as having the most potential for agricultural expansion. In relation to the developed countries, the projection foresees that their arable land will tend to decline (BRUINSMA, 2009). This scenario reflects the great economic opportunities that Brazil can achieve over the years through investments in a well-oriented agricultural expansion.

To avoid unnecessary deforestation such as happened in past advancements of the agricultural frontier in the country (NEPSTAD et al., 1999; ASNER et al., 2005; KLINK; MACHADO, 2005; MORTON et al., 2006) and following trend of decreasing deforestation (BROWN et al., 2005; SOARES-FILHO et al., 2010; RUDORFF et al., 2011; MACEDO et al., 2012), agricultural expansion planning is indispensable to allocate suitable areas already deforested to agriculture in Brazil. Therefore, the main objective of this study is to identify pasturelands for further soybean expansion, going beyond the level of the physical assessment through the combination of

socioeconomic and infrastructure criteria in the model. This study also focuses on the comparison between the soybean and sugarcane models to locate the most suitable areas of pasture for soybean or sugarcane production. The information generated in this study may support those responsible for managing the space in making appropriate decisions, encouraging a more sustainable agricultural expansion in Brazil.

4.2 Material and Methods

A multicriteria model was designed in ModelBuilder (ArcGIS 10) to assess suitable cultivated pasturelands as a planning design model to support an expansion of soybean production in Brazil. Physical land suitability submodel was integrated with infrastructure, economic and social criteria to identify the best locations that could accommodate an advance of the agricultural frontier in the country. The geographic location of transportation modes was also analyzed making information available about alternative flows that could provide a better performance in the transport of agricultural products.

The soybean model followed the same steps of the sugarcane model, although some variables were included and others were eliminated in the analysis. The storage and soybean crushing industry were added while pipelines, mills and employed people were excluded. All the data layers were converted to raster and standardized to a common projection to meet the analysis requirements.

Soil and topography inputs were the same for both frameworks, but different criteria were set for climate. Logical expressions used in the integration of each of the variables in the modeling were also distinctive from the sugarcane model. Each of the variables mentioned was processed separately, spatialized and then integrated through mathematical and logical operations using GIS, indicating areas of possible expansion of soybean in Brazil with a spatial resolution of 90 m x 90 m. Soil, climate and topography in addition to land use and biome datasets were integrated to create a physical land suitability submodel to locate areas according to their suitability for soybean expansion in the country.

A common measurement scale was set for all the inputs to allow the combination of the datasets. In a next step, infrastructure and socioeconomic

variables were integrated with the physical land suitability submodel and weights were set for each of the inputs, which were established through a participatory approach. The purpose of the participatory approach was to enhance the reliability of the model, so a team of five soybean specialists was selected to evaluate and judge the importance that those variables would have in the model.

4.2.1 Soil

The soil suitability for soybean was mapped through the interpretation of the legend of the soil map, the experts' opinion and the soil profile data points, which took into consideration the chemical and physical properties of soils. The same soil suitability map was used as a basis for both sugarcane and soybean models.

4.2.2 Climate

A computational framework based on climate data was developed to calculate the water balance and the climate suitability index to support the physical land suitability submodel (BARRETO, 2013). Spatial and temporal information on climate was combined according to the climate potential for soybean cultivation, and suitability classes were generated for this type of crop.

4.2.2.1 Radiation and Temperature Index

The radiation and temperature index represents the productive potential of soybean in relation to its photosynthetic potential. The index ranges from 0 to 100 and reflects the productive potential under the evaluated climatic condition compared to a condition that is always ideal (optimum temperature and radiation that is not limiting), which results in an optimal production. This index indicates the real yield potential of soybean where there is no water stress during its critical periods of development or if the crop is irrigated properly.

4.2.2.2 Water and Temperature Index

Next, the influence of water stress on soybean yield was assessed. The actual evapotranspiration (under the effect of water stress) is compared with the potential

evapotranspiration (without influence of water deficiency). This index can separately evaluate the influence of lack of water in the crop productivity.

The index ranges from 0 to 100 and reflects the potential of the climate for agricultural activities without the need for irrigation. The real evapotranspiration for the crop is not specified, or did not use a specific crop factor.

4.2.2.3 Basal Temperature Index

Climate data were also analyzed in relation to thermal suitability and restriction ranges for soybean, considering that it has limited development at very low or very high temperatures. Data from the literature were gathered to define the average annual temperature values that indicate suitable conditions or restriction for the development of soybean (Table 9). An index ranging from 0 to 100 was determined for the basal temperature.

Table 9 - Basal temperature used in the definition of the climate suitability for soybean

Crop	Temperature		References
	Unsuitable	Ideal	
Soybean	*Ta<10°C and Ta>35°C	22°C<Ta<33°C	BAHIA (1977)
			CAMARGO et al. (1974)

* Ta - Temperature

4.2.3 Topography

The topographic suitability for crops was evaluated according to the potential for agricultural mechanization. It was considered that mechanization would have a direct effect on the suitability for cultivation. A Digital Elevation Model (SRTM) was the basis for the analysis.

4.2.4 Supporting the decision making using the analytic hierarchy process (AHP)

AHP was used to improve the MCDA for soybean allocation as a way to derive weights for the chosen criteria in the last stage of the modeling. Interviews were

conducted so that each of the specialists in soybean was able to analyze the criteria presented to them in a set of pairwise comparisons. This time, the Expert Choice program was used during the interview for decision making instead of questionnaires. Working on the program facilitated the evaluation since the interviewer had access to the results immediately after the judgments were made, so they were able to decide if the criteria ranking was consistent with what they had in mind or not. In circumstances where they did not agree with the results, the pairwise comparisons were evaluated again. Besides that, the inconsistency ratio was straightaway checked and in some cases the most inconsistent judgments were identified and corrected. Afterwards, individual responses were combined in the decision support software, and an attribute agreement using statistical analysis was implemented to verify the consensus among the specialists. The judgments' agreement between experts for the MCDA for soybean allocation was evaluated using Kendall's W coefficient of concordance.

4.2.5 Using multicriteria decision analysis in decision making for soybean allocation

Soil, climate and topography rasters were integrated to create a map with classes of physical land suitability for soybean cultivation. In this process the maps for each of the mentioned components, in addition to biome and land use rasters, were overlain and combined through mathematical and Boolean logic according to the importance of each input raster in the analysis.

Information about land use was also combined with the other components to exclude water bodies and urban areas from assessment, to filter the effect of relief flattening that the canopy of the Amazon rainforest has on the slope, and to avoid misinterpretation of the Pantanal flood plain area as being potential agricultural areas.

Socioeconomic (elementary school, high school, major, no education and value of production) and infrastructure variables (roads, rail stations, ports, storage and soybean crushing industry) were also added to the next step of the modeling to identify priority areas for soybean expansion.

The combination of individual judgments in the decision making analysis determined the percentage of influence of each raster assigned in the weighted

overlay analysis. Each input raster was then multiplied by the given weight to produce the suitability map for soybean allocation. To create only a suitability map in areas occupied by pasture, an overlay analysis was performed, where the soybean suitability raster was overlain with cultivated pasturelands.

The map resulting from the overlay analysis was then combined with the sugarcane model to identify areas where cultivated pasturelands were best suited for one or the other crop. A pixel-by-pixel analysis was applied to show the contrast between the sugarcane and soybean model in relation to the spatial distribution of priority areas for crop expansion.

4.2.6 Alternative judgments for scenario analysis

Building different scenarios represents a process of analyzing alternative outcomes from the main model. Each scenario (soybean allocation alternative scenario – SAAS) was used as a comparative input raster to determine which values were logically different from the values of the main model with a pixel-by-pixel analysis. A positive value indicates that the cell values on the input scenario had higher suitability and a negative value indicates that the cell values on the input scenario had lower suitability in comparison to the main model while the same values in both inputs were given a value of zero.

Scenarios were also created to show potential implications that the uncertainties related to the different combination of criteria would play out in the MCDA for soybean allocation. Each scenario built in this stage was also compared to the same scenario of the sugarcane model (cane allocation alternative scenario – CAAS) to detect the locations where pasturelands were more suitable for sugarcane than for soybean, and vice versa.

4.3 Results

4.3.1 Physical land suitability submodel for soybean

Figure 62 shows the results of the geographic distribution of climate suitability for soybean with a scale of 3 values. The climate suitability map was combined with the same soil suitability map used in the sugarcane model to create a soil and climate suitability map with a scale of 5 values (Figure 63). Different geographic distribution of climate suitability classes was found for soybean in relation to the sugarcane model.

Figure 62 - Climate suitability classification for soybean: low suitability (1), moderate suitability (2) and high suitability (3)

The physical land suitability submodel was the outcome of combining multiple rasters - soil and climate suitability raster with the biome, land use and topography rasters (Figure 64). As can be seen from the physical land suitability map, the eastern side of the South-Central region becomes less suitable for soybean in comparison to the same areas in the soil and climate suitability map (Figure 63). It is clearly more visible that other areas fall into the high suitability class while very low suitability areas in the northeast of the country shift to the low suitability class.

Figure 63 - Spatial distribution of soil and climate suitability for soybean

Figure 64 - Soil and climate suitability for soybean with environmental land use restrictions, biome and topography integration limiting feasible areas for mechanization

4.3.2 Judgment synthesis of prioritization decisions

The weights derived from the decision making analysis reflect the experience of the participants about soybean production environments. A strong agreement was found between experts during the participatory approach. The coefficient was 0.75, indicating a high level of agreement among them. The agreement among the specialists' ratings is related to each other, leading us to believe that the group average weights describe individual opinions, which was substantiated by the rejection of the null hypothesis (the agreements among the specialist rating are unrelated to each other) at a 5% significance level. The evaluation consistency between experts is described in Table B4.

In relation to the average, P4 had a match score above 50% and was the specialist' judgment agreement with the highest match. The percent of experts' judgment that agree with the average was different for each of the experts. The specialist versus combined average agreement graph exhibits the percent of matched judgments of each specialist compared to the combined judgments (Figure 65).

Figure 65 - Specialists assessment agreement graph. The circle indicates the percent matched and the line a 95% confidence interval for the percent matched of each specialist versus the combined opinion

4.3.3 Implementation of multicriteria decision analysis for the location of pasturelands that are best suited for soybean expansion

Overlaid layers were used to evaluate the capacity of pasturelands to support soybean production. According to the results derived from the analysis of the physical land suitability, 30 Mha were of very low suitability, 26 Mha of low suitability, 29 Mha of moderate suitability and 25 Mha of high suitability for soybean, a total of 110 Mha. The findings obtained from the physical land suitability show that the most suitable areas of pasture are located in the South-Central region (Goiás, Mato Grosso, Paraná, São Paulo, Mato Grosso do Sul and Minas Gerais) and North-Northeast region (Pará, Roraima, Tocantins and Bahia) (Figure 66).

Figure 66 - Area of cultivated pasturelands by land suitability classes for soybean

The outcome from the application of the MCDA is a suitability map that shows all feasible pasturelands for soybean expansion in areas of pasture. Figure 67 exemplifies the results of the decision making analysis, showing that the most suitable pasturelands for soybean allocation were found in major areas of Mato Grosso do Sul, Triângulo Mineiro, west and center of São Paulo, northwestern of Paraná, and sparsely in areas of Mato Grosso, Rondônia, northwest Mineiro and Goiás. Moderately suitable areas for soybean cultivation were more numerous than highly suitable lands that were sparsely distributed.

A pixel-by-pixel analysis comparing the sugarcane and soybean model shows that the areas in blue are more suitable for sugarcane conversion while the areas in red are more suitable for soybean expansion (Figure 68). There is a noticeable prevalence of lands with higher suitability for soybean (36 Mha) than for sugarcane (24 Mha) considering both main models. Areas with higher suitability for sugarcane are mostly located in São Paulo, Minas Gerais and Goiás.

Figure 67 - Suitability map for soybean expansion derived from the decision making process

Figure 68 - Sugarcane vs soybean MCDA model. The red color in the map means that the soybean had higher suitability than the sugarcane model. The blue color means the opposite

4.3.4 Implementing scenario analysis

Based on the seven defined scenarios, the total pasturelands distribution for each of the 5 land suitability classes varies from one scenario to another (Table 10). When the infrastructure criterion has a greater influence on the model, which is the case of the SAAS2, 69% of total pasturelands are defined as being of very low suitability. The same similarities can be observed in the SAAS7, when the infrastructure and economic variable have a greater influence percentage in the model. In the SAAS3, 50% of total pasturelands are concentrated in the limited suitability class, which also suggests a direct effect of the economic criterion in this scenario, but its influence is much lower than the influence that the infrastructure criterion has on the model.

Table 10 - Distribution of cultivated pasturelands by land suitability classes for each of the seven scenarios and the main model

	Main Model	SAAS						
		1	2	3	4	5	6	7
Land Suitability	Area (thousand hectares)							
Limited	0	0	2,078	55,503	0	78	0	5,695
Very Low	37,838	30,090	76,690	29,758	33,978	44,657	42,025	65,897
Low	47,710	26,501	31,905	11,123	40,094	60,154	51,911	29,556
Moderate	25,323	29,256	527	7,825	7,038	6,311	17,190	9,978
High	329	25,353	0	6,991	30,090	0	74	74

In the SAAS1, the edaphoclimatic criterion had an importance of 90%, and 10% of influence was left to the other criteria (Table B6). The proportionality was kept constant for the inputs. Changes in the influence of the criteria, i.e., increasing the importance of the edaphoclimatic variable in the model brought out more suitable classes in relation to the main model. Most of the moderate suitability class was substituted for the high suitability class in Mato Grosso do Sul, west of São Paulo, south of Goiás, eastern of Pará, northwestern of Paraná and Mato Grosso (Figure 69). More areas of high suitability can be found when edaphoclimatic variable has higher priority in the model.

Figure 69 - Suitability map for soybean expansion over pasturelands in the SAAS1

Most pasturelands for soybean allocation in the SAAS1 had higher suitability than the same areas in the main model (Figure 70). Few locations, mainly concentrated in São Paulo, Minas Gerais and Goiás, had higher suitability in the main model than in this scenario due to the differences in the priority weights.

Figure 70 - The SAAS1 versus the main model. The red color in the map means that the main model had higher suitability than this scenario. The blue color means the opposite

An increase in the infrastructure priority to 90% while 10% was left to the other criteria, but still keeping the proportionality between them constant, provides major changes in the spatial distribution of suitability classes in the SAAS2 (Figure 71). The very low and low suitability classes were significantly predominant in this scenario. The moderate suitability class was not considerably allocated and the high suitability class was practically inexistent.

Figure 71 - Suitability map for soybean expansion over pasturelands in the SAAS2

The SAAS2 considerably differs from the main model (Figure 72). The areas in red, which represent great part of the pasturelands in the map, show that the main model had more suitable classes than did this scenario for soybean allocation. Only a few areas in Minas Gerais, Rio de Janeiro, São Paulo, Paraná and Santa Catarina were more suitable than the main model.

Figure 72 - The SAAS2 versus the main model. The red color in the map means that the main model had higher suitability than this scenario. The blue color means the opposite

The SAAS3 shows the allocation of the moderate and high suitability classes in areas where the production value for soybean production is higher. Minas Gerais, south of Bahia, eastern of Pará, Rondônia, Maranhão, São Paulo and Rio de Janeiro were the states that exhibited a considerable expansion in direction to the limited suitability areas (Figure 73). Although Mato Grosso, Mato Grosso do Sul, Goiás and Paraná had substantial areas of high suitability, they also presented areas of limited suitability.

Figure 73 - Suitability map for soybean expansion over pasturelands in the SAAS3

The main model exhibited more areas of high suitability than the SAAS3 (Figure 74). Mato Grosso, Mato Grosso do Sul, south of Goiás and Paraná were the main locations where the SAAS3 had higher suitability values in comparison to the main model.

Figure 74 - The SAAS3 versus the main model. The red color in the map means that the main model had higher suitability than this scenario. The blue color means the opposite

In the SAAS4, a weight of 80% was attributed to the edaphoclimatic criterion, 10% to infrastructure and 10% to the economic criteria. The social criterion had a 0% influence in this analysis. Moderate and high suitability classes were found mostly in Mato Grosso, Mato Grosso do Sul, Goiás, northwestern of Paraná, eastern of Pará, Triângulo Mineiro and west and center of São Paulo (Figure 75). This scenario had more distribution of pixels in the high suitability class than did the main model.

Figure 75 - Suitability map for soybean expansion over pasturelands in the SAAS4

Few areas in the main model (depicted in red) were more suitable for soybean allocation than for the SAAS4 (Figure 76). The map shows the dominance of the blue color, which means that changes in the priority weights favored the distribution of more suitable areas for this scenario.

Figure 76 - The SAAS4 versus the main model. The red color in the map means that the main model had higher suitability than this scenario. The blue color means the opposite.

Each of the main criteria received the same influence percentages (25%) in the SAAS5. The limited suitability class increased in this scenario, although the limited suitability areas can barely be observed. Besides that, the high suitability class is absent, i.e., there is no area of high suitability in the map (Figure 77). The increase of areas of low and very low suitability, and the decrease of moderate suitability areas were the most noticeable changes in this scenario in comparison to the main model.

Figure 77 - Suitability map for soybean expansion over pasturelands in the SAAS5

The main model presented more areas of high suitability than did the SAAS5 (Figure 78). Many areas of less suitability were found in this scenario. It also showed more areas of less suitability when compared to the main model. Only small areas represented by blue are indicative of higher suitability areas in the SAAS5, when the main criteria have the same priority (weights) in the model.

Figure 78 - The SAAS5 versus the main model. The red color in the map means that the main model had higher suitability than this scenario. The blue color means the opposite

In the SAAS6, the following weights were assigned to the multiple raster layers, physical land suitability had a 50% influence, infrastructure a 25% influence, economic a 25% influence and social a 0% influence. Low suitability class was substituted for the moderate suitability, and very low suitability class was substituted for the low suitability classes when comparing this scenario to the main model (Figure 79).

Figure 79 - Suitability map for soybean expansion over pasturelands in the SAAS6

The SAAS6 did not show as much variation as did some of the other scenarios compared to the main model. The differences between this scenario and the main model were basically slight shifts in the suitability distribution classes, varying from -1 to 1 (Figure 80).

Figure 80 - The SAAS6 versus the main model. The red color in the map means that the main model had higher suitability than this scenario. The blue color means the opposite

Major changes took place in the SAAS7 when increasing the influence of the economic criterion to 50% and assigning 25% to the infrastructure criterion and 25% to the edaphoclimatic criterion. The main variations occurred considerably more in the very low suitability class than in the other classes (Figure 81).

Figure 81 - Suitability map for soybean expansion over pasturelands in the SAAS7

The variations in the distribution of the suitability classes in the SAAS7 in relation to the main model are presented in Figure 82. The main model exhibited more areas of high suitability than did the SAAS7.

Figure 82 - The SAAS7 versus the main model. The red color in the map means that the main model had higher suitability than this scenario. The blue color means the opposite

4.3.5 Soybean versus sugarcane suitability

Discrepancies were detected between the scenarios in the sugarcane and soybean model. Depending on the influence of the variables in the model, the pasturelands become either more suitable for sugarcane or for soybean production. CAAS1 versus the SAAS1, CAAS3 versus SAAS3, CAAS4 versus SAAS4, CAAS6 versus SAAS6, CAAS7 versus SAAS7 were the most favorable scenarios for the allocation of sugarcane (Figure 83). The CAAS2 versus SAAS2 were the most favorable for the allocation of soybean. The CAAS5 versus the SAAS5 shows not much difference for the allocation of both crops, considering that 55% of pasturelands were more suitable for sugarcane and 45% for soybean.

The scenarios presented show a series of different views from the main model obtained from shifts in the priorities in each of the main criteria. The changes in the distribution of the suitability classes in both models are also identified to provide visual information about where the most suitable pasturelands for soybean or sugarcane production are located.

CAAS1
(44 Mha)
vs
SAAS1
(26 Mha)

CAAS3
(50 Mha)
vs
SAAS3
(27 Mha)

CAAS2
(5 Mha)
vs
SAAS2
(31 Mha)

Figure 83 - Discrepancies between the sugarcane and soybean MCDA model scenarios. The red color in the map means that the soybean model had higher suitability (area in hectares) than the sugarcane model. The blue color means the opposite

CAAS4

(41 Mha)

vs

SAAS4

(22 Mha)

CAAS5

(22 Mha)

vs

SAAS5

(27 Mha)

CAAS6

(34 Mha)

vs

SAAS6

(24 Mha)

CAAS7

(34 Mha)

vs

SAAS7

(21 Mha)

Figure 83 - Discrepancies between the sugarcane and soybean MCDA model scenarios. The red color in the map means that the soybean model had higher suitability (area in hectares) than the sugarcane model. The blue color means the opposite

4.4 Discussions and Conclusions

Meeting the dual goals of increasing agricultural production and choosing a development that is sustainable are the challenges to balance human needs and change drivers of deforestation in Brazil. Seeking to follow the trend of increasing productivity without compromising sustainability, this study designs a model to locate suitable areas of cultivated pasturelands that could be used to support soybean expansion in Brazil.

Considering the physical land suitability submodel, pasture with moderate and high land suitability for soybean cultivation covers 49% of the total cultivated pasturelands (54 Mha), which represents twice the area occupied by soybean in Brazil, currently estimated at 25 Mha (IBGE, 2012). These data suggest that the amount of pasturelands with moderate and high land suitability for soybean would be sufficient to meet future demand for this type of crop, sparing lands and avoiding indirect land use changes in the short term in Brazil.

The perspective of creating more space, through the conversion of pasturelands to agricultural use here presented, could be usefully applied in Brazil as a way to expand the agricultural frontier in the country without compromising its forests, and so increasing significantly crop production to meet the domestic and world demand for food and biofuel. As stated by WWF (2013a), the conversion of pasturelands to agricultural use would be enough to double the Brazilian area of croplands.

According to WWF (2013b), if incentives are not provided to support the conversion of pastures to agricultural use, a deforestation rate of 10 Mha will be expected to take place in the Cerrado in the next 10 years for the production of grain and sugarcane. Therefore, to reduce the pressure on the ecosystems and prevent new areas to be opened for agricultural expansion, pasturelands with agricultural potential identified in this study should be used to supply the demand for agricultural lands.

Converting pasture to croplands has been pointed out by several studies as an alternative pathway to achieve a sustainable agricultural development (DEFRIES et al., 2010; MATSON; VITOUSEK, 2006; MACEDO et al., 2012). It has also been acknowledged that improvements of food production can arise from a more efficient

use (intensification) and management of pasturelands (NEPSTAD et al., 2009). However, it is necessary to take into consideration the fact that intensification and productive use of pasturelands would likewise be a challenge and would need to be well addressed.

Climate is the only input variable that discriminates the geographic distribution of the physical land suitability for soybean and sugarcane, since the same soil, topography, land use and biome inputs were applied in both models. In comparison to the physical land suitability for sugarcane, what is noticeable is that there is a 64% difference in the amount of pasturelands in the very low suitability class in Minas Gerais. The high number for the low suitability class suggests that the topography variable highly influenced the distribution of classes in the soybean model, particularly, in Minas Gerais. Even though the models present dissimilarities in the spatial distribution of land suitability classes, Minas Gerais, São Paulo, Paraná, Goiás, Mato Grosso do Sul, Mato Grosso and Pará were found in both models to be the states that cover large areas of pastures with moderate and high agricultural potential that could be used for agricultural expansion, as a strategy to spare land and subsequently mitigate greenhouses gas emissions in Brazil.

The land suitability submodel for sugarcane has more areas of moderate and high suitability than does the soybean submodel. However, the combination of experts' judgments makes the final model more suitable for soybean than for sugarcane expansion, considering the amount of pasture area per hectare in the moderate suitability class. The number of areas in the high suitability class was not very representative in both main models.

A participatory approach was part of the decision making analysis, counting on the help of experts' knowledge of soybean production environments to increase the reliability of the model. The AHP was chosen as a technique to convert the experts' knowledge into weights. This technique was useful to capture the subjective judgments related to the importance that each criterion plays in the model, transforming them into quantitative data.

The outcome of the soybean model is the result of comparing a set of criteria through a participatory process in which professional knowledge is assumed to lead toward better decision making. When infrastructure, economic and social variables are combined with the physical land suitability submodel, and weights are

established through a combination of experts' opinion, there is a decrease in the land suitability for soybean expansion.

"What if" scenarios were built to demonstrate how changes in the weights given by the experts impact the final results. The scenarios present variations according to the importance given to the main criteria, and the differences in relation to the main model are identified on the maps. The variations represent shifts in the distribution of the suitability classes when changes are made in the main criteria. Considering the influence that each criterion plays in the model, the areas of pasture become either more suitable for sugarcane or soybean allocation.

CAAS1 and CAAS4, SAAS1 and SAAS4 are the most favorable scenarios for sugarcane and soybean expansion. In both models, there is a decrease in the areas of high suitability as the influence of the edaphoclimatic variable on the model decreases, which means that the addition of infrastructure, social and economic criteria to the physical land suitability submodel results in less areas of high suitability when those variables have greater influence on the MCDA. As the percentage of total weight given to the infrastructure criterion increases in both sugarcane and soybean models, more areas fall into the lower suitability classes. This demonstrates how much the infrastructure elements influence on the distribution of the land suitability when this variable has high priority in the model.

In terms of logistics, pasturelands located in Rondônia and west of Mato Grosso have the most competitive alternative of modal transportation to the north and northeast of the country and to the international market (areas belonging to the Northwest Corridor) due to the lowest logistics costs in comparison to other corridors (CONAB, 2006). Likewise GEIPOP (2001) considers the significance of the Northwest Corridor in the soybean production framework, and also highlights the importance of the North Central and Northeast Corridors because of their strategic location. Situated in the agricultural frontier zone, these three corridors are very close to the ports of northern countries, which provide a lower freight cost, besides avoiding the intense use of roads and traffic jams in the south and southeast ports.

The information generated in this study serves as a basic reference for the implementation of land policies. The multicriteria framework developed here may assist decision makers in evaluating the resource allocation according to the prospect presented in the main model and in each of the alternative scenarios, which

could guide public and private initiatives to make plans and appropriate decisions, and so direct efforts and allocate investments in priority areas for soybean or sugarcane expansion.

The designed model shows encouraging results that can support policymakers with visual strategic information about where investments and efforts for the advance of the agricultural frontier should be directed in Brazil. The model designed is simple, which makes it practical to support policy and decisions to achieve better results through the integration of a physical land suitability submodel with infrastructure and socioeconomic variables. The advantage is that the calibration seems to be practical, which means that the model could be refined and adjusted accordingly, the influence of criteria easily altered and other variables included, so that the model can be rerun.

The different scenarios can provide policymakers with different alternative locations of soybean or sugarcane regarding the influence that each criterion plays in the model, which can help stakeholders, strategically place investments for sustainable agricultural development in Brazil. Future research in this area is needed to help identify geographic location of underused pastures and likewise suitable areas for cattle ranching intensification at a national scale.

References

- ASNER, G.P.; KNAPP, D.E.; BROADBENT, E.N.; OLIVEIRA, P.J.; KELLER, M.; SILVA, J.N. Selective logging in the Brazilian Amazon. **Science**, Washington, v. 310, n. 5747, p. 480-482, Oct. 2005.
- BAHIA. Secretaria do Planejamento de Ciências e Tecnologia. **Atlas climatológico da Bahia**. Salvador: Centro de Planejamento da Bahia, 1977.14 p.
- BLISARD, N.; LIN, B.H.; CROMARTIE, J.; BALLENGER, N. America's changing appetite: Food consumption and spending to 2020. **Food Review**, Washington, v. 25, n. 1, p. 2-9, Mar./June 2002.
- BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. Assessoria de Gestão Estratégica. **Indicators and statistics of the Brazilian balance of trade**. Disponível em: <<http://www.agricultura.gov.br/internacional/indicadores-e-estatisticas/balanca-comercial>>. Acesso em: 02 fev. 2012.
- BROWN, J.C.; KOEPPE, M.; COLES, B.; PRICE, K.P. Soybean production and conversion of tropical forest in the Brazilian Amazon: The case of Vilhena, Rondonia. **AMBIO: A Journal of Human Environment**, Stockholm, v. 34, n. 6, p. 462-469, Aug. 2005.
- BRUINSMA, J. **The resource outlook to 2050**. Rome: FAO, 2009. 33 p.

CAMARGO, A.P.; PINTO, H.S.; PEDRO JUNIOR, M.J.; BRUNINI, O.; ALFONSI, R. R.; ORTOLAN, A.A. Aptidão climática de culturas agrícolas. In: SECRETARIA DA CULTURA. **Zoneamento agrícola do Estado de São Paulo**. São Paulo, 1974. v. 1, cap. 4, p.109-149.

COMPANHIA NACIONAL DE ABASTECIMENTO. **Corredores de escoamento da produção**. Disponível em: http://www.conab.gov.br/conabweb/geotecnologia/sigabrasil/html_sigabrasil/eixoesc_oamento.html. Acesso em: 02 out. 2013.

DEFRIES, R.; RUDEL, T.; URIARTE, M.; HANSEN, M. Deforestation driven by urban population growth and agricultural trade in the twenty-first century. **Nature Geoscience**, New York, v. 3, n. 3, p. 178-181, Mar. 2010.

DEMIRBAS, A. Political, economic and environmental impacts of biofuels: A review. **Applied Energy**, Barking, v. 86, n. 1, p. S108-S117, Nov. 2009.

FAAIJ, A. Bio-energy in Europe: changing technology choices. **Energy Policy**, Guildford, v. 34, n. 3, p. 322-342, Feb. 2006.

FAO. **Top production: soybean 2011**. Disponível em: <http://faostat.fao.org/site/339/default.aspx>. Acesso: 02 jun. 2012.

FREIRE DE SOUSA, I.; BUSCH, L. Networks and agricultural development: The case of soybean production and consumption in Brazil. **Rural Sociology**, New Jersey, v. 63, n. 3, p. 349-371, 1998.

GEIPOPOT. Empresa Brasileira de Planejamento de Transporte. **Corredores Estratégicos de Desenvolvimento: alternativas de escoamento de soja para a exportação**. Brasília, 2001. 221p.

GRAHAM, D.H.; GAUTHIER, H.; DE BARROS, J.R.M. Thirty years of agricultural growth in Brazil: crop performance, regional profile, and recent policy review. **Economic Development and Cultural Change**, Chicago, v. 36, n. 1, p. 1-34, Oct. 1987.

GRAU, H.R.; AIDE, M. Globalization and land-use transitions in Latin America. **Ecology and Society**, Ottawa, v. 13, n. 2, p. 16-28, 2008.

GUO, X.; MROZ, T.A.; POPKIN, B.M.; ZHAI, F. Structural change in the impact of income on food consumption in China, 1989–1993. **Economic Development and Cultural Change**, Chicago, v. 48, n. 4, p. 737-760, July 2000.

HEADEY, D.; FAN, S. Anatomy of a crisis: the causes and consequences of surging food prices. **Agricultural Economics**, Amsterdam, v. 39, n. 3, p. 375-391, Nov. 2008.

HERTEL, T.W.; TYNER, W.E.; BIRUR, D.K. The global impacts of biofuel mandates. **Energy Journal**, Cleveland, v. 31, n. 1, p. 75, 2010.

HILL, J.; NELSON, E.; TILMAN, D.; POLASKY, S.; TIFFANY, D. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. **Proceedings of the National Academy of Sciences of the United States of America**, Washington, v. 103, n. 30, p. 11206-11210, July 2006.

HIMMEL, M.; DING, S.Y.; JOHNSON, D.K.; ADNEY, W.S.; NIMLOS, M.R.; BRADY, J.W.; FOUST, T.D. Biomass recalcitrance: Engineering plants and enzymes for biofuels production. **Science**, Washington, v. 315, n. 5813, p. 804-807, Feb. 2007.

HUO, H.; WANG, M.; BLOYD, C.; PUTSCHE, V. Life-cycle assessment of energy use and greenhouse gas emissions of soybean-derived biodiesel and renewable fuels. **Environmental Science & Technology**, Easton, v. 43, n. 3, p. 750-756, 2008.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Sistema IBGE de recuperação automática**. Disponível em: <<http://sidraibge.gov.br>>. Acesso em: 03 fev. 2012.

KLINK, C.A.; MACHADO, R.B. Conservation of the Brazilian cerrado. **Conservation Biology**, Boston, v. 19, n. 3, p. 707-713, June 2005.

LAMBIN, E.; MEYFROIDT, P. Global land use change, economic globalization, and the looming land scarcity. **Proceedings of the National Academy of Sciences of the United States of America**, Washington, v. 108, n. 9, p. 3465-3472, Mar. 2011.

MACEDO, M.; DEFRIES, R.S.; MORTON, D.C.; STICKLER, C.M.; GOLFORD, G.L.; SHIMABUKURO, Y.E. Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. **Proceedings of the National Academy of Sciences of the United States of America**, Washington, v. 109, n. 4, p. 1341-1346, Jan. 2012.

MAHAR, D.J.; ASSEO, M.; COATES, J.; GOODLAND, R.; HOCOMBE, S.; LANDERS, J.; REDWOOD, J.; SCHULZ, R.; TCHEYAN, N.; WATSON, N. **Brazil: integrated development of the Northwest frontier**. The World Bank, Latin America and the Caribbean Regional Office, 1981. Disponível em: <http://econ.worldbank.org/external/default/main?pagePK=64165259&theSitePK=469372&piPK=64165421&menuPK=64166093&entityID=000178830_98101903340026>. Acesso em: 12 out. 2013.

MARCHANT, M.A.; FANG, C.; SONG, B. Issues on adoption, import regulations, and policies for biotech commodities in China with a focus on soybean. **AgBioForum**, Columbia, v. 5, n. 4, p. 167-174, 2003.

MATHEWS, J. Biofuels: what a biopact between North and South could achieve. **Energy Policy**, Guildford v. 35, n. 7, p. 3550-3570, July 2007.

MATSON, P.; VITOUSEK, P. Agricultural intensification: will land spared from farming be land spared for nature? **Conservation Biology**, Boston, v. 20, n. 3, p. 709-710, June 2006.

MEADE, B.; MUHAMMAD, A.; RADA, N. Income growth in developing countries can increase U.S. agricultural exports. **Amber Waves**, Washington, v.9, n. 1, p. 18-25, 2011.

MORTON, D.C.; DEFRIES, R.S.; SHIMABUKURO, Y.E.; ANDERSON, L.O.; ARAI, E.; DEL BON ESPIRITO-SANTO, F.; FREITAS, R.; MORISETTE, J. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. **Proceedings of the National Academy of Sciences**, Washington, v. 103, n. 39, p. 14637-14641, Sept. 2006.

NASS, L.; PEREIRA, P.; ELLIS, D. Biofuels in Brazil: an overview. **Crop Science**, Madison, v. 47, n. 6, p. 2228-2237, Nov./Dec. 2007.

NEPSTAD, D.; STICKLER, C.; ALMEIDA, O. Globalization of the Amazon soy and beef industries: Opportunities for conservation. **Conservation Biology**, Boston, v. 20, n. 6, p. 1595-1603, Dec. 2006.

NEPSTAD, D.; VERSSIMO, A.; ALENCAR, A.; NOBRE, C.; LIMA, E.; LEFEBVRE, P.; SCHLESINGE, P.; POTTER, C.; MOUTINHO, P.; MENDOZA, E.; COCHRANE, M.; BROOKS, V. Large-scale impoverishment of Amazonian forests by logging and fire. **Nature**, London, v. 398, n. 6727, p. 505-508, Jan. 1999.

NEPSTAD, D.; SOARES-FILHO, B.S.; MERRY, F.; LIMA, A.; MOUTINHO, P.; CARTER, J.; BOWMAN, M.; CATTANEO, A.; RODRIGUES, H.; SCHWARTZMAN, S.; MCGRATH, D.G.; STICKLER, C.M.; LUBOWSKI, R.; PIRIS-CABEZAS, P.; RIVERO, S.; ALENCAR, A.; ALMEIDA, O.; STELLA, O. The end of deforestation in the Brazilian Amazon. **Science**, Washington, v. 326, n. 5958, p. 1350-1351, Feb. 2009.

RATHMANN, R.; SZKLO, A.; SCHAEFFER, R. Land use competition for production of food and liquid biofuels: an analysis of the arguments in the current debate. **Renewable Energy**, New York, v. 35, n. 1, p. 14-22, Jan. 2010.

RUDORFF, B.F.T.; ADAMI, M.; AGUIAR, D.A.; MOREIRA, M.A.; MELLO, M.P.; FABIANI, L.; AMARAL, D.F.; PIRES, B.M. The soy moratorium in the Amazon biome monitored by remote sensing images. **Remote Sensing**, Switzerland, v. 3, n. 1, p. 185-202, Jan. 2011.

SHEEHAN, J.; CAMOBRECO, V.; DUFFIELD, J.; GRABOSKI, M.; SHAPOURI, H. **Life cycle inventory of biodiesel and petroleum diesel for use in an urban bus**. Golden: National Renewable Energy Lab., 1998. 288 p.

SOARES-FILHO, B.; MOUTINHO, P.; NEPSTAD, D.; ANDERSON, A.; RODRIGUES, H.; GARCIA, R.; DIETZSCH, G.; MERRY, F.; BOWMAN, M.; HISSA, L.; SILVESTRINI, R.; MARETTI, C. Role of Brazilian Amazon protected areas in climate change mitigation. **Proceedings of the National Academy of Sciences**, Washington, v. 107, n. 24, p. 10821-10826, June 2010.

SPEHAR, C.R. Impact of strategic genes in soybean on agricultural development in the Brazilian tropical savannahs. **Field Crops Research**, Amsterdam, v. 41, n. 3, p. 141-146, June 1995.

UNITED STATES DEPARTMENT OF AGRICULTURE. **Oilseeds:** world markets and trade. Disponível em:
<<http://www.fas.usda.gov/oilseeds/circular/2011/March/oilseeds.pdf>>. Acesso em: 11 jun. 2012.

UNITED STATES SOYBEAN EXPORT COUNCIL. **How the global oilseed and grain trade works.** 2011. Disponível em: <http://www.unitedsoybean.org/wp-content/uploads/2013/07/RevisedJan12_GlobalOilSeedGrainTrade_2011.pdf>. Acesso em: 12 out. 2013.

WORLD WILDLIFE FUND. **Biofuels:** production can be increased without deforestation of the Amazon and the Cerrado. Disponível em:
<http://www.wwf.at/de/view/files/download/forceDownload/?tool=12&feld=download&sprach_connect=930>. Acesso em: 18 set. 2013a.

_____. O impacto do mercado mundial de biocombustíveis na expansão da agricultura brasileira e suas consequências para as mudanças climáticas. Disponível em:
<http://d3nehc6yl9qzo4.cloudfront.net/downloads/relatorio_biocombustiveis_wwf_brasil_jul09.pdf>. Acesso em: 23 nov. 2013b.

YEN, S.T.; FANG, C.; SU, S.J. Household food demand in urban China: a censored system approach. **Journal of Comparative Economics**, San Diego, v. 32, n. 3, p. 564-585, Sept. 2004.

APPENDICES

APPENDIX A

1 Structuring the interview

The growth of agriculture represents an important part of the economic strategy in Brazil. Strong agricultural tradition, favorable edaphoclimatic conditions, and application of modern technology are the greater contributors to the Brazilian agricultural performance in the agribusiness sector. The performance of this sector has been characterized by enhanced productivity and profitability with great contribution in generating jobs and income in the country. The success of Brazilian agribusiness can still be improved, considering that the country still has suitable areas to expand crops production. To reach that success, it is also necessary to plan for this expansion.

The development and planning of agricultural areas play a fundamental role in the economy, making the investments in agribusiness even more attractive to producers. In this perspective, a good design and planning of new locations for agricultural expansion in the country should consider the available resources and the minimization of impacts over the environment, an expansion planning that meets the basics of a sustainable development. A decision making process for selecting sites should then involve appropriate criteria when finding suitable areas for land use. Accordingly, an effective allocation of crops should take into consideration, infrastructure, socioeconomic, and environmental criteria to identify areas for agricultural development in Brazil.

Successful planning depends on the combination of information and knowledge to find strategic locations to allocate croplands. However, the selection of suitable areas for agricultural expansion, through an integrated planning, is a complex decision problem. To help with that complexity, we proposed a model based on a multicriteria decision analysis supported by the AHP to determine the best areas in term of agronomical suitability in addition to the combination of infrastructure and socioeconomic criteria for sugarcane and soybean expansion in Brazil. The first step taken was to establish the criteria to be used for assessing a better selection of sites for crop expansion. Required data were collected based on significant factors for agricultural development. The elements were chosen considering primary needs and data availability for the whole country. Important criteria were selected referent to

physical land suitability, infrastructure and socioeconomic factors. The use of several criteria make it necessary to determine how much each criterion influences the decision making process, and whether or not they have the same level of importance over each other.

To supply the decision making process, the knowledge of specialists was indispensable to set preferences among chosen criteria in the identification of suitable areas for agricultural expansion. Professor Gerd Sparovek was responsible for the selection of the specialists who took into consideration their level of experience about sugarcane and soybean production environments.

The level of preferences was set in pairwise comparison matrices. The comparisons analyze the importance of each one of the overall factors that represent the main variables such as physical land suitability, socioeconomic and infrastructure. The next step was then to define subcriteria in subsequent level of hierarchy in the comparison process.

After defining the criteria, the first structured interview was designed considering the input received. Any additional information that the specialists suggested was added. The respondents were asked to identify the importance of each criterion by using numbers from 1 to 9. In order to identify relevant criteria, the respondents were asked about their preferences between two pairs of criteria. Specifically the respondents were asked, "Thinking about areas to expand sugarcane in Brazil, what is the importance of the criteria considered in the selection of those areas? Are the variables x and y of equal importance?" If the answer was "yes" 1 was marked on the matrix. If the answer was "not" the next question asked was, "Which one is more important?" "How far is that criterion more important than the other? Slightly more important (3), important (5), very important (7) or extremely important (9)?" A four-point scale was used to rate the factors. The numerical rating 2, 4, 6 and 8 were used to rate intermediate preferences between the pair of criteria that did not satisfied any of the others numerical rating (3, 5, 7 or 9).

Individual meetings by phone, Skype and personal interviews carried out the research where the purposes of the study were presented to the specialists. The questionnaires were sent by email before the meeting, so they could have an idea about the objective of the study, get familiar with the pairwise comparisons, and know how the interview was going to be conducted, what would require less time filling out

the matrices. The judgments were documented on paper for all pairwise comparisons for the sugarcane model. In the soybean model, the judgments were entered and stored directly in the software.

Interviews were conducted with ten professionals of sugarcane, identified by P1 to P10. We started with some general guidelines to orientate the expert on how the application form worked to make sure that it was clear. The structured interview, according to the AHP method, consisted of objective questions, previously presented, about the respondents' preferences among the set of criteria. We provided them with fourteen criteria that were suitable to collect information about sites selection for sugarcane expansion. The pairwise matrices were filled out by the interviewer or by the specialists, considering the specialists answers. At the end the respondents were requested to suggest any other professional that they judged indispensable in participating in the structured interviews.

The interviews were quite satisfactory. The presence of the interviewer was essential to support the specialists with the questionnaires that were a bit different than those usually applied. During the process of pairwise comparison the experts were asked why they chose one criteria over another. This was necessary to make sure that they were not guessing, but using their experience to make judgments about the variables. In general, they considered that the method applied was a little bit difficult to understand in the beginning, which required more time to comprehend it, making more sense at it goes through.

Having received the inputs of the respondents, the criteria were processed to derive the weights to feed the MCDA. Mathematical calculations were done using the Expert Choice 2000 software to convert the experts' judgments to weights for each of the fourteen criteria. The eigenvector associated with the highest eigenvalue for each matrix was estimated. The eigenvector gives the order of priority, and is calculated by the normalization of the components of the matrix equivalent to the proportion of each element in relation to their sum. Each matrix is evaluated by its eigenvalue to verify the consistency and the quality of the data. The relative weights were obtained for each line of the hierarchy from the top to the bottom. The subcriteria weights computations were processed in relation to the weight criterion on a level immediately above in the hierarchy. The ordering of the criteria was made considering the calculated weights corresponding to the relative importance of each criterion regarding the general objective.

2 Questionnaire applied to the specialists in sugarcane

Multicriteria decision analysis in the selection of areas for the expansion of sugarcane in Brazil

Context

The way the agricultural occupation is implemented in Brazil constitutes a key factor in the planning of the agricultural sector. In this context, it is believed that the combination of different elements involved in systematic space is of great importance for an effective strategy planning of agricultural expansion to better allocate sugarcane cultivation in the country. So, what is proposed in this research is a MCDA model that takes into account a physical land suitability evaluation model (edaphoclimatic: soil, climate, biome, land use and topography) and variables related to infrastructure and social and economics.

Objective

The purpose of the interview is to count on the collaboration of experts' knowledge in agricultural planning to evaluate a set of criteria for our MCDA. The interview will be held directly and we will ask you to assign numerical values to the variables in the decision matrices according to their relative importance in the model. Such variables are outlined below (Figure A1):

Figure A1 - Evaluated variables in the decision making process for sugarcane allocation

The general criteria considered in the hierarchical analysis are described below:

Edaphoclimatic. Physical land suitability evaluation assess the agricultural suitability considering the physical and chemical characteristics of soils, topography, biome, land use and climate conditions to produce with no need of irrigation.

Infrastructure. Assess the structure available in the country for a possible expansion of new agricultural areas.

Economic. Assess the historical measure of economic productivity of municipalities with a known production value.

Social. Analyzes the availability of workforce required in different levels of the agricultural activity.

And subcriteria that have influence on the upper criteria:

Employed People in Farming. Assess the number of people employed in temporary crops cultivation by municipalities normalized by the total population of each municipality. They were considered as people with some level of knowledge in the agricultural activities.

Education. Assess the level of education of people normalized by the population size of each municipality (ages between 18 and 44) (IBGE / Census 2010).

Age Structure. Assess the age structure of people living in the municipalities normalized by population size of each municipality (ages between 18 and 44) (IBGE / Census, 2010).

Value of Agricultural Production. The value of agricultural production is a proxy for added value. It is the multiplication of the production by the average prices received by producers of the municipality weighted by the quantities harvested along the reference year of the survey (IBGE, 2006). The criterion represents the value of agricultural production of sugarcane in R\$ 1,000 as a partial measure of productivity.

Assigning values will be based on pairwise comparisons. For each pairwise comparison a criterion is evaluated in relation to another. Therefore, your assessment should consider "how much" a criterion is more important than the other.

Your experience and knowledge of agricultural production environments will be sufficient to assign values to the criteria. Use the blank spaces in the matrices for assigning values, if you have any question please refer the help of the interviewer.

The following table specifies the ordinal values to be used to determine the degree of preference among the criteria (Table A1).

Table A1 - Degree of preference between two criteria in the AHP

Numerical Rating	Degree of Preference	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate Importance	Slightly favor one activity over another
5	Strong Importance	Strongly favors one activity over another
7	Very Strong Importance	Dominance of an activity demonstrated in the practice
9	Extreme Importance	The evidence favoring one activity absolutely and
2,4,6,8	Intermediate values	When compromise is needed
Reciprocals of above	When comparing elements i and j if i is a number different of zero, then j has a reciprocal value ($a_{ij} = 1/a_{ji}$)	For inverse comparison

The judgment of "how much" a criterion is more important than the other should contemplate a qualitative analysis (equal, moderate, strong, very strong and extremely) and not the intensity of the associated values (1, 2, ..., 9). The degree of importance has no relation whether a criterion is 1, 2, 3, 4, 5, 6, 7, 8 or 9 times more important than the other, but the degree of preference that is qualitative. Therefore, the numbers serve only as identifiers.

Take a look at the following demo that exemplifies how the matrices should be filled according to the previously mentioned degrees of preference (Figure A2). To complete the matrix, it is necessary to make comparisons among all the criteria per lines.

Figure A2 - Example of how to fill out the comparison matrix

If the criterion A has a very strong importance compared to the criterion B, you add the number 7 in the line 1 (A), column 2 (B) of the matrix. If the criterion C has strong importance compared to the criterion A, 1/5 is added at line 1 (A), column 3 (C). Therefore, considering that the criterion A is more important than the criterion B, and criterion C is more important than the criterion A, logically the criterion C is more important than the criterion B. Since the criterion C is extremely important compared to the criterion B, 1/9 is added in the line 2 (B), column 3 (C).

An inverse value (1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8 or 1/9) should be used when the compared criterion is less preferable in relation to the other (If A has very strong importance in comparison with criterion B, when the criterion B is compared with the criterion A - line 2, column 1 - the value to be assigned is the reciprocal value of 1/7).

It is, therefore, based on your experiences, the interpretation of the relative importance of a criterion compared to another.

Tip: To help you filling out the matrix, complete only the cells to the right of the main diagonal. The lower part of the matrix (main diagonal left) will be filling out automatically by the program with reciprocal values associated with the top of the matrix.

1 - Variables involved in the modeling of agricultural expansion for sugarcane in Brazil. The question that must be answered to fill this matrix is: what is the importance of each criteria compared with each other to select the best locations for expansion of sugarcane cultivation in Brazil?

Table A2 - Comparison matrix of the main criteria in accordance with the general purpose previously mentioned

	Edaphoclimatic	Infrastructure	Social	Economic
Edaphoclimatic	1			
Infrastructure		1		
Social			1	
Economic				1

2 - Subdivision of the variables involved in the modeling, now considering only the variables that is part of the infrastructure criterion.

Table A3 - Comparison matrix for the infrastructure sub-criterion. In the pairwise comparison, what is the degree of importance of the criteria in terms of infrastructure?

	Transport	Facilities
Transport	1	
Facilities		1

Table A4 - Comparison matrix for the transport sub-criterion. In the pairwise comparison, what is the degree of importance of the criteria in terms of transport?

	Roads	Railroads	Ports	Pipelines
Roads	1			
Railroads		1		
Ports			1	
Pipelines				1

3- Subdivision of the variables involved in the modeling, now considering only the variables that is part of the **social** criterion.

Table A5 - Comparison matrix for the social sub-criterion. In the pairwise comparison, what is the degree of importance of the criteria in social terms?

	Age Structure	Education	Labor
Age Structure	1		
Education		1	
Labor			1

Table A6 - Comparison matrix for the age structure sub-criterion. In the pairwise comparison, what is the degree of importance of the criteria in terms of age structure?

	Ages 18-44	Ages 44-49
Ages 18-44	1	
Ages 44-49		1

Table A7 - Comparison matrix for the education sub-criterion. In the pairwise comparison, what is the degree of importance of the criteria in terms of education?

	Elementary	High School	Major	No Education
Elementary	1			
High School		1		
Major			1	
No Education				1

3 Participants comments on questions in the survey

This section presents the matrices that were resultant from the comparison analyses evaluated by the specialists in sugarcane and soybean. The matrices were obtained from the Expert Choice program. The general consensus and individual judgments matrices were added to explain the criteria preferences in the analysis.

3.1 General consensus comments in relation to the judgments of the specialist in sugarcane

The consensus indicates that the emphasis is more on the edaphoclimatic than on the other factors (Figure A3). That is because the specialists believe that the absence of physical land suitability in a certain area would impact the economic viability of a project making it less viable.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclim		1.73939	1.17566	3.85527
Infrastructu			(1.21645)	2.30004
Economic				2.82756
Social	Incon: 0.00			

Figure A3 - General criteria comparison matrix used to support the MCDA for sugarcane allocation

In relation to the infrastructure criteria, the transport is moderately more important than facilities (Figure A4), which shows the importance that the transportation undertakes in the agricultural system.

	Transport	Facilities
Transport		1.51933
Facilities	Incon: 0.00	

Figure A4 - Comparison matrix for the transport and facilities subcriteria (Infrastructure criterion)

Pipelines were considered slightly more important than ports, which were more important than roads (Figure A5). Railroads were considered the least important of all. Although pipelines are still not part of the transportation system reality in Brazil, the specialists believe that the contribution of this transportation mode is going to add to the increase of Brazilian competitiveness in the market for ethanol.

	Roads	Railways	Ports	Pipelines
Roads		1.10404	(1.19252)	(1.15013)
Railways			(1.44973)	(1.4174)
Ports				(1.04322)
Pipelines	Incon: 0.00			

Figure A5 - Comparison matrix for the transportation subcriteria

Education was slightly more important than people employed in temporary crops (Figure A6). On the other hand, the age structure was not considered so important in the comparisons.

	Age Structure	Education	Labor
Age Structure		(2.83876)	(2.99198)
Education			1.07502
Labor	Incon: 0.00		

Figure A6 - Comparison matrix for the social criteria

In the age structure comparison matrix, the age group between 18 and 44 were considered more important than between 44 and 49 (Figure A7). The comparison between these variables was controversial among the specialist. Some of them believe that age does not affect the capacity of work of an individual and others believe that younger employees are easier to train.

	Age 18-44	Age 44-49
Age 18-44		2.80363
Age 44-49	Incon: 0.00	

Figure A7 - Comparison matrix for the age structure subcriteria

Compared to the other criteria, the weight given to high school was the highest (Figure A8). In general, the specialists believe that there is no need for a higher level of education because wherever a mill is installed it provides professional training in sugarcane production. Everyone is trained, no matter if they have a reasonable level of education or not, but what it is needed is at least a degree of education that enables them to learn.

	Elementary	High School	Major	No Education
Elementary		(1.81501)	1.07428	4.56269
High School			1.90337	8.42284
Major				4.50377
No Education	Incon: 0.00			

Figure A8 - Comparison matrix for the education subcriteria

3.2 Individual comments regarding the judgments of sugarcane specialists

Interviewed P1

To P1 the edaphoclimatic is more important than the infrastructure criterion (Figure A9). According to the specialist, infrastructure can be built in areas of fertile soils. However, having infrastructure in lands with unsuitable soils is not ideal for agriculture, considering the amount of money that will be spent to make the soil arable. So undoubtedly, edaphoclimatic is more important than infrastructure. But how much? This will depend specifically on each region in Brazil.

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		1.58	2.52	2.21
Infrastructure			1.82	1.73
Economic				(1.64)
Social	Incon: 0.01			

B.

Figure A9 - A. Relative importance of the criteria for the selection of sites for sugarcane allocation. B. Priorities calculation and inconsistency of the results

The edaphoclimatic and social factors are more important than the economic criterion because they directly influence the economic criterion. The specialist adds that the insertion of new technologies in the field requires people with at least some type of preparation to work on modern equipment, but it should take into consideration that people can also be trained.

Transportation is more important than utilities (Figure A10) due to the high cost of deploying infrastructure in a certain area.

A.

	Transport	Facilities
Transport		5.0
Facilities	Incon: 0.00	

B.

Figure A10 - A. Relative importance of the subcriteria in relation to infrastructure. B. Priorities calculation and inconsistency of the results

Roads and pipelines are the most important mode of transportation (Figure A11). Thinking in terms of progress, the pipelines are important for the development of new areas. However, the pipelines are not part of the Brazilian reality yet.

Roads networks are more accessible than railroads in Brazil, which makes roads one of the most important transportation modes in the country. Unfortunately, the access to railroads still very restricted to some areas in the territory.

Ports transportation is not so efficient in Brazil, and advancements need to be made in such area. The existence of ports is not a limitation for sugarcane expansion, and sugarcane can still be cultivated in areas far from waterways.

A.

	Roads	Railways	Ports	Pipelines
Roads		5.0	3.0	1.0
Railways			(3.0)	(5.0)
Ports				(3.0)
Pipelines	Incon: 0.02			

B.

Roads	.390	
Pipelines	.390	
Ports	.152	
Railways	.068	
Inconsistency = 0.02		

Figure A11 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

Age is more important than education (Figure A12). It is more important to have people physically able to work than to have people with higher level of education, especially because it is not possible to find everyone in a population with a college degree. Although it is common to find more people with low level of education in the country, it is important to have people with a certain level of education to be able to operate machines.

A.

	Age Structure	Education	Labor
Age Structure		2.12	(1.67)
Education			(2.51)
Labor	Incon: 0.01		

B.

Labor	.493	<div></div>
Age Structure	.331	<div></div>
Education	.175	<div></div>
Inconsistency = 0.01		

Figure A12 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

Older people are more refractory to new technologies, for that reason it is easier to train younger than older people to work in the field with modern equipment. To P1 it would be more important to have younger people (Figure A13), because they are physically able to work on harvesting crops, which would be a good add in the production process.

A.

	Age 18-44	Age 44-49
Age 18-44		9.0
Age 44-49	Incon: 0.00	

B.

Age 18-44	.900	<div></div>
Age 44-49	.100	<div></div>
Inconsistency = 0.		

Figure A13 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

Analyzing the education criterion, P1 believes that it is not necessary to have a workforce so qualified (Figure A14). They have to have a minimal level of education, mainly because it is much easier to bring skilled people from different regions.

A.

	Elementary	High School	Major	No Education
Elementary		3.0	7.0	3.0
High School			3.0	3.0
Major				(3.0)
No Education	Incon: 0.06			

B.

Figure A14 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

Interviewed P2

P2 considers the economic variable the most important criterion in the sugarcane expansion context (Figure A15). The specialist explains that if there is an economic viability in the project everything else is manageable. P2 also states that there are a lot of areas to expand the agriculture in Brazil, such as eroded pasturelands in the northwest and west of Paraná, and lands with livestock in the northeastern and west of São Paulo, abundant areas in Mato Grosso do Sul, Mato Grosso and Goiás. The specialist also explains that those areas could be used for the conversion to agriculture.

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		2.24	(1.367)	2.5
Infrastructure			(2.158)	1.5
Economic				3.25
Social	Incon: 0.01			

B.

Figure A15 - A. Relative importance of the criteria for the selection of sites for sugarcane allocation. B. Priorities calculation and inconsistency of the results

The areas for agricultural expansion can have poor soil and weather conditions, but if there is water, there is an economic viability for the agricultural activity, especially because poor soils are considered cheap lands. Cheaper lands counterbalance the production cost, the poor weather is compensated by the irrigation, and the crop replenishes the nutrients in the soil. According to P2, a region could have the best infrastructure, but if the payback were not profitable then it would not be economically viable to produce there. In relation to the social aspect, it is not as important as the other factors.

When the question is the importance of transport compared to facilities, P2 justifies that transportation is far more important than facilities (Figure A16), since it has a strong influence on the economic viability. To show the importance of transportation, P2 gives an example of sugar harvest. The specialist says that with the change in the transport legislation, the cost of transportation will increase in 2013, whereas the ethanol will tend to have the same price unless the federal government actually decides to change the gasoline price. So what is likely to happen in 2013 is that is not going to be a sugar harvest season, because of the issue with transportation states the specialist. The fleet of trucks is not going to be enough to replace the lack of transportation. On the other hand, the ethanol is going to be transported through pipelines, which is going to lower the price of ethanol. So at the end the cost of transportation will change the harvest model, which is going to beneficiate the ethanol production.

A.

	Transport	Facilities
Transport		7.0
Facilities	Incon: 0.00	

B.

Figure A16 - A. Relative importance of the subcriteria in relation to infrastructure. B. Priorities calculation and inconsistency of the results

Sugarcane cultivation was concentrated in areas close to mills to minimize costs with transportation. However, this supply model has changed. The cultivated

areas with sugarcane go up to 70 km. Besides that mills have internal roads, which by the way do not meet the requirements of the Brazilian transportation law. Then, instead of traveling with a truck with two trailers carrying 70 or 80 tons, they travel with three trailers, carrying 120 tons. Consequently, the carrying capacity is increased.

The railroads have an availability problem, and the construction of pipelines is more dependent on private initiative than on government. There are partnerships already working on the shipping of agricultural products in some terminals, and the specialist supposes that they will grow very fast, because it is just a matter of economic investments. Pipelines will be an excellent mode of transportation for ethanol in the future. However it is not possible to determine the importance of pipelines today. But in relation to Brazilian reality, the most important transportation mode is still roads (Figure A17). Ports are slightly more important than pipelines because they are essential to the transportation of agricultural products overseas. In fact that prevailing weight is because there are ports in the country, and pipelines still under progress. However, it should take into consideration that both are fundamental. To P2 40% to 50% of sugarcane production is going to be carried out through pipelines and ports.

A.

	Roads	Railways	Ports	Pipelines
Roads		7.0	3.0	1.0
Railways			(7.0)	(7.0)
Ports				1.0
Pipelines	Incon: 0.06			

B.

Roads	.417	
Pipelines	.303	
Ports	.236	
Railways	.043	
Inconsistency = 0.06		

Figure A17 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

Age structure does not matter much (Figure A18), considering that everything is mechanized in agriculture today.

A.

	Age Structure	Education	Labor
Age Structure		(7.0)	(9.0)
Education			(3.0)
Labor	Incon: 0.08		

B.

Labor	.655	<div></div>
Education	.290	<div></div>
Age Structure	.055	<div></div>
Inconsistency = 0.08		

Figure A18 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

Both age structures have the same capacity to work (Figure A19). Sometimes, older people have more experience, but if they are young, it is possible to train them as well.

A.

	Age 18-44	Age 44-49
Age 18-44		1.0
Age 44-49	Incon: 0.00	

B.

Age 18-44	.500	<div></div>
Age 44-49	.500	<div></div>
Inconsistency = 0.		

Figure A19 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

High level of education is not so important (Figure A20), for the reason that there is only need for a few people in the sugarcane production system. Besides, mills promote training to the employees through Senai, Senac, etc. Everyone is trained. It does not matter if they have education or not. Of course, it would be better if the person were not illiterate, since the capacity to learn does matter. Not in the sense that people need to have a major diploma, but people need at least to have a degree of education that enables them to learn.

A.

	Elementary	High School	Major	No Education
Elementary		(1.833)	5.0	9.0
High School			5.5	27.5
Major				7.0
No Education	Incon: 0.06			

B.

Figure A20 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

Interviewed P3

To P3 the edaphoclimatic and the economic criteria have equal importance (Figure A21), which means that both criteria are fundamental in the agricultural expansion planning process. The social criterion is not so important, considering that the lack of labor would be much easier to be replaced than a lack of land suitability. The social criterion is not an ultimate variable to take into consideration in the sites selection for sugarcane expansion. The agricultural expansion is somehow indifferent to it.

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		1.0	1.0	5.0
Infrastructure			1.0	3.0
Economic				5.0
Social	Incon: 0.01			

B.

Figure A21 - A. Relative importance of the criteria for the selection of sites for sugarcane allocation. B. Priorities calculation and inconsistency of the results

Ideally, it would be important to allocate new agricultural areas near to railroads, ports and pipelines because they are the most efficient modes of transportation (Figure A22). However, they are not very accessible in the country. That explains why roads are more in use in Brazil.

A.

	Roads	Railways	Ports	Pipelines
Roads		(5.0)	(3.0)	(3.0)
Railways			1.0	1.0
Ports				1.0
Pipelines	Incon: 0.01			

B.

Figure A22 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

P3 believes that the labor criterion is more important than the other factors (Figure A23). It is important to have a certain level of education, however it is not priority for agriculture. Workers can be trained and people can always come from somewhere else.

A.

	Age Structure	Education	Labor
Age Structure		3.0	(5.0)
Education			(6.0)
Labor	Incon: 0.09		

B.

Figure A23 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

If I had to consider the importance of the social criterion, I would say that the age group between 18 and 44 would be a better workforce to be considered in the selection of sites for sugarcane expansion (Figure A24).

A.

	Age 18-44	Age 44-49
Age 18-44		7.0
Age 44-49	Incon: 0.00	

B.

Age 18-44	.875	
Age 44-49	.125	
Inconsistency = 0.		

Figure A24 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

A good educational level is important for some job placements in agriculture (Figure A25), but to expand to places with a population with high level of education is not always ideal for the reason that workers will not want to work in every position.

A.

	Elementary	High School	Major	No Education
Elementary		(1.5)	(1.478)	2.333
High School			1.0	3.0
Major				3.091
No Education	Incon: 0.00			

B.

Major	.333	
High School	.331	
Elementary	.231	
No Education	.106	
Inconsistency = 0.00087		

Figure A25 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

Interviewed P4

The edaphoclimatic criterion is more important than the other criteria (Figure A26). Agricultural activity could be adapted to soils that are not very suitable for crops cultivation, although that would lead to higher costs for farmers, holding up

their competitive edge. Additional investments to make soil more suitable for agriculture would directly affect the costs of production.

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		1.28	1.773	3.2
Infrastructure			1.389	2.778
Economic				2.0
Social	Incon: 0.00			

B.

Edaphoclimatic	.374	<div></div>
Infrastructure	.300	<div></div>
Economic	.216	<div></div>
Social	.111	<div></div>
Inconsistency = 0.00051		

Figure A26 - A. Relative importance of the criteria for the selection of sites for sugarcane allocation. B. Priorities calculation and inconsistency of the results

P4 considers the social criterion the least important criterion in the spatial land planning for sugarcane allocation. According to the specialist, even though a region does not have sufficient labor, it is not difficult to attract more workers from other regions. So, it is easier to allocate labor because of the mobility of people.

A.

Transport	.500	<div></div>
Facilities	.500	<div></div>
Inconsistency = 0.		

B.

	Transport	Facilities
Transport		1.0
Facilities	Incon: 0.00	

Figure A27 - A. Relative importance of the subcriteria in relation to infrastructure. B. Priorities calculation and inconsistency of the results

P4 found difficulty in making the assessment in relation to transport. As the specialist said, all modes of transportation are complementary and do not substitute each other. P4 considers roads and ports essential for the movement of agricultural

products. Thinking about the economic aspect of transportation, railroad is more important than roads because of the lower costs, affirms the specialist (Figure A28).

A.

	Roads	Railways	Ports	Pipelines
Roads		(1.833)	(1.571)	(1.35)
Railways			1.138	1.375
Ports				1.179
Pipelines	Incon: 0.00			

B.

Railways	.318	
Ports	.276	
Pipelines	.233	
Roads	.174	
Inconsistency = 0.00004		

Figure A28 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

Age structure and labor are more important than education (Figure A29).

A.

	Age Structure	Education	Labor
Age Structure		2.0	1.0
Education			(2.0)
Labor	Incon: 0.00		

B.

Age Structure	.400	
Labor	.400	
Education	.200	
Inconsistency = 0.		

Figure A29 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

The population group between 18 and 44 is more important than between 44 and 49 (Figure A30) in a sense that the first group represents a greater section of the population than the second one.

A.

	Age 18-44	Age 44-49
Age 18-44		2.0
Age 44-49	Incon: 0.00	

B.

Age 18-44	.667	
Age 44-49	.333	
Inconsistency = 0.		

Figure A30 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

Taking into account the replacement of labor by machinery, P4 recognizes that elementary and high school are more important than college and illiterate due to the necessity of basic knowledge for machine operation (Figure A31).

A.

	Elementary	High School	Major	No Education
Elementary		(1.739)	2.056	3.1
High School			2.889	4.8
Major				1.6
No Education	Incon: 0.00			

B.

High School	.464	
Elementary	.290	
Major	.151	
No Education	.095	
Inconsistency = 0.0015		

Figure A31 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

Interviewed P5

Analyzing the Brazilian agricultural scenario, P5 evaluates the economic criterion as the most important of all (Figure A32). According to the specialist you can even change the production system, the soil may be poor, but if the business does not have economic viability it becomes quite limiting. P5 states that it is clear the essential function that the transportation infrastructure plays in the agricultural

production, although their bottlenecks are well recognized in Brazil. The specialist says that there are some expectations about the infrastructure in the country, such as “will it come one day”? “Is it going to take a lot or a little bit of time”? “Would it lead to economic loss for agribusiness”? Those questions will always be part of the main concerns in the agribusiness sector affirms P5.

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		(2.9)	(5.8)	3.333
Infrastructure			(1.943)	8.75
Economic				18.0
Social	Incon: 0.00			

B.

Figure A32 - A. Relative importance of the criteria for the selection of sites for sugarcane allocation. B. Priorities calculation and inconsistency of the results

The reality of agricultural growth that has been observed in Brazil is a breakthrough toward areas with lack of infrastructure. Although the infrastructure is very important, the presence of major infrastructure is not a requirement for agricultural development. Places like Mato Grosso do Sul and southern of Goiás have an overall infrastructure shortage. However, they have minimum infrastructure necessary for agricultural expansion, which represents at least some type of accessibility. Besides, a business can even build its own roads. After all, it is the economic rules that will dictate that viability.

What makes a project not feasible is the production cost. Let's have São Francisco Valley as an example, the soil and climate in that region are very poor. However, I can create a project with irrigated sugarcane, since I have water availability and technology, I can also replenish all the nutrients needed in the soil to support production, and the price of the land will certainly be cheaper, right? Says P5. What happens is that the increment of those elements could convert that area in high profitable zones, even knowing that the edaphoclimatic is not so optimal.

It would compensate more for farmers to invest in a production system that counterbalances the edaphoclimatic deficiency than a system that has agricultural

potential but little economic viability. So, it is the economic analysis that dictates the rules of the game. I can even have a better condition in the Cerrado than in São Francisco Valley. The physical land suitability could be better, could be possible to produce without irrigation in that place, but let's say that it could be done with a greater project risk. So, the development of a project in that area would not be as interesting as a more advanced and more expensive one (São Francisco Valley). It seems inconsistent, but the expensive one would be more profitable because of a better economic return due mainly to the lower land price.

The social criterion is not as important as the other criteria if you take into consideration the mechanization of crops. It is expected a reduced number of employees in the field because the insertion of machinery in Brazilian agriculture. Although there is some concern with the social criterion, and in fact it is a criterion used to calculate the project viability, agricultural suitability is more important. Even if there are not enough local employees, you can import them from other centers. The social criterion may even be restrictive, but it is not limiting.

Thinking about transportation infrastructure, it would be ideal that areas for agricultural expansion had easy access to railroads, ports and pipelines. It is clear that areas with those types of infrastructure would be great to build mills, but this is not the reality in Brazil. I am not going to look for areas to expand sugarcane based on the location of a specific type of transportation. It is not possible to base a project only on the importance of those variables. It is necessary to be aware of the infrastructure availability that exists in the country.

The proximity to railroads, ports and pipelines is more important than to roads (Figure A33), but again this is not the reality of Brazilian transportation. Road is the mode of transportation with the easiest accessibility in Brazil. The access to another transportation mode would account just as a bonus for land planning. Areas have railroads? Yes? Great. If the area has pipelines is even better, and I would even pay more for the land because it will certainly escalate in price in the future, especially in places where the ethanol will be transported through pipelines, connecting the producer directly to the consumer, the contribution margin will probably be greater. We should prioritize areas with access to transportation to ensure a good distribution of agricultural production, but not specifically toward a particular mode of

transportation. Actually, the opportunity cost of land and the technology available to produce in such environment has higher priority in selecting areas for expansion.

A.

	Roads	Railways	Ports	Pipelines
Roads		(5.0)	(7.0)	(9.0)
Railways			(2.0)	(3.0)
Ports				(3.0)
Pipelines	Incons: 0.04			

B.

Pipelines	.533	
Ports	.259	
Railways	.166	
Roads	.042	
Inconsistency = 0.04		

Figure A33 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

The expansion of sugarcane cultivation in Brazil will focus mainly on ethanol, not on sugar production. Sugar consumption will increase only if there is an increase in population. To produce sugar, the sugarcane cultivated in the country is already enough. The market will not allow a vegetative growth that grows with the population and with the increase in purchasing power of some countries like China and India. In other countries, as in Brazil, many people have switched their consumption of sugar to other substitute products. Therefore, we expect a slow growth for that product in market, which does not justify large agricultural expansions into new areas. The current expansion will be directed to supply the ethanol demand, but of course the producers will also continue to produce sugar.

The tendency of modern agriculture is to use the minimum amount of labor. It would be interesting to have employees with at least some type of technical knowledge. In this context education is more important than age as the market look for workers to operate complex machinery (Figure A34).

A.

	Age Structu	Education	Labor
Age Structure		(2.346)	2.0
Education			4.267
Labor	Incon: 0.00		

B.

Figure A34 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

It would be better to employ younger workers under 44 (Figure A35), but that also depends on the function that the employee will perform in the agricultural production. Thinking about the mechanization, it would be better to have people trained by Senai between the ages of 30 and 40.

A.

	Age 18-44	Age 44-49
Age 18-44		3.0
Age 44-49	Incon: 0.00	

B.

Figure A35 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

Major is more important than high school (Figure A36). In fact, all other levels of education are more important than illiterate. People with college degree is very important in the administrative sector such as managers, agronomists, psychologists, supervisors, accountants, etc.

A.

	Elementary	High School	Major	No Education
Elementary		(1.857)	(5.3)	5.0
High School			(2.192)	6.5
Major				13.25
No Education	Incon: 0.02			

B.

Figure A36 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

In general, what usually happens in agricultural planning is that farmers get in contact with companies that are traditional in developing agricultural projects in Brazil. The farmers select the most important variable to be considered in the prioritization of areas, and the company finds the best areas in accordance with the customer needs.

Interviewed P6

The physical land suitability has direct effect in the economic viability of a project, and it is the most important criterion in the decision analysis (Figure A37). That is because if a certain area is not physically suitable, it may contribute to the failure of a project. The same thing can be applied to areas that have precarious infrastructure. As the physical land suitability and infrastructure directly affect the economic viability, so does the social criterion. However, it would be easier to allocate workers in areas with minimum edaphoclimatic and infrastructure suitability, as labor can migrate from other parts of the country. The social aspect may be limiting because of the high labor cost, but with no land suitability a certain area becomes reasonably impracticable for agricultural expansion.

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		1.679	7.833	4.273
Infrastructure			5.2	2.167
Economic				(1.6)
Social	Incon: 0.01			

B.

Edaphoclimatic	.511	
Infrastructure	.302	
Social	.121	
Economic	.066	
Inconsistency = 0.0052		

Figure A37 - A. Relative importance of the criteria for the selection of sites for sugarcane allocation. B. Priorities calculation and inconsistency of the results

To plan for an agricultural expansion in Brazil we have to make decisions considering the infrastructure available in the country, and not base on future ones. For this reason, roads are the most important mode of transportation that exists in the country (Figure A38). About pipelines, well, they are still under design.

A.

	Roads	Railways	Ports	Pipelines
Roads		3.0	3.0	9.0
Railways			1.0	7.0
Ports				9.0
Pipelines	Incon: 0.05			

B.

Roads	.525	
Ports	.228	
Railways	.210	
Pipelines	.036	
Inconsistency = 0.05		

Figure A38 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

It would be better to find employees with minimum level of education to work. So, to me, among education, age structure and labor criteria, education would be the most important criterion in sites selection for sugarcane expansion (Figure A39). It would also be better to have workers between 18 and 44 to work in those areas (Figure A40).

A.

	Age Structure	Education	Labor
Age Structure		(8.75)	(2.125)
Education			3.941
Labor	Incon: 0.00		

B.

Education	.732	<div></div>
Labor	.183	<div></div>
Age Structure	.085	<div></div>
Inconsistency = 0.0002		

Figure A39 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

A.

	Age 18-44	Age 44-49
Age 18-44		7.0
Age 44-49	Incon: 0.00	

B.

Age 18-44	.875	<div></div>
Age 44-49	.125	<div></div>
Inconsistency = 0.		

Figure A40 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

In relation to education, it is necessary that employees have minimum education qualifications for work, although it is not essential that they have a high educational level (Figure A41).

A.

	Elementary	High School	Major	No Education
Elementary		(3.846)	(2.692)	2.167
High School			1.486	7.0
Major				5.833
No Education	Incon: 0.00			

B.

High School	.473	<div></div>
Major	.339	<div></div>
Elementary	.127	<div></div>
No Education	.061	<div></div>
Inconsistency = 0.00183		

Figure A41 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

Interviewed P7

The edaphoclimatic is the most important criterion in an investment project analysis (Figure A42). In areas with no suitability for sugarcane the cost of production can be extremely high. In such cases, the area can even have good infrastructure, however this is not enough to make a successful project. It is from the economic viability assessment that the success or lack of success of a project is evaluated.

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		4.455	2.042	8.167
Infrastructure			(1.929)	2.0
Economic				3.429
Social	Incon: 0.00			

B.

Figure A42 - A. Relative importance of the criteria for the selection of sites for sugarcane allocation. B. Priorities calculation and inconsistency of the results

The most important means of transport in the sugarcane production context would be railroads (Figure A43). Access to ports and pipelines become a competitive advantage for mills, when areas for agricultural expansion are close to them. It is also very common for mills to build their own roads for internal transportation of their products.

A.

	Roads	Railways	Ports	Pipelines
Roads		(7.0)	(4.0)	(6.0)
Railways			3.0	2.0
Ports				(3.0)
Pipelines	Incon: 0.04			

B.

Railways	.473	
Pipelines	.324	
Ports	.152	
Roads	.052	
Inconsistency = 0.04		

Figure A43 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

Some functions require that employees have a certain level of education for a better performance in the sugarcane production process. Now, about age structure, that is not so important in sites selection for sugarcane expansion (Figure A44).

A.

	Age Structure	Education	Labor
Age Structure		(3.0)	(2.0)
Education			3.0
Labor	Incon: 0.05		

B.

Education	.594	
Labor	.249	
Age Structure	.157	
Inconsistency = 0.05		

Figure A44 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

Older people can perform a range of functions in modern agriculture. However, in some mills where the harvest process is still manual, it is necessary that employees are younger (Figure A45).

A.

	Age 18-44	Age 44-49
Age 18-44		3.0
Age 44-49	Incon: 0.00	

B.

Figure A45 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

Illiterate workers would only be employed to cut sugarcane. It is necessary that workers have minimum level of education to better meet the demands of a modern agriculture (Figure A46).

A.

	Elementary	High School	Major	No Education
Elementary		(1.406)	2.0	8.0
High School			3.0	9.0
Major				5.0
No Education	Incon: 0.01			

B.

Figure A46 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

Interviewed P8

The edaphoclimatic is more important than infrastructure (Figure A47). This is because it is possible to attract investments to improve existing infrastructure or build new infrastructure, however the same logic cannot be applicable to the edaphoclimatic suitability. So, if a particular region is not suitable for the cultivation of sugarcane, it is more difficult to overcome the edaphoclimatic restrictions than the infrastructure limitations. What could be done to meet the demand of water for agricultural production if there is no water available? What could be done to make the

soil suitable for cultivation if the soils are extremely poor? Certain areas in Brazil have edaphoclimatic restrictions that make the cultivation of sugarcane very difficult.

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		1.533	4.6	2.556
Infrastructure			2.909	1.684
Economic				(1.727)
Social	Incon: 0.00			

B.

Figure A47 - A. Relative importance of the criteria for the selection of sites for sugarcane allocation. B. Priorities calculation and inconsistency of the results

The social aspect is also limiting, although you can attract workers from other parts of the country, encouraging them through higher salaries. The social aspect can also be a restraining factor due to all the existing labor legislation that must be fulfilled, the sustainability aspects involved and the issue of local community. How about if the expansion is performing in areas near to the demarcation of indigenous lands? How are you going to put the Indians to work? Difficulties are expected when the subject comes to the social matter. I believe that the social factor is relevant in choosing areas for agricultural expansion, however it is not as important as the edaphoclimatic suitability.

Now, how the economic aspect influence the decision making analysis for the selection of sites for agricultural expansion? The answer is quite simple. If a project has no viability, it will be subject to failure. So when certain areas have favorable climate and soil conditions, the economic aspect ends up being a consequence. A project may become no longer economically viable depending on its location. If it is located in a region far away from the consumers, you will need a good logistic system that favors the flow of products, but you must consider that the production cost will be higher.

The presence of roads - both for domestic and international market - is extremely important to the flow of production, and to make the connection to ports. For the installation of distilleries would be interesting to have pipelines near to them,

and for sugarcane production roads or railroads (Figure A48). Before the recent expansion of sugarcane production, the vast majority of mills were mixed, producing both sugar and ethanol. A boom of new investment applied to distilleries has been observed since 2005 with the insertion of foreign capital for ethanol production. Currently, what has been noticed is that some distilleries began to deploy sugar mills to compensate the profitability when ethanol price is low in the market.

A.

	Roads	Railways	Ports	Pipelines
Roads		1.0	3.0	1.0
Railways			3.0	1.0
Ports				(3.0)
Pipelines	Incon: 0.00			

B.

Figure A48 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

The labor market in the Brazilian agricultural sector has required more and more people with a certain level of education. Schooling is essential for agriculture expansion (Figures A49 and A50), however what has been observed is that the level of education is still very low in Brazil. Having only primary school is not enough today. Higher is the education of the employees better is the performance of a business.

A.

	Age Structure	Education	Labor
Age Structure		(8.571)	(5.0)
Education			2.727
Labor	Incon: 0.02		

B.

Education	.654
Labor	.280
Age Structure	.065
Inconsistency = 0.02		

Figure A49 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

A.

	Elementary	High School	Major	No Education
Elementary		(1.821)	3.0	7.0
High School			3.643	10.2
Major				5.0
No Education	Incon: 0.03			

B.

High School	.495
Elementary	.321
Major	.144
No Education	.040
Inconsistency = 0.03		

Figure A50 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

The age range is also very important considering that child labor is not employed in agricultural activities anymore. Some agricultural activities require physical exertion, so workers should be between 18 and 44 (Figure A51).

A.

	Age 18-44	Age 44-49
Age 18-44		1.26
Age 44-49	Incon: 0.00	

B.

Age 18-44	.558
Age 44-49	.442
Inconsistency = 0.		

Figure A51 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

Interviewed P9

The first thing you should consider when making an investment is whether the project is economically viable or not. The success of a project depends on the edaphoclimatic conditions that have direct effect in the economic criterion. That is the reason why the economic criterion is so important (Figure A52). In relation to the social criterion, it is easier to train and educate people than to build infrastructure or improve environmental conditions.

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		4.0	(9.0)	3.0
Infrastructure			(9.0)	1.0
Economic				9.0
Social	Incon: 0.08			

B.

Economic	.737	
Edaphoclimatic	.149	
Social	.058	
Infrastructure	.055	

Figure A52 - A. Relative importance of the criteria for the selection of sites for sugarcane allocation. B. Priorities calculation and inconsistency of the results

Regarding transportation, if the production were directed to export market, areas with greater accessibility to ports should be prioritized (Figure A53). About roads, they are very important in any investment model. The others may vary with the type of project.

A.

	Roads	Railways	Ports	Pipelines
Roads		4.11	(3.57)	3.0
Railways			(5.0)	(3.0)
Ports				5.0
Pipelines	Incon: 0.09			

B.

Ports	.565	
Roads	.247	
Pipelines	.122	
Railways	.066	
Inconsistency = 0.09		

Figure A53 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

Age is almost irrelevant in sites selection for sugarcane expansion, particularly in the context of mechanization (Figure A54). Areas with employed people in agriculture, who already have experience in agricultural activities, would be better because of the difficulty in finding qualified employees to work.

A.

	Age Structu	Education	Labor
Age Structure		(13.0)	(9.0)
Education			2.708
Labor	Incon: 0.04		

B.

Education	.659	
Labor	.300	
Age Structure	.041	
Inconsistency = 0.04		

Figure A54 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

The age structure criterion is not part of a project viability assessment. So, there is no priority between individuals of the two groups (Figure A55).

A.

	Age 18-44	Age 44-49
Age 18-44		1.0
Age 44-49	Incon: 0.00	

B.

Age 18-44	.500	
Age 44-49	.500	
Inconsistency = 0.		

Figure A55 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

It is not expected to find qualified labor with high levels of education (Figure A56). Therefore, it is expected that this labor will need some type of training.

A.

	Elementary	High School	Major	No Education
Elementary		(2.929)	(3.143)	9.0
High School			1.0	20.5
Major				22.0
No Education	Incon: 0.00			

B.

Major	.425	
High School	.410	
Elementary	.147	
No Education	.018	
Inconsistency = 0.00321		

Figure A56 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

Interviewed P10

When deciding on an investment, the economic viability is the first factor to be evaluated. The project will or will not have a financial return? This decision is made based on the land suitability assessment for agricultural production. Thinking about the investment decision, the variables that affect the economic viability should be considered in any decision making.

The edaphoclimatic is more important than infrastructure. This is because if a chosen area for investment has appropriate infrastructure, but do not have edaphoclimatic suitability, the project may become economically unviable. Now, if the selected areas have edaphoclimatic suitability, but do not have adequate infrastructure, the project can still be successful. About the social aspect, it is a major limiting variable in all investment, and it is closely related to the economic criterion.

The lack of appropriate environmental conditions, sometimes, leads to an inappropriate economic return. On the other hand, the lack of infrastructure may or may not affect the economy. In fact, the composition of all factors affects the economic viability of a project. For an economic viability assessment it is required that lands have, at least, minimum physical land suitability to produce sugarcane. The edaphoclimatic criterion is limiting in the economical analysis, and therefore it is of crucial importance in selecting areas (Figure A57). If the physical land suitability had no importance in the economic viability assessment, sugarcane would be cultivated in Rio Grande do Sul.

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		3.538	1.095	9.2
Infrastructure			(3.727)	3.0
Economic				8.2
Social	Incon: 0.00			

B.

Figure A57 - A. Relative importance of the criteria for the selection of sites for sugarcane allocation. B. Priorities calculation and inconsistency of the results

The physical land suitability interferes tremendously in productivity. That explains why a sugarcane variety developed in São Paulo is not suited for Cerrado, which has different environmental conditions. The influencing factors are very unlike and diverse, but I think the main decision is to analyze whether the project is economically viable, and to be viable it has to have a combination of infrastructure, edaphoclimatic and social criteria.

The social criterion is also important in a project viability analysis. Even experts had already unsuccessful experiences, when the social aspect was not taken into consideration in the analysis. I can say that it was a significant learning curve that they faced. I participated in a project in Goiás, in a traditional region of livestock. When there was a party in the city people that worked in the mill did not go to work. Why? It was a cultural factor not showing to work on that occasion. It was part of their culture that was not taken into account in the analysis of investment.

Another example comes from a mill in São Paulo with tradition in agribusiness since 1953. The owners decided to create a project in Goiás. The built scenarios were quite optimistic in the project viability. Then, it was expected a quite successful economic return. As it was a new project, they had to buy brand new harvesters. They believed that the harvesters would yield much more there, since the terrain was flat, despite knowing that the production would be slightly lower in comparison to São Paulo due to the edaphoclimatic conditions. However, the land price much cheaper would compensate it. After three to four years, with the project already deployed, the harvesters had a crop yield much lower in Goiás compared to São Paulo, even though the machines were brand new, and the terrain had an excellent flat

topography. So, what was the cause of lack of success? It was the amount of harvesters' breakage there that was much greater than in São Paulo. This breakage has to do with the fact that workers, who operated the machines there, were part of the local labor that previously worked in livestock. These people did not have as much experience in operating harvesters as those in São Paulo. This created an economic loss that was not in the built scenarios. Why they did not predict the failure? It was because they underestimated the social factor in the economic viability assessment. Now, when you ask some mills owners, what is the biggest bottleneck for a fast agricultural growth in Brazil today, "is it the lack of money to invest"? "Is it the lack of infrastructure"? They will respond it is the lack of labor in sufficient quantity and quality. It is difficult to find qualified labors, considering that they have to be more qualified than they were 10, 15 years ago.

The social aspect has been the subject of significant complains by mill owners. I have acquired through my experiences that the social aspect did not have as much importance as it should have in project viability. I can say that it was a significant learning curve from those projects in the past, because nobody thought about it. In a certain way, some mill owners have learned from their mistakes. Today, mill owners and experts are already aware of the importance of social factors, especially cultural and educational.

Brazil suffers from shortage of skilled labor, which is considered an obstacle for investors. Therefore, to go to Goiás and set up a project in a region that is not traditional in the production of sugar and ethanol brought an economic return much slower than ever imagined by agricultural consultants, considering that the labor was far less qualified there. Mills needed to create infrastructure to bring workers from other parts of the country and train local workers, which had a direct effect in the production cost.

About transportation, what type of transport would be more important in the agricultural expansion context? A multimodal transport would be ideal. However, in the Brazilian transportation scenario, road is the type of transport that is the most important among all (Figure A58). This transportation mode has several carriers, which increases the range of accessibility. So, the business is not locked into a single carrier. Besides, the mills can even have their own truck fleet, which represents other alternative for transportation.

A.

	Roads	Railways	Ports	Pipelines
Roads		2.0	1.0	2.0
Railways			(2.0)	(2.0)
Ports				1.0
Pipelines	Incon: 0.02			

B.

Roads	.340	
Ports	.281	
Pipelines	.239	
Railways	.140	
Inconsistency = 0.02		

Figure A58 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

In general, mills have two means of transport (roads and railroads). Some mills prefer to sign a contract with railroad, but they have the option to use roads as well. Sometimes roads are even a little bit cheaper than railroads. Of course we have to consider that with the new truck driver law that requires mandatory rest period for truck drivers, it is expected to have an increase in the shipping price for agricultural products. Anyway, if the mills did not have the option to transport their products through roads, the transport via railroads would be even more expensive because the railroads carrier would charge a lot more, since it would be the only transportation mode available in the area.

I think if I had to compare roads and ports, which one would weigh more in a decision making analysis, I would say, ideally, ports are moderately more important than roads. However, what happens is ports are not taken into consideration in sites selection. This is because areas near to ports are much more expensive and, in general, are areas already occupied. Mills have expanding their areas toward Goiás because that state has more lands available for expansion than São Paulo. Actually, everything is a tradeoff, depending on the production cost at each location. Accessibility to ports should not be considered as a determining factor in sites selection. Otherwise, most of the potential areas for expansion would be unfeasible.

The option to transport ethanol by pipelines would reduce the shipping cost considerably, even knowing that pipelines cannot transport sugar. It is a fact that pipelines represent a promising future for ethanol, however a decision making

analysis cannot be based only on a single type of transport. Again, the ideal is to have a multimodal transport.

It would be much better to have more qualified labor where the mills are installed. In some locations such as in Goiás, labor is, in general, not so qualified, which means that mill owners have to hire workers from other parts of the country. What happens is, sometimes, those people do not adapt in those places. We also have been observing employers substituting large contingents of workers with elementary school by people with high school because education is very important in the agribusiness sector.

Manual harvesting has been replaced by mechanized harvesting. Employees who will operate computerized and very expensive machines have replaced manual cultivators. Mills are heavily investing in precision agriculture and in their workers to improve their knowledge. Thus, the higher is the level of education the better is the ability of that individual to adapt to new technologies.

Illiterates are a major social problem in Brazil. How are they going to be incorporated into the modern technological world? They will be completely rejected in the labor market if they do not adapt to the new market conditions. The individual who has primary education will also find difficulty in remaining competitive in the market.

Age has no importance in the decision making process for sugarcane allocation (Figure A59). How about employed people in the agriculture? The question is: educate this labor or select more educated workers than those already employed? Let's think about the two alternatives. I think that labor has stronger importance than education (Figure A60). Although that labor is less educated, they have a good experience on farming. Educate this labor or improve it is a very important factor today.

A.

	Age 18-44	Age 44-49
Age 18-44		3.0
Age 44-49	Incon: 0.00	

B.

Age 18-44	.750	
Age 44-49	.250	
Inconsistency = 0.		

Figure A59 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

A.

	Age Structure	Education	Labor
Age Structure		(9.0)	(8.0)
Education			(2.0)
Labor	Incon: 0.07		

B.

Labor	.571	
Education	.374	
Age Structure	.054	
Inconsistency = 0.07		

Figure A60 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

Mill owners are hiring workers that are already in the market and train them, but education is still a major factor. To be absorbed by the labor market, workers need to have some type of education (Figure A61). They must have some basis such as to know how to read, to do math, to learn how to operate a GPS and to identify problems in the harvesters.

A.

	Elementary	High School	Major	No Education
Elementary		(4.545)	(3.182)	3.667
High School			1.767	17.667
Major				7.0
No Education	Incon: 0.01			

B.

High School	.550	
Major	.302	
Elementary	.113	
No Education	.035	
Inconsistency = 0.01		

Figure A61 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

3.3 Individual comments regarding the judgments of soybean specialists

Interviewed E1

Lands with poor infrastructure but with agricultural suitability are still viable for farming if the shipping cost were favorable. However an area with good infrastructure but with no suitability for crop production becomes unviable. According to the interviewed, the comparison between the edaphoclimatic and the economic criteria is complex. After all, their priority depends on the capital available for investment, whether the capital is venture or conservative considering a high or low interest rate. If there is ample liquidity in the market and the capital available for investment is a venture capital, the edaphoclimatic factors will tend to be prioritized in selecting areas for agricultural expansion. On the other hand, if the investment is conservative, the physical land suitability will not be prioritized because the expansion can be directed to areas of low productivity for the reason that, considering the type of capital, it is known what will be the return on investment.

Edaphoclimatic and economic criteria may also have equal importance. Let me provide you with an example, the specialist says. In 2007 there was ample availability of credit in Brazil and abroad. Investors bought lands for agricultural production and were given preference to those with high agricultural suitability. After that period, the interest rates increased and the market became a little more conservative. In this scenario of ample liquidity, producers were investing even in lands of low suitability such as those of western of São Paulo, since the lands had

minimum conditions for agricultural production. Therefore, the importance of those variables is defined by the market rules. However, if I had to rank the variables in a context of agricultural expansion, I would say that the edaphoclimatic is the most important variable to be considered in a decision making analysis (Figure A62).

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		1,606	5,273	19,333
Infrastructure			3,3	11,0
Economic				7,0
Social	Incon: 0,02			

B.

Figure A62 - A. Relative importance of the criteria for the selection of sites for soybean allocation. B. Priorities calculation and inconsistency of the results

In the soybean production context, the labor is not so important. That is because the production is a capital-intensive activity, land intensive, but not labor intensive. A few employees are necessary, and workers can be brought from other regions whenever they are needed. Taking a close look on the variables, I would say that the edaphoclimatic factors are still more important than the other criteria.

Transport is more important than facilities (Storage and soybean crushing industry) (Figure A63).

A.

	Transport	Facilities
Transport		6,0
Facilities	Incon: 0,00	

B.

Figure A63 - A. Relative importance of the subcriteria in relation to infrastructure. B. Priorities calculation and inconsistency of the results

Railroads can have a cheaper shipping cost, but ports are more important in terms of logistics (Figure A64).

A.

	Roads	Railways	Ports
Roads		(2,909)	(3,0)
Railways			(1,781)
Ports	Incon: 0,03		

B.

Figure A64 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

Both storage and soybean crushing industry have the same importance (Figure A65).

A.

	Storage	Mills
Storage		1,0
Mills	Incon: 0,00	

B.

Figure A65 - A. Relative importance of the subcriteria in relation to facilities. B. Priorities calculation and inconsistency of the results

The age is not so important for the soybean agribusiness. However is necessary that workers, who work with machines, have physical health and some type of education. Higher education is not so important, only for those working in offices, but not for those working directly in the field (Figures A66, A67 and A68).

A.

	Age Structure	Education
Age Structure		(1,55)
Education	Incon: 0,00	

B.

Education	,608	<div></div>
Age Structure	,392	<div></div>
Inconsistency = 0,		

Figure A66 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

A.

	Ages between 18-44	Ages between 44-49
Ages between 18-44		3,0
Ages between 44-49	Incon: 0,00	

B.

Ages between 18-44	,750	<div></div>
Ages between 44-49	,250	<div></div>
Inconsistency = 0,		

Figure A67 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

A.

	Elementary	High School	Major	No Education
Elementary		(5,0)	(3,0)	7,0
High School			5,0	9,0
Major				9,0
No Education	Incon: 0,16			

B.

High School	,610	<div></div>
Major	,232	<div></div>
Elementary	,125	<div></div>
No Education	,033	<div></div>
Inconsistency = 0,16		

Figure A68 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

Interviewed E2

What we have seen in many Brazilian states is a plenty amount of grazing areas and considerable parts of them are degraded. Those lands are still cheap. However there is no advancement of the agricultural frontier to those areas. Why?

The answer to this question is related to soil limitations that prevent the advancement of the agricultural frontier toward degraded pasturelands. For this reason the edaphoclimatic variable is limiting for agricultural expansion. If a certain area does not have favorable edaphoclimatic conditions for agricultural production, it becomes unviable to support an expansion. The edaphoclimatic is the most important variable to take into consideration in an economic analysis of projects (Figure A69).

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		7,0	5,0	9,0
Infrastructure			(2,0)	7,0
Economic				7,0
Social	Incon: 0,13			

B.

Figure A69 - A. Relative importance of the criteria for the selection of sites for soybean allocation. B. Priorities calculation and inconsistency of the results

The economic variable is more important than infrastructure. Taking Mato Grosso as an example, when trading companies and farmers settled there, there were no roads, not even minimum infrastructure necessary for agricultural production. However, there were favorable edaphoclimatic conditions and that was what mattered to the producers. In some places the infrastructure still has not got there. The roads are bad and often unpaved, directly impacting the production and the profitability of producers, but not enough to derail agricultural production down. The infrastructure, in this particular case, ends up not being a limiting factor.

The variable infrastructure is very sensitive to international, national crisis, etc. In stable and optimistic scenarios, the infrastructure issue can be solved because the producers and the government can find alternatives for the transport of agricultural production. On the other hand, in a crisis scenario, the presence of infrastructure becomes crucial. Let me explain how that works. A falling of commodity prices marked 2004, 2005 and 2006. These years were very unfavorable to soybean and

corn production for the two major producing states Paraná and Mato Grosso. In Paraná, profit margins at some point remained stable moving to a lower range, and in Mato Grosso they were negative. The negative margins were a reflection of the logistical conditions available in the state. The distance from Mato Grosso to the main consumption centers and ports for exportations is 3 to 4 times bigger than from Paraná. If Mato Grosso had had adequate infrastructure such as access to ports, railroads, not only poor roads, the state would not have been so affected by the crisis. Today we need to auction corn in Mato Grosso considering that it is not feasible to export the production with the current freight rates.

Infrastructure and economic criteria are important, but they are not limiting for agricultural development. There are alternatives for the lack of them. In relation to the social criterion, it has practically no importance in the agricultural expansion context. In many agricultural expansion areas, workers are brought from other regions.

Facilities are more important than transport (Figure A70). It is more important to have storage before, do business with producers, and then think about the logistics after. The order of importance would be that.

A.

	Transport	Facilities
Transport		(2,0)
Facilities	Incon: 0,00	

B.

Facilities	,667	
Transport	,333	
Inconsistency = 0,		

Figure A70 - A. Relative importance of the subcriteria in relation to infrastructure. B. Priorities calculation and inconsistency of the results

Roads are still the most important mode of transportation (Figure A71), and also a way to connect with other modal. In some areas they are the only way to transport the agricultural products.

A.

	Roads	Railways	Ports
Roads		3,0	2,0
Railways			(3,0)
Ports	Incon: 0,05		

B.

Roads	,528	
Ports	,333	
Railways	,140	
Inconsistency = 0,05		

Figure A71 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

The storages are more important than the soybean crushing industry (Figure A72). The producers hardly negotiate directly with the industry. They negotiate with the storage and the storage with the industry. In general, the producers do not participate in the negotiation.

A.

	Storage	Mills
Storage		2,0
Mills	Incon: 0,00	

B.

Storage	,667	
Mills	,333	
Inconsistency = 0,		

Figure A72 - A. Relative importance of the subcriteria in relation to facilities. B. Priorities calculation and inconsistency of the results

Agriculture in Brazil walks toward the increasing use of modern technology in the field. So, there is a constant need for new training, courses, and insertion of new technologies. Thus, it is easier when you offer such professional training to workers that have a higher educational level. That is the reason why I consider a higher level of education more important than age structure (Figure A73).

A.

	Age Structure	Education
Age Structure		(2,0)
Education	Incon: 0,00	

B.

Education	,667
Age Structure	,333
Inconsistency = 0,		

Figure A73 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

There difference is not so substantial between the two ages group (Figure A74). The age does not influence much in selecting labor.

A.

	Ages between 18-44	Ages between 44-49
Ages between 18-44		1,49
Ages between 44-49	Incon: 0,00	

B.

Ages between 18-44	,598
Ages between 44-49	,402
Inconsistency = 0,		

Figure A74 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

The type of work required by the agriculture today is a more skilled labor. There is a preference for workers with higher educational level even for fieldwork (Figure A75). High school education is already a good level. But it would be better to invest in a region with a more qualified labor because it would be easier to incorporate new technologies there.

A.

	Elementary	High School	Major	No Education
Elementary		(9,0)	(5,0)	5,0
High School			(3,0)	9,0
Major				9,0
No Education	Incon: 0,19			

B.

Figure A75 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

Interviewed E3

The edaphoclimatic is more important than the other variables because it is limiting (Figure A76). It is the combination of the physical land suitability and land prices that will determine the economic viability of a business and their impact over the allocation of investments. However, the edaphoclimatic is the variable that will delimit areas of higher or lower suitability for soybean production what makes any economic model more sensitive to it. With regard to infrastructure, soybean expands to places without it at first, so this variable ends up not being a limiting factor. Infrastructure is aggregative value, minimize costs and enhance results, but it has much lesser influence than the edaphoclimatic on soybean allocation. Concerning the economic variable, I would say, it is preferable to have a technical knowledge to base an investment than to have a production history of these areas. Now, some producers will give you an opposite answer.

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		9,0	2,0	9,0
Infrastructure			(5,0)	3,0
Economic				7,0
Social	Incon: 0,05			

B.

Figure A76 - A. Relative importance of the criteria for the selection of sites for soybean allocation. B. Priorities calculation and inconsistency of the results

In practice, the agricultural frontier regions, where soybean is expanding, are areas with lack of skilled labor. Regions with a better social aspect do not have much influence on sites selection for soybean expansion because workers are mobile and can be easily hired from other regions, i.e., they migrate, and others can be trained, but the edaphoclimatic conditions are fixed, they do not migrate. We end up having to import professionals from other places. Logically, as the social aspect of the regions improves we get benefits from it. And soybean is the type of crop that provides technological and human development. It is not only soybean but also the agriculture as a whole. In one of our farms in Piauí for example, we adopted a rural community school near to it. This is a way to promote the development of the social aspect in the region.

The infrastructure has also influence on the selection of areas due to its impact on the costs and the revenue deductions. The cost is slightly smaller when better are the transport and the facilities. Depending on the scale of production, the farm itself builds its own storage. But if a small farm cannot build its own facilities, their presence becomes crucial. For large producers, facilities are not reason for much concern. They do not need soybean crushing industry, or even storages, because they store their own product. Therefore, facilities' priority depends somewhat on the scale. In actuality, what farmers need are good roads, nearby railroads and efficient ports. The transportation infrastructure always has an important weight. However, when taking the scale into account, the dependence on

facilities can be either insignificant or extremely important. Mathematically speaking, I would say that transportation and facilities have the same weight (Figure A77).

A.

	Transport	Facilities
Transport		1,0
Facilities	Incon: 0,00	

B.

Figure A77 - A. Relative importance of the subcriteria in relation to infrastructure. B. Priorities calculation and inconsistency of the results

There is a tendency for lands near to ports to become more expensive, however this cannot be generalized. There are areas in Mato Grosso today that cost 20,000 Reais per hectare, and they are 2,000 km away from the port. On the other hand, there are areas in Maranhão, which the land cost varies between 4,000 to 5,000 Reais per hectare, and they are 500 to 600 km away from the Port of Itaqui in São Luis. In this circumstance, I 'm not going to choose an area considering their proximity to ports. I 'm choosing them regarding the price of land. Now, if you ask me, which land would be better for investments, those near to ports or with a better road? Suppose I have an area for investment, which is close to Ponta Grossa in Paraná. The area is 200 km away from the Port of Paranaguá by unpaved road. We have to take into consideration the fact that this area is close to the port, but far from an efficient road network. On the other hand, the other area in Mato Grosso, which is 2,000 km from the Port of Paranaguá, is very close to paved road network. If I had to choose between the two areas to make an investment, I would rather invest in the area near to Ponta Grossa. Why? It is because freight has more impact in the soybean production. Using a reference value of 0.12 cents ton/km traveled on paved roads, and 0.15 to 0.18 cents ton/km traveled in precarious road, I would say there is a big difference if the area to be invested is 200 km or 2,000 km away from the port. The impact of a good or precarious road network is much smaller than the distance in this case. So, the proximity to ports is what mostly will impact on transportation costs

and on the final price of soybean. That is the reason why the transportation accessibility is so important in the soybean expansion planning (Figure A78).

A.

	Roads	Railways	Ports
Roads		(2,0)	(9,0)
Railways			(9,0)
Ports	Incon: 0,05		

B.

Ports	,814	
Railways	,114	
Roads	,072	
Inconsistency = 0,05		

Figure A78 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

The soybean crushing industries are more important than the storages (Figure A79). We should consider that the crushing industries are also storages. The point is that the industry has a demand for soybean, so the guarantee of a demand is much higher when there is a soybean crushing industry nearby. Storage can store more or less soybean throughout the year. The industry will always consume soybean because of the necessity to keep it working. Therefore, it is better to have a consumer center than a warehouse nearby.

A.

	Storage	Mills
Storage		(2,0)
Mills	Incon: 0,00	

B.

Mills	,667	
Storage	,333	
Inconsistency = 0,		

Figure A79 - A. Relative importance of the subcriteria in relation to facilities. B. Priorities calculation and inconsistency of the results

The educational level is more important than age (Figure A80). It is not so visible a drastic change in the agricultural profits related to age structure, i.e., there is no significant difference in the capacity of a young or an older individual when we

compare it to the educational level. There is always a preference for hiring workers with better education than hiring workers based on their age group.

A.

	Age Structure	Education
Age Structure		(99,0)
Education	Incon: 0,00	

B.

Figure A80 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

There is no distinction to be made between age groups (Figure A81).

A.

	Ages between 18-44	Ages between 44-49
Ages between 18-44		1,0
Ages between 44-49	Incon: 0,00	

B.

Figure A81 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

A higher level of education is very important (Figure A82). The higher the educational level the better is to train that individual.

A.

	Elementary	High School	Major	No Education
Elementary		(3,0)	(9,0)	13,0
High School			(2,0)	27,0
Major				57,0
No Education	Incon: 0,02			

B.

Figure A82 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

Interviewed E4

The edaphoclimatic is the most important variable in the selection of sites for agricultural expansion considering that some areas in Brazil have physical restrictions for soybean cultivation (Figure A83). In my view there is no point having an excellent infrastructure in a certain area, if there is no physical conditions for agricultural production. Now, if an area has feasible physical land suitability but no infrastructure, it is just a matter of time to start building it.

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		1,2	2,0	5,333
Infrastructure			1,65	4,286
Economic				2,5
Social	Incon: 0,00			

B.

Figure A83 - A. Relative importance of the criteria for the selection of sites for soybean allocation. B. Priorities calculation and inconsistency of the results

Transportation is more important than facilities (Figure A84). Accordingly, it is better to have road in good condition to transport the production than to have

storage. There is a lack of storage in Mato Grosso, and we suffer with the lack of roads in Maranhão. The presence of good roads has a higher priority over storages.

A.

	Transport	Facilities
Transport		1,47
Facilities	Incon: 0,00	

B.

Figure A84 - A. Relative importance of the subcriteria in relation to infrastructure. B. Priorities calculation and inconsistency of the results

Ports are the most important variable in the transportation infrastructure criterion (Figure A85). It would be very strategic to invest in areas near to ports. Railroads are also important.

A.

	Roads	Railways	Ports
Roads		(2,0)	(4,615)
Railways			(2,4)
Ports	Incon: 0,00		

B.

Figure A85 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

Education is more important than age structure due to the necessity of a more skilled workforce (Figure A86). Age does not have much influence on the selection of workers, but education does (Figure A87). There is no advantage in having young people without much training. A better education is very important (Figure A88).

A.

	Age Structure	Education
Age Structure		(2,0)
Education	Incon: 0,00	

B.

Education	,667	
Age Structure	,333	
Inconsistency = 0,		

Figure A86 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

A.

	Ages between 18-44	Ages between 44-49
Ages between 18-44		1,25
Ages between 44-49	Incon: 0,00	

B.

Ages between 18-44	,556	
Ages between 44-49	,444	
Inconsistency = 0,		

Figure A87 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

A.

	Elementary	High School	Major	No Education
Elementary		(2,0)	(2,0)	4,0
High School			(2,0)	4,0
Major				6,0
No Education	Incon: 0,03			

B.

Major	,445	
High School	,288	
Elementary	,203	
No Education	,064	
Inconsistency = 0,03		

Figure A88 - A. Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

Interviewed E5

Regarding soybean production, I can say that lands are scarce for soybean expansion in the country. Therefore, the physical land suitability is more important than the other variables (Figure A89). The physical conditions are considered a

limiting factor, besides that they are directly related to the economic return on an investment. The social aspect is also very important given that an agricultural expansion requires trained labor in all operational levels able to work with modern technology, which is very difficult to find in agricultural frontier regions.

A.

	Edaphoclimatic	Infrastructure	Economic	Social
Edaphoclimatic		5,0	2,0	2,0
Infrastructure			(3,0)	(2,0)
Economic				1,0
Social	Incon: 0,01			

B.

Figure A89 - A. Relative importance of the criteria for the selection of sites for soybean allocation. B. Priorities calculation and inconsistency of the results

Transportation infrastructure is more important than facilities as transport depends more on government investment than facilities does (Figure A90). Issues related to the scarcity of facilities can be easily solved through the construction of silos on the farms.

A.

	Transport	Facilities
Transport		2,0
Facilities	Incon: 0,00	

B.

Figure A90 - A. Relative importance of the subcriteria in relation to infrastructure. B. Priorities calculation and inconsistency of the results

Ports are the most important mode of transport because they are very strategic for soybean transportation considering its low shipping cost (Figure A91).

A.

	Roads	Railways	Ports
Roads		(2,0)	(4,0)
Railways			(2,0)
Ports	Incon: 0,00		

B.

Figure A91 - A. Relative importance of the subcriteria in relation to transport. B. Priorities calculation and inconsistency of the results

Storages are more important than soybean crushing industry (Figure A92). First we should think about having close access to the storage, and after about having the industry.

A.

	Storage	Mills
Storage		2,0
Mills	Incon: 0,00	

B.

Figure A92 - A. Relative importance of the subcriteria in relation to facilities. B. Priorities calculation and inconsistency of the results

Education is more important than age structure because of the skills required in the soybean production (Figure A93).

A.

	Age Structure	Education
Age Structure		(2,0)
Education	Incon: 0,00	

B.

Figure A93 - A. Relative importance of the subcriteria in relation to the social criterion. B. Priorities calculation and inconsistency of the results

A younger age group is better to work with (Figure A94). That is the reason for its preference. They are easy to teach, and they tend to have a better interactivity in regard to the demands of work that is needed.

A.

	Ages between 18-44	Ages between 44-49
Ages between 18-44		1,5
Ages between 44-49	Incon: 0,00	

B.

Figure A94 - A. Relative importance of the subcriteria in relation to age structure. B. Priorities calculation and inconsistency of the results

Workers with a higher education are needed in the soybean production activities, but those with at least a high school diploma are so far enough (Figure A95). In all of our farms we have teaching programs for workers, especially the functionally illiterate ones, in an attempt to eradicate illiteracy.

A.

	Elementary	High School	Major	No Education
Elementary		(5,0)	(5,0)	6,5
High School			3,0	26,5
Major				15,5
No Education	Incon: 0,05			

B.

Figure A95 - Relative importance of the subcriteria in relation to education. B. Priorities calculation and inconsistency of the results

APPENDIX B

Table B1 - Data characterization on land use

Biome	Source	Date	Format	Scale
Caatinga	MMA - PROBIO - APNE	2002	Shapefile - Mosaic	1:250000
Cerrado	MMA - PROBIO - FAGRO - EMBRAPA CERRADOS	2002	Shapefile - 402 p.	1:250000
Mata Atlântica	MMA - PROBIO - IESB	2002	Shapefile - Mosaic	1:250000
Pampa	MMA - PROBIO - UFRGS	2002	Shapefile - Mosaic	1:250000
Pantanal	MMA - PROBIO - EMBRAPA INFORMÁTICA AGROP.	2002	Shapefile - Mosaic	1:250000
Amazônico	MMA - PROBIO - FUNCATE	2002	Shapefile - Mosaic	1:250000
	PRODES -INPE	2000-2007	GeoTiff	60m x 60m
	DETER - INPE	04/30/08	Shapefile - Mosaic	25 ha
	SAD - IMAZON Geo	Jul-08	Shapefile - Mosaic	6.25 ha

Table B2 - Evaluation parameters and weights of the criteria used in the MCDA for sugarcane allocation

Indicator	Parameters	Judgment Weights (% Influence)										Combined
		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	
Edaphoclimatic		39.70	31.90	32.10	37.40	10.20	51.10	55.00	44.30	14.90	42.90	37.70
Infrastructure		27.50	16.70	28.40	30.00	29.00	30.20	13.00	28.80	5.50	12.20	22.90
Transport		22.91	14.61	14.20	15.00	14.50	22.65	6.50	23.99	2.75	1.35	13.81
Roads (km)	1=>50; 2=50; 3=10; 4=5; 5=3	8.93	6.09	1.22	2.61	0.61	11.89	0.34	7.20	0.68	0.46	3.25
Railroads (km)	1=>100; 2=100; 3=30; 4=15; 5=3	1.56	0.63	4.73	4.77	2.41	4.76	3.07	7.20	0.18	0.19	2.79
Ports (km)	1=>1000; 2=1000; 3=250; 4=100; 5=20	3.48	3.45	4.13	4.14	3.76	5.16	0.99	2.40	1.55	0.38	3.88
Pipelines (km)	1=>150; 2=150; 3=30; 4=10; 5=5	8.93	4.43	4.13	3.50	7.73	0.82	2.11	7.20	0.34	0.32	3.91
Facilities		4.59	2.09	14.20	15.00	14.50	7.55	6.50	4.81	2.75	10.85	9.09
Mills (km)	1=>100; 2=100; 3=35; 4=15; 5=5	4.59	2.09	14.20	15.00	14.50	7.55	6.50	4.81	2.75	10.85	9.09
Economic		14.00	39.40	32.10	21.60	57.60	6.60	25.10	9.80	73.70	40.40	29.40
Value of Production (R\$ 1,000)	1=10; 2=30; 3=70; 4=430; 5=96,900	14.00	39.40	32.10	21.60	57.60	6.60	25.10	9.80	73.70	40.40	29.40
Social		18.80	12.00	7.40	11.10	3.20	12.10	6.80	17.10	5.80	4.50	10.00
Age Structure		6.22	0.66	1.44	4.44	0.84	1.03	1.07	1.11	0.24	0.24	1.46
Age 18-44 (%)	1=86; 2=88; 3=89; 4=91; 5=94	5.60	0.33	1.26	2.96	0.63	0.90	0.80	0.62	0.12	0.18	1.08
Age 44-49 (%)	1=11; 2=12; 3=14; 4=16; 5=27	0.62	0.33	0.18	1.48	0.21	0.13	0.27	0.49	0.12	0.06	0.38
Education		3.29	3.48	0.65	2.22	1.92	8.86	4.04	11.18	3.82	1.68	4.33
Elementary (%)	1=31; 2=38; 3=44; 4=54; 5=84	1.74	1.11	0.15	0.64	0.27	1.12	1.34	3.59	0.56	0.19	1.09
High School (%)	1=9; 2=10; 3=12; 4=13; 5=30	0.85	1.93	0.22	1.03	0.48	4.19	1.83	5.54	1.57	0.93	1.97
Major (%)	1=2; 2=3; 3=4; 4=5; 5=16	0.22	0.35	0.22	0.34	1.11	3.00	0.70	1.61	1.62	0.51	1.03
No Education (%)	1=5; 2=7; 3=12; 4=20; 5=38	0.48	0.08	0.07	0.21	0.07	0.54	0.17	0.45	0.07	0.06	0.23
Labor (%)	1=1; 2=6; 3=11; 4=20; 5=365	9.27	7.86	5.31	4.44	0.44	2.21	1.69	4.79	1.74	2.57	4.20
Kendall's W		0.50	0.62	0.60	0.68	0.41	0.55	0.71	0.65	0.54	0.67	0.53
Level of Significance		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table B3 - Multiple linear regression equations for the independent variables longitude, latitude and altitude of the stations to estimate monthly average temperature by zones
(continue)

Month	Zone 1	Zone 2	Zone 3	Zone 4
	Latitude and longitude (degree) and altitude (meters)			
Jan	$y=44.11-0.010443*\text{lat}-0.006673*\text{alt}$	$y=14.23+0.003549*\text{long}-0.005266*\text{alt}$	$y=26.506461-0.000005*\text{alt}^2-1.265956$	$y=26.506461-0.000005*\text{alt}^2$
Feb	$y=42.46-0.009752*\text{lat}-0.006492*\text{alt}$	$y=17.24+0.002449*\text{long}-0.0052*\text{alt}$	$y=26.506461-0.000005*\text{alt}^2-1.265956$	$y=26.506461-0.000005*\text{alt}^2$
Mar	$y=41.8-0.010305*\text{lat}-0.006062*\text{alt}$	$y=24.28-0.000205*\text{long}-0.005278*\text{alt}$	$y=26.506461-0.000005*\text{alt}^2-1.265956$	$y=26.506461-0.000005*\text{alt}^2$
Apr	$y=34.8-0.008464*\text{lat}-0.00497*\text{alt}$	$y=33.93-0.005234*\text{long}-0.005234*\text{alt}$	$y=34.664048-0.513316*\text{lat}-0.000005*\text{alt}^2$	$y=34.664048-0.513316*\text{lat}-0.000005*\text{alt}^2$
May	$y=31.85-0.00854*\text{lat}-0.004462*\text{alt}$	$y=34.38-0.005368*\text{long}-0.005379*\text{alt}$	$y=36.156325-0.644805*\text{lat}-0.005172*\text{alt}$	$y=36.156325-0.644805*\text{lat}-0.005172*\text{alt}$
Jun	$y=34.32-0.011195*\text{lat}-0.004066*\text{alt}$	$y=29.49-0.00427*\text{long}-0.005322*\text{alt}$	$y=33.822532-0.680707*\text{lat}-0.000004*\text{alt}^2$	$y=33.822532-0.680707*\text{lat}-0.000004*\text{alt}^2$
Jul	$y=32.65-0.010495*\text{lat}-0.003864*\text{alt}$	$y=32.04-0.005482*\text{long}-0.004816*\text{alt}$	$y=33.822532-0.680707*\text{lat}-0.000004*\text{alt}^2$	$y=33.822532-0.680707*\text{lat}-0.000004*\text{alt}^2$
Aug	$y=40.29-0.014063*\text{lat}-0.004248*\text{alt}$	$y=22.78-0.002088*\text{long}-0.004338*\text{alt}$	$y=38.260611-0.871328*\text{lat}+0.003221*\text{alt}-0.000006*\text{alt}^2+0.7222$	$y=38.260611-0.871328*\text{lat}+0.003221*\text{alt}-0.000006*\text{alt}^2$
Sep	$y=45.06-0.015784*\text{lat}-0.004725*\text{alt}$	$y=14.94+0.001034*\text{long}-0.004449*\text{alt}$	$y=41.940204-0.908572*\text{lat}-0.004171*\text{alt}+1.044569$	$y=41.940204-0.908572*\text{lat}-0.004171*\text{alt}$
Oct	$y=47.06-0.015651*\text{lat}-0.005501*\text{alt}$	$y=11.29+0.004708*\text{long}-0.004708*\text{alt}$	$y=38.074965-0.652347*\text{lat}-0.000005*\text{alt}^2+0.057348$	$y=38.074965-0.652347*\text{lat}-0.000005*\text{alt}^2$
Nov	$y=48.52-0.014888*\text{lat}-0.006176*\text{alt}$	$y=5.69+0.005342*\text{long}-0.004799*\text{alt}$	$y=26.811993-0.000005*\text{alt}^2-2.289133$	$y=26.811993-0.000005*\text{alt}^2$
Dec	$y=46.16-0.012304*\text{lat}-0.006311*\text{alt}$	$y=6.7+0.005644*\text{long}-0.005057*\text{alt}$	$y=19.902931+0.126868*\text{long}-0.000005*\text{alt}^2-1.509252$	$y=19.902931+0.126868*\text{long}-0.000005*\text{alt}^2$
Annual	$y=40.46-0.011661*\text{lat}-0.005246*\text{alt}$	$y=20.6-0.000087*\text{long}-0.004989*\text{alt}$	$y=33.479962-0.473747*\text{lat}-0.000005*\text{alt}^2$	$y=33.479962-0.473747*\text{lat}-0.000005*\text{alt}^2$

Table B3 - Multiple linear regression equations for the independent variables longitude, latitude and altitude of the stations to estimate monthly average temperature by zones
(conclusion)

Month	Zone 5	Zone 6	Zone 7	Zone 8
Latitude and longitude (degree) and altitude (meters)				
Jan	$y=25.4922-0.186151*lat+0.112997*long-0.00560437*alt$	$y=27.4163-0.0018177*lat+0.00054168*long-0.0058556*alt$	$y=-25.9924-0.00513*lat^2-2.67684*long-0.03354*long^2-0.000006*alt^2$	$y=26.3565+0.0489*lat-0.0004*long-0.0064*alt$
Feb	$y=26.5073-0.18557*lat+0.0914547*long-0.0055381*alt$	$y=27.5197-0.0006285*lat-0.00005155*long-0.0059595*alt$	$y=26.34049-0.000006*alt^2$	$y=22.9491+0.0081*lat-0.0534*long-0.0055*alt$
Mar	$y=24.5729-0.262232*lat+0.156385*long-0.00544252*alt$	$y=28.224-0.00173932*lat-0.00006055*long-0.00589032*alt$	$y=26.32828-0.000006*alt^2$	$y=24.2764-0.0462*lat-0.0308*long-0.006*alt$
Apr	$y=23.8086-0.46015*lat+0.221168*long-0.00509255*alt$	$y=28.371-0.00347634*lat-0.00000128*long-0.00579838*alt$	$y=33.81864+2.04365*lat-0.00392*long^2-0.00589*alt+0.04897*lat*long$	$y=26.6495-0.0437*lat+0.0082*long-0.0063*alt$
May	$y=22.8704-0.552452*lat+0.22967*long-0.0046566*alt$	$y=28.9292-0.00309112*lat-0.00124306*long-0.00574797*alt$	$y=24.51485-0.03856*lat-0.0062*alt+0.01487*lat*long$	$y=25.9785-0.0934*lat-0.0034*long-0.0065*alt$
Jun	$y=22.6165-0.63349*lat+0.218271*long-0.00480673*alt$	$y=25.3831-0.00353616*lat-0.00012449*long-0.00598387*alt$	$y=24.46099-0.0391*lat^2-0.00673*alt+0.01339*lat*long$	$y=25.679-0.0203*lat-0.0126*long-0.0071*alt$
Jul	$y=19.1005-0.641427*lat+0.320528*long-0.00509414*alt$	$y=23.3989-0.00335117*lat+0.000376175*long-0.00617636*alt$	$y=27.7085+1.4875*lat-0.0064*alt+0.02993*lat*long$	$y=24.9309-0.0087*lat-0.0271*long-0.0073*alt$
Aug	$y=12.5133-0.628241*lat+0.493722*long-0.0049308*alt$	$y=19.1678-0.00332503*lat+0.002464*long-0.00623187*alt$	$y=36.16463+4.08316*lat-0.00459*long^2+0.00017*alt*lat+0.09392*lat*long$	$y=21.1802+0.004*lat-0.1115*long-0.0059*alt$
Sep	$y=15.1033-0.688942*lat+0.510375*long-0.00513752*alt$	$y=22.6133-0.00567717*lat+0.0028432*long-0.00592896*alt$	$y=40.52614+4.83384*lat-0.00667*long^2-0.00696*alt+0.11274*lat*long$	$y=22.4018-0.0368*lat-0.0915*long-0.0077*alt$
Oct	$y=18.8003-0.624257*lat+0.431918*long-0.00550874*alt$	$y=26.4312-0.00845717*lat+0.00322588*long-0.00590571*alt$	$y=-54.51334-0.01407*lat^2-3.87154*long-0.04503*long^2-0.000006*alt^2$	$y=21.9537+0.0913*lat-0.1114*long-0.0069*alt$
Nov	$y=19.9533-0.392559*lat+0.307999*long-0.00544291*alt$	$y=27.5998-0.00787031*lat+0.00277384*long-0.00600977*alt$	$y=-68.59439-0.01385*lat^2-4.68628*long-0.05634*long^2-0.000006*alt^2$	$y=22.4456+0.0856*lat-0.0942*long-0.0055*alt$
Dec	$y=22.8347-0.247034*lat+0.184212*long-0.00546014$	$y=27.0979-0.00482634*lat+0.00177331*long-0.00599963*alt$	$y=-50.90658-0.00996*lat^2-3.86843*long-0.04736*long^2-0.000006*alt^2$	$y=25.029+0.1328*lat-0.0414*long-0.0061*alt$
Annual	$y=21.1083-0.46368*lat+0.278922*long-0.00522254*alt$	$y=26.3272-0.00399483*lat+0.00092305*long-0.0059453*alt$	$y=32.45762+1.87032*lat-0.00297*long^2-0.000006*alt^2+0.04181*lat*long$	

Source: Barretto (2013)

Table B4 - Evaluation parameters and weights of the criteria used in the MCDA for soybean allocation

Indicator	Parameters	Judgment Weights (% Influence)					
		E1	E2	E3	E4	E5	Combined
Edaphoclimatic		53.10	64.70	56.00	39.90	45.40	55.10
Infrastructure		32.50	12.90	8.10	32.80	9.20	17.00
Transport		27.85	4.30	4.05	19.52	6.14	10.32
Roads (km)	1=>50; 2=50; 3=10; 4=5; 5=3	3.96	2.27	0.29	2.56	0.88	1.80
Railroads (km)	1=>100; 2=100; 3=30; 4=15; 5=3	9.61	0.60	0.46	5.04	1.76	2.36
Ports (km)	1=>1000; 2=1000; 3=250; 4=100; 5=20	14.26	1.43	3.30	11.92	3.50	6.16
Facilities		4.65	8.60	4.05	13.28	3.06	6.68
Storage (km)	1=>110; 2=70; 3=40; 4=25; 5=10	2.32	5.74	1.35	6.64	2.04	3.57
Industries (km)	1=>110; 2=70; 3=40; 4=25; 5=10	2.32	2.87	2.70	6.64	1.02	3.11
Economic		12.00	18.90	31.60	19.70	23.80	21.80
Value of Production (R\$ 1,000)	1=0; 2=11,340; 3=34,020; 4=93,555; 5=725,760	12.00	18.90	31.60	19.70	23.80	21.80
Social		2.40	3.50	4.30	7.70	21.50	6.10
Age Structure		0.94	1.17	0.04	2.56	7.16	1.18
Age 18-44 (%)	1=86; 2=88; 3=89; 4=91; 5=94	0.71	0.70	0.02	1.43	4.30	0.72
Age 44-49 (%)	1=11; 2=12; 3=14; 4=16; 5=27	0.24	0.47	0.02	1.14	2.86	0.47
Education		1.46	2.33	4.26	5.14	14.34	4.92
Elementary (%)	1=31; 2=38; 3=44; 4=54; 5=84	0.18	0.21	0.39	1.04	1.35	0.61
High School (%)	1=9; 2=10; 3=12; 4=13; 5=30	0.89	0.84	1.17	1.48	8.43	2.08
Major (%)	1=2; 2=3; 3=4; 4=5; 5=16	0.34	1.21	2.66	2.29	4.30	2.08
No Education (%)	1=5; 2=7; 3=12; 4=20; 5=38	0.05	0.08	0.04	0.33	0.26	0.14
Kendall's W		0.71	0.58	0.76	0.87	0.77	0.75
Level of Significance		0.05	0.05	0.05	0.05	0.05	0.05

Table B5 - Alternative weights (% influence) used in the scenario analysis for the sugarcane model

Indicator	Scenario Analysis						
	CAAS1	CAAS2	CAAS3	CAAS4	CAAS5	CAAS6	CAAS7
Edaphoclimatic	90	5	5	80	25	50	25
Infrastructure	4	90	3	10	25	25	25
Transport	2	54	2	6	15	15	15
Roads	1	13	0	1	4	4	4
Railroads	0	11	0	1	3	3	3
Ports	1	15	1	2	4	4	4
Pipelines	1	15	1	2	4	4	4
Facilities	1	36	1	4	10	10	10
Mills	1	36	1	4	10	10	10
Economic	5	4	90	10	25	25	50
Value of Production	5	4	90	10	25	25	50
Social	2	1	1	0	25	0	0
Age Structure	0	0	0	0	4	0	0
Age 18-44	0	0	0	0	3	0	0
Age 44-49	0	0	0	0	1	0	0
Education	1	1	1	0	11	0	0
Elementary	0	0	0	0	3	0	0
High School	0	0	0	0	5	0	0
Major	0	0	0	0	3	0	0
No Education	0	0	0	0	1	0	0
Labor	1	1	1	0	11	0	0

Table B6 - Alternative weights (% influence) used in the scenario analysis for the soybean model

Indicator	Scenario Analysis						
	SAAS1	SAAS2	SAAS3	SAAS4	SAAS5	SAAS6	SAAS7
Edaphoclimatic	90	7	7	80	25	50	25
Infrastructure	4	90	2	10	25	25	25
Transport	2	55	1	6	15	15	15
Roads	0	10	0	1	3	3	3
Railroads	1	13	0	1	3	3	3
Ports	1	33	1	4	9	9	9
Facilities	1	35	1	4	10	10	10
Storage	1	19	0	2	5	5	5
Industries	1	16	0	2	5	5	5
Economic	5	3	90	10	25	25	50
Value of Production	5	3	90	10	25	25	50
Social	1	1	1	0	25	0	0
Age Structure	0	0	0	0	5	0	0
Age 18-44	0	0	0	0	3	0	0
Age 44-49	0	0	0	0	2	0	0
Education	1	1	1	0	20	0	0
Elementary	0	0	0	0	3	0	0
High School	0	0	0	0	9	0	0
Major	0	0	0	0	9	0	0
No Education	0	0	0	0	1	0	0