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Land management in Mexican sugarcane crop fields

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ABSTRACT

The sucrose contained in sugarcane is the main input for sugar production in Mexico. It is thus necessary to examine the ability of Mexican sugarcane farms to provide raw material in order to achieve a better sustainability and competiveness of sugar industry. Therefore, area expansion for sugar, bioenergy and biofuels will depend on weather and soil conditions, production cost changes, land tenure and plot size and the level of continued investment by stakeholders for innovations. Sugarcane cultivation is mainly located in the rainfed cultivation system; accordingly, crop fields have heterogeneous productivity, with a decrease of 11% in the last decade, and high vulnerability to weather effects. Therefore, requires a multidisciplinary approach, as Precision Agriculture (PA), Remotely Sensed yield estimation and Agro Ecological Zoning (AEZ), focused at regional and local scale, considering the biophysical constraints to improve the sustainable sugarcane production. The main findings of this study, with the application of AEZ and PA tools, showed that Mexican sugarcane crop fields have a differentiated land suitability into four levels: 20.07% of the total planted area is classified as high aptitude, 56.34% as medium, and 23.59% as low with high vulnerability to climate variability; We also determined that total potential sugarcane yield is 78.11 t ha^{-1}, but actual yield is 68.60 t ha^{-1} (12% lower) because in 777,078 ha for the 2016/2017 harvest season; 13 sugar mills (25.5%) produced cane yield below 60 t ha^{-1}, 21 between 60 and 80 t ha^{-1} (41.2%) and 17 above 80 t ha^{-1} (33.3%). Therefore, the unsuitable areas must be converted to agroecological management practices in combination with conventional approaches to increase yields. The Mexican sugar industry requires public policies differentiated by agro-ecological zone for yield and productivity optimization.

1. Introduction

This paper is organized as follows: first, a literature review is presented regarding the Mexican sugar industry and constraints for productivity in crop fields and their relevance for this research. Next, the multicriteria evaluation for agroecological zoning with available data is described and preliminary thematic maps were built to reflect the effect of biophysical constraints in sustainability and potential productivity of current sugarcane crop fields. Then, the results and discussion and future directions explained. Remotely sensed cane yield estimation is not considered in this research

Sugarcane (*Saccharum* spp.) accounts for 80% of global sucrose production. The sugarcane agroindustry integrates agricultural activities (cultivation, managament, harvesting and transportation of feedstock) with unit operations in sugar mills, *trapiches* and distilleries (de Souza et al., 2014). Mexico is the world's seventh largest sugar producer[1] and it consumes 47 kg per capita in raw form. Sugarcane as raw material is cultivated by 184,000 growers in 227 municipalities across 15 of Mexico's 32 states, covering over 777,078 ha[2] and representing a

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[1] The sugar production cycle in Mexico runs from October to September of the following year.

[2] This places sugarcane as the second most valuable agricultural commodity in the country, preceded only by grain corn. Likewise, sugarcane constitutes one of the 10 largest crops (out of approximately three hundred) covering 3.9% of total harvested area in the yearly agricultural cycle. Sugarcane is concentrated in tropical and subtropical climates, where the states of Veracruz, San Luis Potosí and Jalisco stand out with a combined contribution of almost 60% of the national sugarcane and sugar production.

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total producction of 53,308,643 t year^{-1} in 2017 (CONADESUCA, 2017). Approximately 65% of the cultivated area is planted with three varieties: Mex 69–290, CP 72–2086 and Mex 79–431 (Aguilar-Rivera, 2017; Sentíes-Herrera et al., 2017). This results in a total of 5,957,170 t of sugar and 40,912,149 L of ethanol from molasses, produced in 51 sugar mills using conventional technology and management systems. The sugar agroindustry represents 0.5% of the national gross domestic product (GDP), 2.5% of the manufacturing sector and 11.5% of the primary sector GDP, and it is a significant generator of rural and industrial employment for more than 2.2 million people (García and Manzini, 2012 and INFOCAÑA, 2015). The area dedicated to sugarcane cultivation has been increasing significantly over the past few years in response to growing domestic and international demand for sugar within the North American Free Trade Agreement (NAFTA) and the high prices it can fetch as feedstock. However, as an agribusiness it is characterized by a complex synergy between reduced use of core technology and higher production costs. It must deal with a wide range of climates, challenging topography (land with slopes > 20%) and a low control and management of weeds, pests and disease. Each sugar mill has a supply area of more than 50 km^2. Sugarcane is mostly grown in small parcels (< 3 ha) with family labor, low irrigation (< 30%) covered by small system as lowland or gravity, low mechanical harvesting (< 15%) and extensive trash burning prior to harvesting (> 90%). Producers must contend with increased agrochemical and fertilizer prices from importation, higher number of ratoons (7 to 10 years or more) in the fields, inappropriate financing and other limitations (Martínez-Torres et al., 2013; Castañeda-Castro et al., 2014; Guerrero-Carrera et al., 2015). However, according to Martínez-Guido et al. (2016), sugarcane is the crop with the highest acreage and growth potential for biorefineries in several Mexican states and municipalities (Fig. 1).

The Mexican sugar agroindustry needs to restructure its productive process to better deal with complex constraints and stakeholder perceptions (Aguilar-Rivera, 2017) (Fig. 2). A multidisciplinary approach is needed to assess its agro-economic response in a range of agro-ecological conditions, to obtain higher rentability and reduce production and processing costs. This approach must be built from sustainability and competiveness methods to formulate future action plans involving crop diversification with technological operations such as precision agriculture (PA) and agro-ecological zoning (AEZ) (Salgado, 2010; Fernandes et al., 2011; van Wart et al., 2013; França et al., 2014 and Baez-Gonzalez et al., 2017). These tools, along with the detailed study of climate and soil, will improve sugarcane crop productivity and reduce environmental impacts from inputs like agrochemicals and fossil fuels (Acosta, 2011; Aguilar-Rivera et al., 2012; Gómez-Merino et al., 2014a,b; Sentíes-Herrera et al., 2014; Izquierdo-Hernández et al., 2016; García et al., 2016 and Santillán-Fernández et al., 2016 and Neto et al., 2017).

Despite the importance of the sugar agroindustry in Mexico, and the number of people that depend on it, this industry has structural and operational features that inhibit greater competitiveness. Therefore, according to Hissa (2014), there is a need to incorporate the spatial component into planning tools for sugarcane production to answer the following questions: (1) How sensitive is the sector to changes in the environment, infrastructure and prices? (2) Which areas hold the highest productive potential? (3) Which are the most threatened?

Fig. 3 depicts the growth of both land area used and sugarcane yield for several decades. The expansion of land for sugarcane production in recent years has been significant, especially after 1960, when domestic sugar demand for manufacture of soft drinks, desserts and fast food was accelerating. However, productivity fell during the 2008/2009 season, registering an actual production of 67 t ha^{-1}. Insufficient production derived on the need to bring more land into sugarcane production that was previously devoted to other uses, such as wild pastures for livestock, cultivation of ornamentals, fruits or corn, or incurring deforestation of mountain areas.

2. Constraints for Mexican sugar industry and biorefineries competiveness

The Mexican sugarcane production system, as raw material, is embedded in a mosaic of cultural, social, political, economic, technical and educational factors that limit industrial production. To solve this problem, it is necessary to begin with the primary sector: Agriculture. The agrarian structure in Mexico in general, and sugarcane crops in particular, is characterized by its high fragmentation/atomization (i.e., the high prevalence of production units of small size): Farm fragmentation has been identified as a major barrier to productivity. There is currently a debate regarding the relationship between the size of sugarcane plots, their use of inputs, agro-ecological suitability for sugarcane and their productivity. This literature and novel approaches to evaluate constraits are practically nonexistent for the case of Mexican farms (Singelmann, 1996, 1995; Campos-Ortiz and Oviedo-Pacheco, 2014; Baez-Gonzalez et al., 2017; Sentíes-Herrera et al., 2017) (Figs. 4 and 5 and Table 1).

Therefore, it is necessary to apply technologies such as precision farming to optimize and minimize the effect of the complex production structure of small plots. Pérez Zamorano (2007) concluded that a high atomization of sugarcane farms undermines their productivity by restraining: (i) their access to credit aimed at acquiring production inputs, machinery and equipment, and crop renewal, among others; (ii) the management of water resources; and (iii) the efficient utilization of labor.

The present study evaluates the agro-ecological zoning (AEZ) of Mexican sugarcane crop fields using geographical information system (GIS), global positioning system (GPS) and remote sensing (Landsat images) tools based on physical and chemical properties of soils and weather data focused at the national, regional and local scale in conventional management to achieve sustainability of sugar industry and future biorefineries.

3. Materials and methods

AEZ is a planning tool for public policy makers that defines land resource mapping units. It is used to identify unique combinations of soil, climatic characteristics and/or land cover for a specific range of potentials and constraints for land use related to agriculture and management practices. In this context, GIS tools are very useful for assessment, improving data processing and visualization (Patel et al., 2000). Here, AEZ is employed to group relatively homogenous sugarcane regions in terms of soil, climate and physiography as well as conducive moisture availability periods (length of growing season) for Mexican sugarcane crop fields for appropriate land use, and the variations of maximum and minimum yields obtained in the 57 sugarcane supply zones during the harvest seasons of 2007–2008 to 2016–2017 to establish the classes or typology of potential productivity (high, medium, low and not suitable) (Figs. 6 and 7). This study was carried out for Mexican sugarcane crop fields with the AEZ in a GIS framework (FAO, 2007; van Wart et al., 2013; Bravo-Mosqueda et al., 2014; Baez-Gonzalez et al. (2017)

3.1. Remote sensing analysis

High spatial resolution remote sensing imagery were used to identify and map sugarcane fields (digital crop characterization) from 57 supply zones existing during the 2010/2011 harvest season. Digital processing techniques from the software ILWIS 3.3 were carried out utilizing 32 multi-spectral satellite images (Landsat 7 ETM + bands 1 through 7 with channel combinations 4-3-2, 4-5-3, 3, 4, 5 and 7-4-2). These images have 8-bit radiometric resolution (256 digital levels of each pixel of the image ranging from full black (0) to full white (255) color), 7 bands and 625 m^2 per pixel with spatial resolution of 30 m × 30 m (0.09 ha) and a coverage of 185 km × 185 km. The panchromatic band 8 has a resolution of 15 m. The process was based on