

REGIONAL SIMULATION APPROACH FOR EVALUATING A NEW SUGARCANE VARIETY USING SYSTEM DYNAMICS

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System Dynamics, Strategy.**

Abstract

THE SUGARCANE industry is a complex system involving sugarcane growers and sugarcane mills. Technical evaluations whose purpose is the restructuring of sugarcane production must be based on a systematic methodology. The National Agricultural Research Centre for the Kyushu Region in Japan is trying to breed a new type of sugarcane which has early maturing and high ratoonability. Such a sugarcane variety would bring a trade-off between lower sugar content, an important quality of sugarcane, and a long-term increase in the sugarcane raw material supplied by sugarcane growers to mills. Against this backdrop, a simulation model was developed based on system dynamics that accounted for the area required to cultivate a new sugarcane variety and the first date on which the sugarcane mill operations would begin. This model regards sugarcane growers and the sugarcane mill located in a given area as a single entity. A crucial factor in this model is the pol value, which increases gradually in weekly increments until it reaches a peak mid-season and then declines. Furthermore, the simulation uses five ratoon cycles / years. The model consists of three units, each with 'Cropping', 'Quota', and 'Evaluation', where the output includes sugarcane production volumes, raw sugar volumes, and profitability (production costs per raw sugar unit). A scenario analysis showed a decrease in profitability during the first two years, but pointed to an increase in the third year. This suggests that the change would benefit both sugarcane growers and mills. Analysis of various scenarios will help in formulating strategies for the sugarcane industry by enabling mid- and long-term forecasts.

Introduction

Introducing new technologies that result in radical reforms in sugarcane production tends to be met with resistance, due to the complexity of the sugarcane industry, which makes it hard to grasp and evaluate the effects of new technologies. One such technology is the new type of sugarcane variety which has an early maturing capacity currently being pursued in Japan (Sugimoto *et al.*, 2001; Irei *et al.*, 2005).

Simulation analysis is suitable for assessing such complex systems. Among various simulation analysis methods, a system dynamics approach was used because it accounts for temporal factors and permits quantitative evaluations. System dynamics was developed in the 1950s to help corporate managers improve their understanding of industrial processes, and is currently being used throughout the public and private sector for policy analysis and design. This approach is ideal for evaluating various factors in complex systems such as the global computer model 'World3' for the Club of Rome (Donella *et al.*, 2004). It is therefore considered an appropriate tool for analysing a complex system such as the sugarcane industry.

In the sugar industry, MAGI is one of the most advanced simulation systems currently available (Le Gal *et al.*, 2003). MAGI has the following features: (1) It handles processes ranging from farming to milling; (2) the simulation is based on weekly increments; and (3) it emphasises distribution efficiency. MAGI is designed primarily to evaluate changes in sugarcane production, the reorganisation of mills to which sugarcane is supplied, changes in delivery rules, and changes in supply chain capacity. These characteristics make MAGI a useful tool for managing the complexities inherent in the sugarcane industry. MAGI has already seen use as part of management efforts to improve the sugarcane industry (Lejars *et al.*, 2008; Le Gal *et al.*, 2008). However, MAGI can simulate at most a period of one year. This is inadequate for modelling the effects of changes in sugarcane production over several years. Another simulation tool was needed to evaluate multiple ratoon cycles of sugarcane.

An alternative approach is to base the simulation on econometric methods, which pose their own drawbacks, including a limited capacity to accommodate structural changes resulting from the deployment of new technologies. For these reasons, a simulation model was developed using system dynamics. There are many system dynamics software programs such as 'iThink/Stella', 'PowerSim' and 'Vensim'. Vensim is produced by Ventana Systems, which offers a free introductory version of its software, Vensim PLE, which can be downloaded from the web and was the software of choice in this study.

Characteristics of sugarcane production in Japan

In Japan, sugarcane is harvested from winter to spring. With declining sugarcane production volumes, the duration of operation of sugarcane mills has also declined. This has resulted in the concentration of harvesting tasks, the most time-consuming and labour intensive stage of sugarcane production.

Cultivation typically involves two principal operations: spring-planting, summer -planting, with ratooning taking place after both the harvest of spring-and-summer planted sugarcane. The summer-planting yields a crop every other year, offering consistent and high yielding but poor land use efficiency (Table 1). In response, current efforts focus on increasing the ratoon-based crop to boost sugarcane production volumes and income for growers. Spring-planted sugarcane has a lower yield but better land use efficiency.

Table 1—Sugarcane production in Japan (2007).

Category	Class	Unit	
Grower		Number	27 025
Harvested area	Total	Ha	22 037
	Summer-planting	Ha	8028
	Spring-planting	Ha	3404
	Ratoon	Ha	10 604
Average yield	Total	T/ha	68
	Summer-planting	T/ha	83
	Spring-planting	T/ha	58
	Ratoon	T/ha	60
Harvest per grower		Ha/grower	0.81
Sugar mill	Total	Number	24
	Raw sugar mill	Number	17
	Brown sugar mill	Number	7
Sugarcane production	Total	T	1 498 869
	Raw sugar mill	T	1 429 132
	Brown sugar mill	T	69 737

Source: Kagoshima and Okinawa Prefectural Government.

Features of the new sugarcane variety

One of current Japanese breeding programs focuses on early-maturing sugarcane varieties and related cultivation methods.

This approach achieves high and stable yield of new plantings based on a summer-planting operation and harvested in autumn (from October to November).

This promotes sprouting in the ratoon cycle, since the weather is warmer at this time than during the ordinary harvest season. This leads to consistent ratooning and higher yields.

However, sugarcane harvested at this time has lower pol values than crops harvested during the ordinary harvest season. Since sugarcane pricing is based on quality (i.e., pol value), higher pol values mean higher prices and more income for the grower.

This factor has discouraged widespread cultivation of the new sugarcane variety. Sugarcane mills also prefer sugarcane with high pol values since raw sugar can be obtained more efficiently from such crops.

For this reason, earlier harvests offer no short-term incentives for either sugarcane growers or mills. We believe that this widespread and unquestioned acceptance of the idea that sugarcane must have high pol values is a major factor hampering the widespread adoption of early-maturing sugarcane varieties.

Overview of the model

Purpose of the simulation

A regional agricultural production model was designed based on an early-maturing sugarcane variety. A requirement was to formulate a scenario, despite the disadvantage in terms of pol value, offering long-term benefits not just to sugarcane growers but to sugarcane mills. A simulation explored in quantitative terms the likelihood of achieving this objective.

Features of the model

One of the features of the model is that it treats a sugarcane mill and sugarcane producers consisting of many growers as a single control constituent.

Thus, the results of the simulation provide evaluation indices such as annual sugarcane production volumes for an entire area and aggregate sugar production costs per product.

In practice, the sugarcane variety and crop type selected by each grower vary widely. Dates for delivery of the sugarcane raw materials to the sugarcane mills are generally set based on grower requests.

If rain prevents a harvest, the delivery schedule must be reviewed and adjusted. Among other factors, this complicates the process of delivering raw materials and the efficient operation of a sugarcane mill.

The model, however, assumes a special condition whereby sugarcane production and mill operations proceed rationally and efficiently.

The model is not designed to present a realistic situation. Instead, it produces a theoretical framework for region-specific models and provides guidelines for formulating future strategies.

Structure of the model

Changes in sugarcane production have effects that persist for several years. To account for sugarcane quality, we must also consider fluctuations in pol value from harvest to harvest. Thus, we performed a five-year simulation in weekly increments.

This model consists roughly of three sectors: the cropping sector, the quota sector, and the evaluation sector (Figure 1).

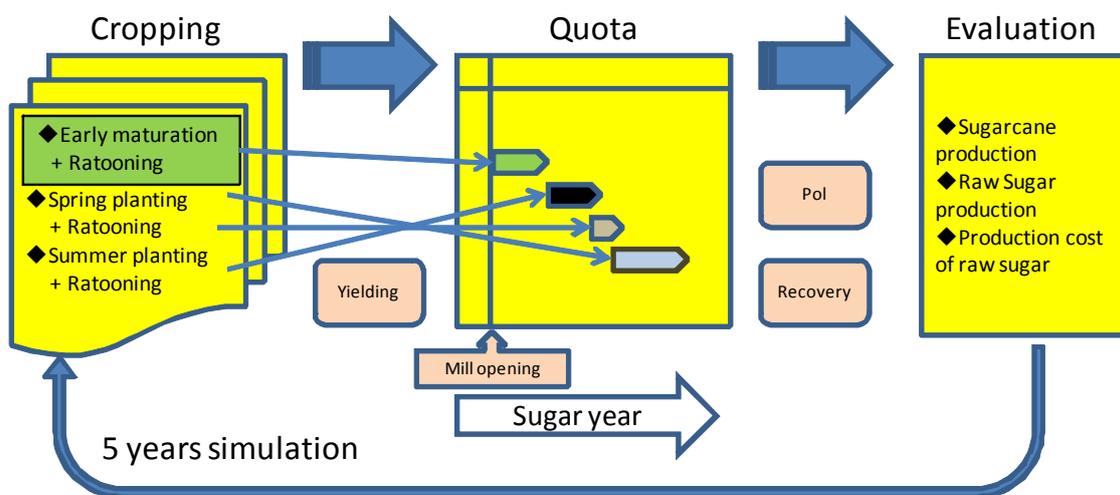


Fig. 1—Simulation structure.

The structure of the model is discussed below, based on the parameters set for the hypothetical area (Tables 2, 3).

Table 2—Cropping hypothesis.

Cropping	Harvest area	Ratoon	Yielding	Pol curve	Quota priority	Soil fertility
Spring-planting	300 ha	–	60 t/ha	Ordinary	5	Rich
Ratoon of spring-planting	1500 ha	5 times	60 t/ha	Ordinary	4	Rich
Summer-planting	300 ha	No ratoon	90 t/ha	Ordinary	3	Poor
Early-maturing		–	90 t/ha	Early-mature	1	Poor
Ratoon of early-maturing		3 times	90 t/ha	Early-mature	2	Poor

Table 3—Mill hypothesis.

Mill opening	January first week
Raw sugar production	$\text{Cane_weight} * \text{Pol} * \text{Recover_rate}$ t
Recover_rate	86%
Proportional cost (per cane)	3000 Yen/t
Fixed cost (per cane)	8000 Yen/t
Sugarcane purchase cost	Domestic price of raw sugar(70 312 Yen/t) * Share of benefit for famer(48%) * Pol * Recovery_rate Yen/t

Source: Ministry of Agriculture, Forestry and Fisheries (2004)

Cropping sector

The spring-planting area is 300 ha, and ratooning is performed five times. The summer-planting area measures 300 ha and yields a crop every other year. The total available harvest area for sugarcane is 2400 ha.

For new planting, spring-planting on the 300 ha area takes precedence. The rest is planted in summer. The early-maturing sugarcane variety is planted instead of the normal summer-planting variety and is planted in the same quantities as for existing summer-plantings.

Additionally, ratooning of the early-maturing sugarcane variety is performed three times (Figure 2).

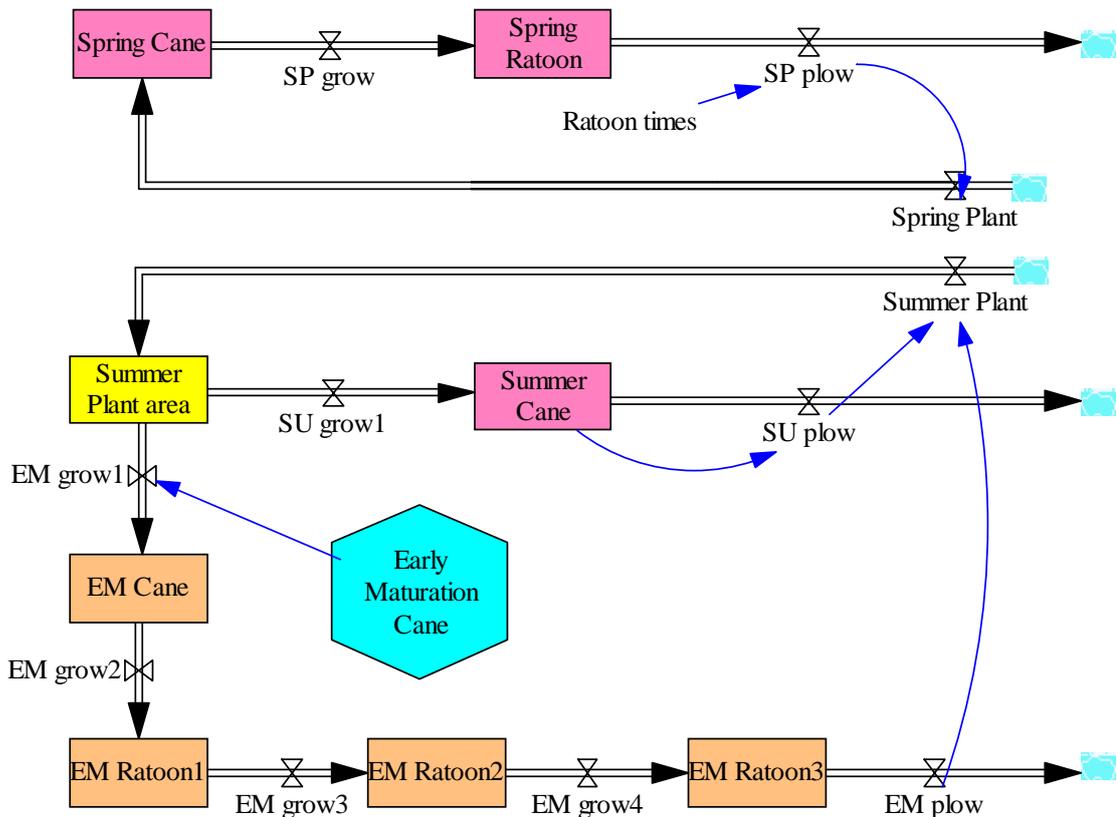


Fig. 2—Cropping model (built by Vensim).

The system dynamics model basically consists of two types of variables: ‘level’ variables that express conditions and ‘rate’ variables that express activities. In Figure 2, the area of each crop type is represented by a level variable, while each valve symbol indicates a rate variable. More specifically, Figure 2 shows that the valve opens once a year to move to the next crop stage.

Quota sector

The sugarcane production volume needed for the upcoming harvest is calculated by multiplying the harvest area for each crop type, which is obtained in the cropping sector, by the crop yield. The yield is 60 t/ha for spring-planting and its ratoons and 90 t/ha for both summer-planting and the early-maturing sugarcane variety. The crushing capacity of the sugarcane mill is 1500 t/day for a weekly quota of 10 500 t. As soon as sugar production begins, the volume of sugarcane raw materials needed each week is allocated in priority order.

Early-maturing sugarcane is granted highest priority. Next, ratooning of the early-maturing sugarcane variety is performed, followed by summer-planting, ratooning for spring-planting, and spring-planting, in that order. This produces a delivery schedule for sugarcane crop types.

Evaluation sector

The evaluation sector produces evaluation indices for sugarcane production volumes, raw sugar production volumes, and sugar production costs. Table 3 shows the parameters and relational expressions assumed.

Pol value is a factor that affects not just raw sugar production volumes, but the amount of money paid to growers. In this model, the pol value varies weekly for both the existing varieties and early-maturing variety. The early maturing variety is assumed to have a higher pol in autumn (Figure 3).

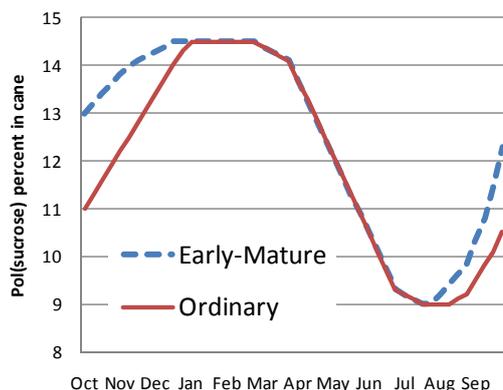


Fig. 3—Change of pol.

The recovery rate for sugarcane pol value was set to 86%, and the yield rate obtained by multiplying by pol and recovery rate was used to calculate raw sugar production volumes. Sugar production costs include a proportional cost, a fixed cost, and sugarcane purchase cost (Table 3). A proportional cost and a fixed cost were set based on data released by the Ministry of Agriculture, Forestry and Fisheries of Japan. Sugarcane purchase cost is calculated by relational expression using pol value. For fixed costs, we calculated total fixed costs based on total crop yields obtained in the simulation based on initial values.

Simulation results and discussion

We performed a simulation based on the introduction of an early-maturing sugarcane variety on a 200 ha area and an early start for sugar production in the first week of November. We compared the results of this simulation with the results of the simulation of the current system (early-maturing sugarcane variety not introduced and sugar production starts in the first week of January).

With regard to harvest area by crop type, the early-maturing sugarcane variety replaced summer-planting and was harvested from the second year (Figure 4).

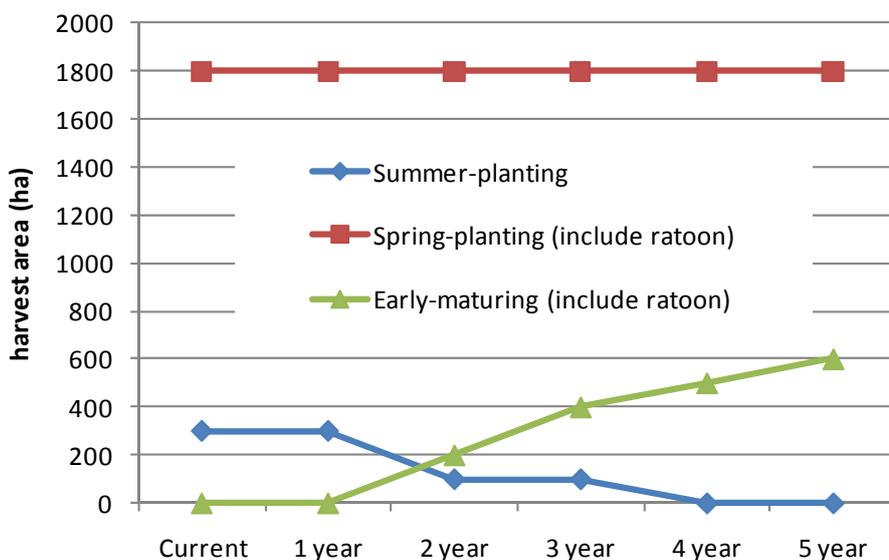


Fig. 4—Cropping simulation.

Sugarcane production begins to increase from the third year, when the harvesting of the ratoons in early-maturing sugarcane variety begins (Figure 5). Note that actual raw sugar production volume drops from current levels in the first and second years. This is because sugar production starts earlier, but the early-maturing sugarcane variety has not reached its full potential.

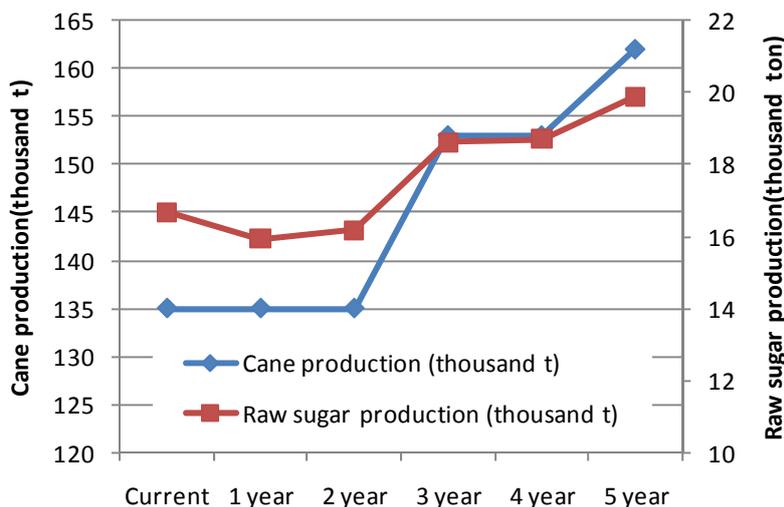


Fig. 5—Cane and raw sugar production simulation.

Consequently, sugar production costs per raw sugar unit, a major index for sugarcane mills, rises for the first two years following the introduction of the early-maturing sugarcane variety. But from the third year, sugar production costs begin to fall (Figure 6). We compared the cost details between the current system and in the fifth year (Figure 7).

As the sugarcane and raw sugar increase, economies of scale effect to decrease average fixed cost. The decline of average fixed cost (fixed cost per raw sugar) contributes significantly to the reduction in sugar production cost per raw sugar.

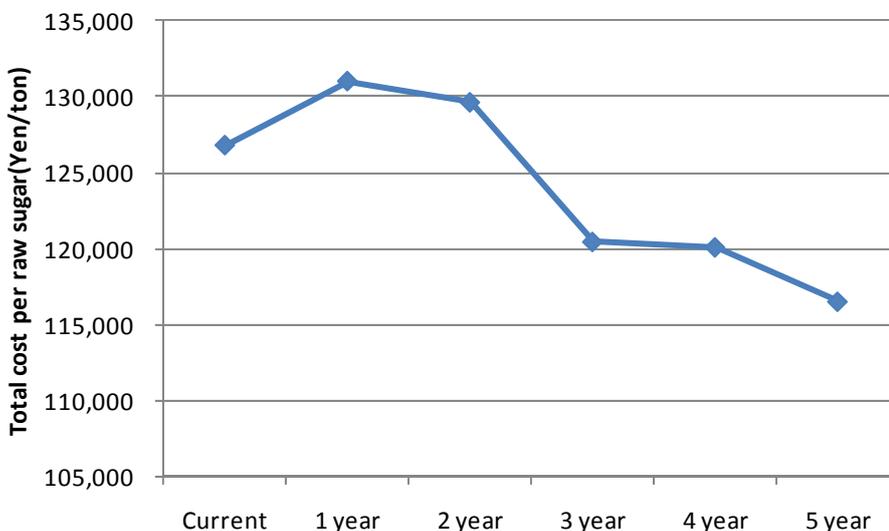


Fig. 6—Cost simulation.

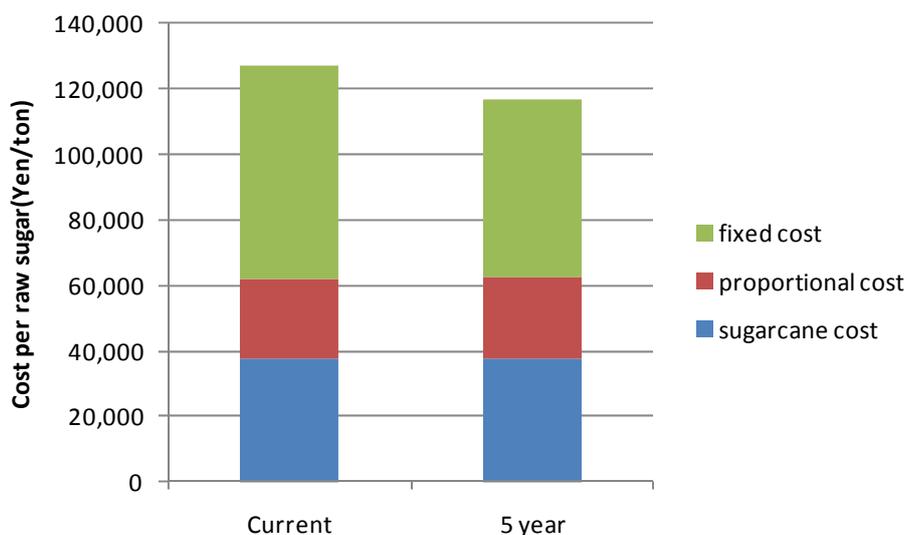


Fig. 7—Detail of costs.

Summary

A simulation model was developed and applied to sugarcane growers and sugarcane mills and simulations performed in which an early-maturing sugarcane variety was introduced. In the resulting scenarios, increased sugarcane production volumes reduced sugar production costs beginning in the third year following the introduction of early maturing varieties.

We believe introducing an early-maturing sugarcane variety will benefit a given region, and that the increased harvest area resulting from increased ratooning operations will improve income for growers. Introducing an early-maturing sugarcane variety offers potential benefits to both sugarcane growers and sugarcane mills.

Many factors affect the state of the sugarcane industry. Evaluating the potential advantages, disadvantages, or risks of any change in the status quo remains difficult. Nevertheless, system dynamics simulation makes it possible to forecast in quantitative terms the effects of such factors. The analysis presented in this paper focused on an early-maturing sugarcane variety, but the simulation method described can also be applied to other factors to help determine how to maximise the profitability of both growers and millers.

The simulation model created can help formulate strategies for the sugarcane industry by enabling mid- and long-term forecasts, which is the first step in the change management process. The second step, if these strategies are actually executed, is the implementation of efficient operational management practices. The MAGI modelling approach can help ensure the effective management of the actual implementation in the second step.

For agricultural business operators, we believe presenting analyses of various scenarios would not only allow them to select appropriate technologies and examine future countermeasures, but also help various parties build a consensus. This notion needs to be tested in the future.

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SIMULATION D'UNE APPROCHE REGIONALE POUR EVALUER DES NOUVELLES VARIETES DE CANNE A SUCRE UTILISANT UN SYSTEME DYNAMIQUE

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**MOTS-CLES: Modèle de Simulation,
Système Dynamique, Stratégie.**

Résumé

L'INDUSTRIE de la canne à sucre est un système complexe impliquant les producteurs de canne et les usiniers. Les évaluations techniques dont le but est la restructuration de la production de canne à sucre doivent être basées sur une méthodologie systématique. Le Centre National de Recherche Agricole pour la région de Kyushu au Japon tente de produire un nouveau type de canne hâtive avec une bonne repousse. Une telle variété de canne apporterait un compromis entre la faible teneur en sucre, le rendement de la canne, et une augmentation à long terme de la matière première fournie par les planteurs aux usines. Dans ce contexte, un modèle de simulation a été développé en fonction de la dynamique du système qui calculerait la superficie nécessaire pour cultiver une nouvelle variété de

caña et la date à laquelle les opérations de l'usine devraient démarrer. Ce modèle concerne les planteurs de canne et une usine situé dans une région spécifique. Un facteur crucial dans ce modèle est la teneur en sucre qui augmente progressivement toutes les semaines jusqu'à ce qu'elle atteigne un maximum en milieu de saison et décline ensuite. En outre, la simulation utilise cinq repousses. Le modèle se compose de trois unités chacune: Recadrage, Quotas et Evaluation, avec pour résultats les productions de canne, le sucre brut et la rentabilité (frais de production par unité de sucre brut). Une analyse du scénario démontre une baisse de rentabilité au cours des deux premières années, mais une augmentation dans la troisième année. Ceci suggère que le changement profiterait aussi bien aux planteurs qu'aux usiniers. L'analyse des différents scénarios permettra l'élaboration de stratégies pour l'industrie de la canne avec des prévisions à moyen et long terme.

ESTRATEGIA DE SIMULACIÓN REGIONAL PARA EVALUAR NUEVAS VARIEDADES DE CAÑA USANDO DINÁMICA DE SISTEMAS

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**PALABRAS CLAVE: Modelos de Simulación,
Dinámica de Sistemas, Estrategia.**

Resumen

LA INDUSTRIA azucarera es un sistema complejo que involucra a los productores de caña y a los ingenios azucareros. Las evaluaciones técnicas que se realicen con el propósito de re estructurar la producción de caña de azúcar deben basarse en una metodología sistemática. El Centro Nacional de Investigación Agrícola para la región de Kyushu en Japón está tratando de desarrollar una nueva variedad de caña de maduración temprana y buena habilidad de soqueo. Esta variedad permitirá obtener un equilibrio entre el bajo contenido de azúcar, una característica de calidad muy importante en la caña y el incremento a largo plazo de materia prima despachada por los proveedores hacia el ingenio. Contra este escenario, se desarrolló un modelo de simulación que se basa en la dinámica de sistemas que toma en cuenta el área que se requiere para cultivar la nueva variedad y la fecha en que empezará la molienda en el ingenio. Este modelo considera como una sola entidad a los proveedores y al ingenio que están localizados en el área de estudio. En este modelo, el valor de la pol es crucial, el cual se incrementa gradualmente por semana hasta que llega a un pico a la mitad del periodo de cosecha y luego declina. Además, la simulación utiliza cinco ciclos de soca/años. El modelo consiste de tres unidades: 'Cultivo', 'Cuota' y 'Evaluación', donde la salida incluye los volúmenes de producción de caña, volúmenes de azúcar crudo y capacidad de generar utilidades (costos de producción por unidad de azúcar crudo). Un análisis de escenarios demostró una reducción de la capacidad de generar ganancias durante los primeros dos años, pero apuntó a incrementarla en el tercer año. Esto sugiere, que el cambio beneficiaría tanto a los productores de caña como a las fábricas. El análisis de varios escenarios ayudará en la formulación de estrategias para la industria de la caña permitiendo realizar pronósticos de producción a mediano y largo plazo.