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The Application and advancement of crop simulation models in sugarcane cultivation

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ABSTRACT

Objective: This study aims to describe the approach of agricultural simulation models and their potential application in sugarcane crops in various regions of Mexico.

Methodology: A comprehensive review and classification of scientific articles indexed in major databases, such as SCOPUS or ELSEVIER, was conducted. The focus was on articles related to agricultural and sugarcane simulation models.

Results: A collection of scientific articles concerning agricultural simulation models for sugarcane crops was analyzed. A detailed description of the models' approaches and application for this crop, along with their potential use in certain regions of Mexico was developed.

Study Limitations: The literature of the application of agricultural simulation models for sugarcane in Mexico in recent years is limited.

Conclusions: Crop simulation models are recognized and widely used as indispensable tools in agricultural research. It is crucial to note that many of the models rely on climate information to produce accurate results. Therefore, obtaining reliable and accurate data is essential to achieve trustworthy and useful results applicable to the relevant agricultural areas.

Keywords: agricultural simulation models, sugarcane, yield, APSIM, DSSAT.

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INTRODUCTION

A model is a schematic representation of a concept, an act of mimicry, or a set of equations, exemplify the behavior of a system. This representation of an object, system, or idea is in a form other than that of the entity itself. It is important to consider that it is a simplified version of a part of reality, not an exact copy. Its purpose is generally to help explain, understand, or improve the performance of a system (Murthy, 2007).

Modeling has gained importance in agronomy and other biological areas due to its ability to provide systematic information about both entire biological system and its specific components, such as the agricultural production system (Guevara, 2007). Therefore, the objective of this review is to describe the approach of agricultural simulation models and

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their potential application in sugarcane crops in various regions of Mexico, through an analysis and classification of scientific articles indexed in major databases such as SCOPUS or ELSEVIER.

Structure and function of simulation models

Simulation models have multiple uses and applications, including crop growth models. These models are based on agricultural systems and scientific principles to generalize and analyze the photosynthetic production process, physiological processes, organ formation, yield, and the relationship between the environment and technology. Following this process, a mathematical model is constructed to perform a quantitative analysis and simulate the crop growth process using a computer. Crop growth modeling is a powerful tool for precise production management, presenting significant theoretical relevance and application value in optimally managed crop (Bo and Jun-Cang, 2010; Ya-Li and Li-Yuan, 2005).

It is important to note that to demonstrate the complex interaction of crop growth with various climatic, hydrological, atmospheric, and agronomic factors, several empirical models have been developed. Initially, these models were based on regression analysis functions, which assume that the variability of crop yields can be explained by a few independent variables (Khan and Walker, 2015).

According to Murthy (2007), models developed in recent years utilize one or more sets of differential equations over time, usually from sowing to final harvest, to estimate agricultural production based on climate and soil conditions, as well as crop management. Authors such as Graves *et al.* (2002) mention that crop growth models prioritize resource management in the agricultural field and have been used to understand, observe, and experiment with cropping systems for the last four decades (Cheeroo-Nayamuth, 2000). They have also been employed as research tools to evaluate the relationships between crop productivity and environmental factors (Adejuwon, 2005).

Approach to crop simulation models

Crop modeling combines the complexities of climate change with the intricacies of physiological functions and other biophysical aspects of crop-soil-atmosphere systems. Historically, it has been reported that the first crop simulation models were developed in the 1980s and were used to simulate the growth of wheat, utilizing conservative physiological functions of the crop. Notably early models included ARCWHEAT1 (Porter, 1984; Weir *et al.*, 1984), the Dutch models SUCROS (Van Laar *et al.*, 1992) and SWHEAT (Van Keulen and Seligman, 1987), and five crop models from the ARS Wheat Yield Project, with CERES-Wheat (Ritchie and Otter, 1985) and WINTER WHEAT (Baker *et al.*, 1985) being the most prominent.

A common feature of these models was that they all operated on a daily time step, either approximating or aggregating processes that occur at a shorter time intervals (Jamieson *et al.*, 2008). The models varied in the details of the physiological processes included and the production constraints addressed. The widely used Australian model, APSIM-Nwheat (Keating *et al.*, 2001), initially relied heavily on CERES-Wheat. Substantial changes were subsequently made to this APSIM-Nwheat to improve its performance and account for a wider range of growth conditions. (Keating *et al.*, 2001; Asseng and Van Herwaarden, 2003; Asseng *et al.*, 2001a, 2001b).

Cheeroo-Nayamuth (2000) reported that the application of crop simulation models began in the 1970s. The most commonly used models were the Environmental Policy Integrated Climate (EPIC) (Williams, 1990), the Decision Support System for Agrotechnology Transfer (DSSAT) (Jones *et al.*, 2003; Jones *et al.*, 1998; Ritchie *et al.*, 1985), and the CROPWAT model (Smith, 1992). However, these models have often been developed for specific localities and are not always applicable to other regions (Adejuwon, 2005). Therefore, when introducing such cropping models in new regions, it is necessary to evaluate their applicability. The use of agricultural models is feasible only if the user has a good understanding of the model's structure, scope, and limitations.

The conventional approach in crop simulation studies has been to run a model for multiple sites and then scale up the results to a regional scope (Iglesias *et al.*, 2000). Additionally, regional yields have been modeled using representative region-specific soil types, crop varieties, and management practices (Moen *et al.*, 1994; Haskett *et al.*, 1995). The fundamental assumption in crop modeling applications is that the model can accurately simulate the processes occurring within the agricultural system (Thorp *et al.*, 2005). It is important to remember that models are only approximate representations of real complex systems (Cheeroo-Nayamuth, 2000).

Application of simulation models in sugarcane crops

In the major sugarcane-producing regions worldwide, systems have been developed to predict sugarcane yield based on agroclimatic information (Scarpari and Beauclair, 2004; Suresh and Krishna-Priya, 2009). These systems use data obtained from remote sensors, and crop simulation models, which frequently integrate climate prediction (Everingham *et al.*, 2015).

A considerable number of models have been developed globally to simulate the yield of sugarcane crops. Among the most important are AUSCANE (Jones *et al.*, 1998), DSSAT/CANEGRO (Jones *et al.*, 2003), QCANE (Liu and Kingston, 1995), APSIM-Sugar (Holzworth *et al.*, 2014; Keating *et al.*, 2001), CASUPRO (Villegas *et al.*, 2005), and the FAO-MZA (Monteiro and Sentelhas, 2014). However, only two of these models, APSIM-Sugar and DSSAT/CANEGRO, are widely accepted.

The number of simulation models applied to sugarcane crops is lower compared to other important crops such as wheat, grass, or soybeans (Marin *et al.*, 2015). For sugarcane, the Decision Support System for Agrotechnology Transfer (DSSAT) is a collection of models that connect the decision support system with crop simulation models. It is used to simulate growth, development, and yield based on soil, plant, and atmosphere dynamics (DSSAT.net, 2019).

The DSSAT comprises several simulation models including CERES, for cereals (barley, corn, sorghum, millet, rice, and wheat), CROPGRO for legumes (dry beans, soybeans, peanuts, and chickpeas), root crops (cassava, potato), and other crops (tomato, sunflower, and grass) (Hoogenboom *et al.*, 2015; Jones *et al.*, 2003; Ines *et al.*, 2001). It also includes the CANEGRO model, which simulates sugarcane growth and development based on agricultural management, daily climate information, crop characteristics, soil properties, radiation efficiency, and proximity to the soil's water deficit (Inman-Bamber *et al.*, 2016).

These models have been widely used by researchers, educators, consultants, extension agents, producers, and policy and decision makers (DSSAT.net, 2019). Furthermore, studies in various parts of the world have employed DSSAT to simulate the effects of climate variability and change on crop production (Basak, 2012; Basak *et al.*, 2009; Karim *et al.*, 1996).

Holzworth *et al.* (2014) mention that the Agricultural Production Systems Simulator (APSIM) has evolved in response to global agriculture demands. It contains interconnected models to simulate crops, soil compression systems and biophysical processes. APSIM has been extensively used by researchers to evaluate agricultural management practices, adaptation strategies to climate change and risk, and competition for agroforestry resources, among other applications.

However, the use of crop simulation models in a specific region may lead to inaccurate crop yield estimates. According to Nain *et al.* (2007), accurate regional crop yield estimation requires precise information on crop types and sowing dates for each field.

The conventional approach in crop simulation studies has been to run a model for several sites and then scale up the results up to a regional scope (Iglesias *et al.*, 2000) or to model regional yields using representative soil types, crop varieties, and management practices (Moen *et al.*, 1994; Haskett *et al.*, 1995). The fundamental assumption in crop modeling applications is that the model can accurately simulate the processes occurring within the agricultural system (Thorp *et al.*, 2005).

Nowadays, crop simulation models are recognized and widely used as an indispensable tool in agricultural research. They enable the development of efficient strategies to improve crop production and adaptation. Moreover, the results obtained assist decision makers in determining optimal crop management measures. It is important to note that many models use climate information to simulate results; therefore, accurate and reliable data are essential to obtain trustworthy and useful outcomes applicable to the relevant agricultural areas.

CONCLUSIONS

With the advancement of technology, it is anticipated that simulation models will integrate the features of various models and combine two or more to optimize their use. Despite its widespread use globally, there is no recent and available information demonstrating the application of these models to sugarcane crops in Mexico.

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