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When do I want to know and why? Different demands on sugarcane yield predictions

Felipe Ferreira Bocca, Luiz Henrique Antunes Rodrigues *, Nilson Antonio Modesto Arraes

School of Agricultural Engineering, University of Campinas, Campinas, SP, Brazil

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A B S T R A C T

The production planning processes of sugarcane mills require quantitative information to support decisions on sugarcane yield and the effects of decisions made during planning. An exploratory study was conducted at a sugarcane mill with the goals of identifying the main decisions influenced by the prospects of future yield and of evaluating the manner in which those forecasts affect planning. Key decisions and their characteristics were identified based on a series of interviews and activity monitoring. These decisions are presented and discussed in relation to various solutions proposed by the scientific community for planning, as well as within the concept of Advanced Planning Systems. The yield forecasts used to inform budgeting and harvesting plans are of critical importance because actions taken based on those forecasts affect the entire value chain, highlighting the need for a decision-making framework that assess the effects of decisions on subsequent processes. Advanced Planning Systems design to the sugar value chain should incorporate the use of yield forecasts for production and must address the uncertainties throughout the entire system. These improvements can enhance the performances of Advanced Planning Systems by producing an integrated planning approach that is based on a comprehensive assessment of the sugar value chain.

1. Introduction

Yield forecasts are a key component used for setting goals, evaluating alternatives, and specifying management plans during the crop production planning process. Given the long growth cycle of sugarcane, yield forecasts are developed well in advance, and time frames of one year or longer are not uncommon. Also as a consequence of the long growth cycle, there are several opportunities to revise forecasts if there is an increase in available information that can be used to produce better yield forecasts. As the harvest approaches, forecasts are no longer revised, and it becomes possible to estimate yields based on visual field surveys or on field sampling, the latter of which is better suited for providing estimates of yield. When there is a longer period between the yield prediction and the harvest (e.g., 6 months or longer), a yield estimate is more appropriately called a yield forecast because several future events, such as future weather events or the emergence of an adverse plant-health conditions, could still affect the yield. Based on this adopted differentiation between an estimate and a forecast, the term forecast is used in this report when referring to the prediction of future results.

Notably, a common practice of the sugarcane sector is the yield estimation by specialists. Sugarcane-production specialists are capable of estimating yield based on visual assessments or of generating yield forecasts based on their knowledge of the region's history, the cultivar performance, the land characteristics, the typical weather, and the occurrences of pests and diseases. In a broader context, yield forecasts are the basis of the sugarcane production planning process, whereas revised forecasts allow for the adjustment of management practices. While yield forecasts are important for sugarcane mills, the quantity of sugar accumulated in the stems is also critical information because it indicates the potential for industrial production in terms of sugar and/or ethanol.

The decisions that can benefit from the use of forecasts and modeling, as described by several authors, vary in scale, are required at various times in advance of harvest, and are performed by multiple distinct decision-makers (Ahumada and Villalobos, 2009; Everingham et al., 2002; Meinke and Stone, 2005), illustrating the complexity of the sugar value chain, as reported by, e.g., Higgins et al. (2007). Ahumada and Villalobos (2009) have reviewed various decision-making support systems for agricultural value chains in terms of the organizational level (operational, tactical or strategic) of decision-making and in terms of the functional process affected (cultivation, harvest, distribution, or storage), while also differentiating the systems in terms of the type of model used (stochastic or deterministic). Meinke and Stone (2005) provided examples of decisions that can benefit from the use of climate forecasts, varying from decisions to support internal harvest logistics

* Corresponding author. Tel.: +55 19 3521 1062; fax: +55 19 3521 1010.
E-mail address: lique@feagri.unicamp.br (L.H.A. Rodrigues).

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to those influencing land-use policies implemented at varying frequencies (intra-harvest to decadal) and varying time scales (months to decades); that study also highlighted the use of models to elaborate yield forecasts. The relationship between the time of decision-making and the time window for decision-making determines which meteorological data are available and which should be forecast. Everingham et al. (2002) used climate forecasts to make decisions affecting the sugar value chain and reported a list of key decisions that were influenced by seasonal climate forecasts. The authors divided the value chain among cane growing, harvesting and transportation, milling and production, and sales. They defined key industry decisions and used the climate forecast to improve decision-making for 4 aspects of these identified processes, including (a) yield forecasting and its effect on sugar sales in future markets, (b) the use of climate forecasting to make decisions regarding irrigation management, (c) determinations of yield at the beginning and end of harvest, and (d) harvesting practices.

When the value-chain decision-making process is analyzed, the impacts of decisions on subsequent echelons can also be analyzed, and the use of forecasts and modeling can improve the decision-making process in a context beyond solely agricultural production, *per se*. Ahumada and Villalobos (2009) characterized the agricultural value chain as consisting of production, harvest, storage, and distribution. Higgins et al. (2007) added the processes related to sugarcane mills, i.e., milling and sugar production, sugar transportation and storage, and the production of other sugarcane-based products (e.g., ethanol and biomass electricity) to the value chain because the chain is agro-industrial in nature. In addition, groups that control more than one mill can benefit from a decision-making process that considers several of the group's units. Higgins et al. (2007) considered the existence of several agents along the sugar value chain to be one of the challenges that is hindering the adoption of a joint decision-making framework. The sugar value chain, based on the divisions of Higgins et al. (2007) and Ahumada and Villalobos (2009), is depicted in Fig. 1. While the reviewed literature and the considerations for the present study refer to the sugar value chain, the results can be extrapolated to other products of the sugarcane complex (e.g., ethanol and electricity).

Given the importance of sugarcane yield forecasts for supporting several decisions made within the agro-industrial sugar value chain and given the ability to revise yield forecasts during the crop development phase, the objectives of this study were (1) to identify the various decision-making and planning processes that are supported by yield forecasts, (2) to assess the manner in which yield information is used within those contexts and the characteristics of its use, and (3) to evaluate the structures of yield models and planning models in relation to the concept of Advanced Planning Systems (APS) and identify any gaps that exist between the models and the APS concept. The results of this study will improve the understanding of the decision-making processes required by the sugar value chain, expanding decision-making beyond processes based solely on climate forecasts by including decisions that could potentially benefit from yield and planning models. We also establish the main characteristics of such decisions, according to the framework of Meinke and Stone (2005).

2. Yield and planning models to support the sugarcane complex

Danese and Kalchschmidt (2011) investigated the effects of forecasts on operational performance and determined that, for manufacturing companies, the adoption of a structured forecasting process oriented towards decision-making has a direct, positive impact on the costs and performance of deliverables. Surprisingly, the results of that study indicate that the impact of a given forecast on operational performance is not mediated by forecasting error, meaning that a smaller error does not necessarily result in better company performance. In addition, their analysis revealed that the adoption of yield-forecasting techniques does not necessarily reduce the forecasting error. According to the authors, the best operational performance is associated with the variable "information collection from different sources to elaborate forecasts", which is related to the acquisition of information from multiple sources, such as both suppliers and consumers, to establish the demand forecast and with the variable "role of forecasting in decision-making", which is related to the extent to which a given forecast is used within multiple contexts by the company. Their variable "use of forecast techniques" was also correlated with better operational performance, not by producing forecasts with smaller error but by limiting the potential effects of judgment biases on forecasts and by providing a single forecast for multiple contexts, helping companies to "align" their planning. The authors emphasized that forecasts should be accurate, be available at the right time, and be readily adoptable to support decision-making according to management needs.

Higgins et al. (2007) noted that the main difference between manufacturing value chains and agricultural value chains is the greater variability of the production system involved. The authors refer to climatic and biophysical variabilities/uncertainties as the main factors contributing to this variability. The production systems of manufacturing chains are more predictable and require demand forecasting, whereas the interactions among controlled and uncontrolled factors in agricultural systems necessitate the use of production (yield) forecasts. For the sugar value chain in the Australian context, the aforementioned authors also highlight the involvement of several decision-making agents and varying scales of decision-making processes, from decisions for individual plots to those affecting an entire mill. The presence of multiple agents in the value chain has been highlighted in Australia by Jiao et al. (2005), in South Africa by Le Gal et al. (2009), and in Thailand by Piewthongngam et al. (2009). In contrast, there is only a single production agent for the conditions described for Venezuela by Grunow et al. (2007) and for Brazil by Jena and Poggi (2013).

The yield forecast can be estimated by several methods depending on the available data. One type of yield forecasting is based on growth models, which, coupled with information on crop handling and weather forecasts, can describe plant growth and can be used to generate yield forecasts. Lisson et al. (2005) refer to APSIM-Sugarcane and Canegro as the two main sugarcane simulation models in use worldwide. This type of model has been used in South Africa and Australia with the goal of forecasting the regional yield for the approaching harvest (Bezuidenhout and Singels, 2007a; Everingham et al., 2002). To bypass the information demands for these applications, Everingham et al. (2009) proposed the combined use of the results of several models (an ensemble) with varying modeling conditions to perform the regional yield forecasting in Australia. Another strategy is to group similar areas into homogeneous blocks to decrease the number of growth simulations that must be performed (Bezuidenhout and Singels, 2007a; Le Gal et al., 2009).

An alternative to the use of growth models is the use of an empirical model, which searches for relationships among crop characteristics and climate conditions to determine the final yield. Meinke and Stone (2005), while discussing modeling approaches for yield forecasting, presented both growth and empirical models as tools to study both climate change and climate variability, defining a climate change as a long-term change and climate variability as the intrinsic climate variation.

One direct consequence of the choice of any modeling strategy is the information required, as well as when this information will

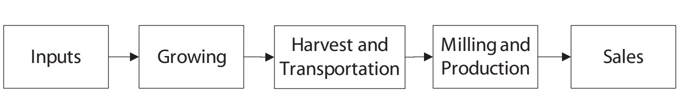

Fig. 1. A simplified sugar value chain for the sugarcane complex.