REVIEW ARTICLE

SYSTEM DYNAMIC FRAMEWORK: INCREASING PRODUCTIVITY OF SUGARCANE TO SUPPORT SUSTAINABLE CULTIVATION

Hawwin Mardhiana^a, Erma Suryani^b, Ully Asfari^a, Muhammad Nasrullah^a

^a Information System, Institut Teknologi Telkom Surabaya, Indonesia

^b Department Information System, Institut Teknologi Sepuluh Nopember, Indonesia

* Corresponding Author E-mail: hawwin@ittelkom-sby.ac.id; erma.suryani@gmail.com

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ARTICLE DETAILS

ABSTRACT

Article History:

Received 03 April 2021

Accepted 08 May 2021

Available online 08 June 2021

Sugarcane as a raw material for producing sugar is a strategic agricultural commodity in economy and sugar industry. With the increase of population, the consumption and demand for sugar will also increase and this causes domestic sugar production to be unfulfilled. Some problem that arise in this commodity include sugarcane productivity and yields are not optimal, how to increase farmer's income from the residue of the sugarcane harvesting. To achieve the basic need of domestic sugar, it is necessary to increase land productivity and sugarcane production in order to support the sustainable of sugarcane cultivation. The result of study show simulation scenario of intensification of the use of quality seeds, the productivity of sugarcane increased by 1.03% per year and increased sugarcane production in smallholder farmers' gardens. PBN production increased by an average of 0.96% per year and PBS increased by an average of 1.52 per year. In addition, there is a scenario of utilizing residual crops in the form of silage and biobriquette in year 2030. This study took a case study at PT. PTPN X Surabaya City which represents the East Java area. The harvested areas used in this study are People's Plantation (PR), National Large Plantation (PBN) and Private Large Plantation (PBS). This study uses a key focus area of sugarcane cultivation to increase sugarcane productivity and production efficiency and support sustainable cultivation.

KEYWORDS

Dynamic System Approach, Sugarcane Productivity, Sustainability of sugar cane cultivation

1. INTRODUCTION

Sugar is one of the strategic plantation commodities in the Indonesian economy, which until now still depends on the supply of sugar cane (Ministry of Agriculture of the Republic of Indonesia, 2015). Sugar is a commodity that is widely used in daily food by humans as a source of energy, sweeteners and preservatives. Based on a report published by International Sugar and Global Sweetener production, global sugar production is contributed by sugar derived from sugar cane by 77.5% (Rajaeifar et al., 2019). Currently the demand for sugar continues to increase in line with the increase in population and increase in community income as well as the development of beverage and food businesses that use sugar as raw material.

In this case it is important to increase agricultural productivity in order to increase sugarcane productivity. In the Ministry of Industry's Strategic Plan, Sugarcane-based Sugar Industry is included in the priority industry in the industrial development action plan with one of the objectives is to ensure the availability of raw materials, increase the efficiency of processing processes and guarantee products. As a tropical country, Indonesia has a high potential for sugarcane production. Sugar cane area reaches 3,473,230 hectares with a total production of about 2,854,300

tons which is mostly cultivated by smallholders (Ditjenbun, 2018; Dirjen Perkebunan, 2019). Outside the sugarcane area to date is dominated by 1) Smallholder Plantation (PR) with a total of 60.17%, Large Private Plantation (PBS) around 25.20% and State Large Plantation (PBN) around 14.63%.

East Java Province is the region with the largest sugarcane plantations in Indonesia and is the leading area where sugar factories are spread across almost all sugarcane development areas. The problems faced in the national sugarcane area are decreasing so that it affects sugarcane productivity, yields that are not yet optimal and the need to increase the income of sugar farmers with sugarcane waste. From these problems, to meet the basic needs of domestic sugar, it is necessary to increase land productivity and sugarcane production to support the sustainability of sugarcane cultivation.

From the various problems that threaten the availability of sugar, in this study a dynamic system model was developed with the PTPN X case study representing East Java. The data used came from PT. PTPN X and the Central Statistics Agency. Along with the problem of complexity, the dynamic systems approach is recognized by researchers and practitioners as a method capable of providing understanding and helping to better

Quick Response Code

Access this article online

Website:
www.sfna.org.my

DOI:
10.26480/sfna.02.2021.105.109

solve complex system problems (Martinez-Moyano and Richardson, 2013; Richmond, 1993). Because of these problems, this study uses a dynamic systems approach to build models. Dynamic systems have the characteristics of complex, non-linear system dynamics, changes in system behavior with time and there is feedback that describes new information about the state of the system, which will then produce further decisions (Suryani, 2006). The model to be developed is a model that can increase the productivity of sugarcane because it reaches the maximum yield value. Simulation models can provide a detailed analysis of the factors that can increase sugarcane productivity, costs and the impact of decisions regarding the system and the model is very useful for analyzing problems and achieving goals.

2. LITERATURE REVIEW

2.1 Sugarcane Yield

Sugarcane yield is a benchmark as the yield of sugar which is determined based on the period during sugarcane milling, it can be described by the yield for every 100kg of milled sugarcane, 10kg of sucrose is obtained. {Citation}{Martin et al., 2016}. The measurement of sugarcane yield is divided into two, namely:

2.1.1 Provisional Yield (RS)

The temporary yield is the result of calculating yield with sugarcane samples to analyze the maturity of sugarcane. In addition to analyzing the maturity of sugarcane, the calculation of the provisional yield obtained from the sap from the first crushed sugar cane is used to determine the sugar yield for farmers quickly. The temporary yield value is obtained from:

$$RS = FR(\text{Yield Factor}) \times NN(\text{value of sap})$$

2.1.2 Effective yield (RE)

The effective yield is used as the official value obtained. The effective yield or real yield is the calculation of the formula as follows:

$$RE = \frac{\text{weigh of sugar produced}}{\text{weight of milled sugarcane}} \times 100\%$$

2.2 Sustainable Agriculture

The concept of sustainability is based on meeting the needs of the current generation without sacrificing future generations to make ends meet. The concept of sustainable agriculture is produces food without polluting the environment and integrates three main objectives, namely environmental health, social and economic aspects (Laurett et al., 2020). The sustainable model aims to achieve production by ensuring the availability of resources for future generations. Several studies address sustainable agriculture to various agricultural systems. In the context of environmentally sustainable agriculture is a farming practice starting from the development of irrigation projects to the use of chemicals that take into account environmental or natural ecological conditions in the long term. These activities include integrated pest control, rotation and grass cultivation systems, land conservation, maintaining water quality, diversifying land and crops, managing plant nutrition (Allen et al., 1991).

In research, Sustainable agriculture is divided into three dimensions, namely 1. Economic dimension, which contains indicators of net farm return, land productivity, crop diversity, and sufficiency of cash flow (Roy et al., 2011). 2. Social dimension, there are indicators of education, input self sufficiency, social involvement, and 3. Ecological Dimension with indicators of Integrated water management, Integrated nutrients, Integrated pest management, Soil quality status, Soil fertility management, Bio diversity. Indicators and measures of the success of strategic goals and objectives are also presented in Sugar Research Australia with five focus areas, namely 1. Optimally adapted varieties, plant breeding and release, 2. Soil health and nutrient management Pest, 3. Disease and weed management, 4. Farming system and production management, 5. Milling efficiency and Technology. This indicator will be the causal variable used for simulation in research.

2.3 Factors Affecting Sugarcane Productivity

Based on interviews and direct surveys with PT. Perkebunan Nusantara X Surabaya, the factors that influence the productivity of sugarcane are the types of seeds and varieties of sugarcane used, water availability (irrigation), weather, handling of pests and diseases of sugarcane, use of chemical fertilizers, use of fertilizers compost, soil health, land area for sugarcane farming, labor in developing sugarcane cultivation and the operational costs used.

2.4 System Dynamics

System Dynamics is a computer-assisted approach to analyzing and designing a policy. Literally every dynamic system is characterized by dependence, mutual interaction, information feedback and causal cycles (Martinez-Moyano and Richardson, 2013). This approach starts from defining the problem dynamically over time to modeling significant variables and developing stock and flow diagrams. Steps The steps involved in the simulation (Sterman, n.d., 2000):

2.4.1 Defining the system

Determining system boundaries and identifying significant variables

2.4.2 Model formulation

formulating the relationship between the components of the model by translating into the system equation using level, rate and auxiliary. The basic structure of a formal system dynamics model is a system of coupled, nonlinear, first-order differential (or integral) equations such as depicted in Equation:

$$\frac{d}{dt}x(t) = f(x,p)$$

where: x = a vector of levels (stocks or state variables), p is a set of parameters, and f is a nonlinear vector-valued function.

1. Retrieval of data required in accordance with the purpose of making a model
2. Model Development
3. Verify the model against errors
4. Model validation with the aim of conforming the model to the real system.

The validation process is divided into two events, namely:

- Means Comparison

$$E1 = \frac{[S - \bar{A}]}{\bar{A}}$$

- Amplitude Variations Comparison

$$E2 = \left| \frac{Ss - Sa}{Sa} \right|$$

Where:

S = average rate of simulation

$\bar{A}$ = average rate of data

Ss = standard deviation of simulation

Sa = standard deviation of data

Conducting scenarios with the aim of improving system performance in accordance with the wishes and goals. Sekanrio is divided into two, namely: a. Parameter scenario is done by changing the model parameter value. It is relatively easy to do because it only makes changes to the parameter values and their impact on the model output. b. Structural scenario is done by changing the model structure. This scenario requires global knowledge in order for the new structure proposed to improve system performance. Model interpretation with the aim of drawing conclusions from the simulation model output and Documentation.

From Figure xx, it can be seen that the highest average productivity is large private plantations (PBS) where the average productivity reaches 6.67 tonnes / ha with the highest productivity value is 8.24% in 2008. From the evaluation of the land area sub model, PBS has Sugarcane harvested land is the lowest compared to PBN and PBS but has the highest productivity value of sugarcane of the two. PBN land productivity has an average of 4.6 tonnes / ha when compared to PR and PBS is the lowest.

4. MODEL VALIDATION

Model validation is carried out to ensure that the model created describes the real system, in this study the model validation was carried out with two testing programs, namely Yaman Barlas. The Yaman Barlas test validated by means of the mean comparison statistical test and the comparison test of the amplitude variation or % error variance. Model validation is required to check the model accuracy. A model will be valid if the error rate is less than 5% and error variance is less than 30% (Yaman barlas). This study validates the land area sub-model, land productivity and production sub-model. The following are the validation results can be seen in Table 1 and table 2.

Table 1: Validation (Mean Comparisson)

variable	Average of Simulation	Average of Data	Error Rate
Land area PR	264247.1766	265247.1	0.37%
Land area PBN	72914.30387	265247.172904.1	0.013%
Land area PBS	107237.5656	107207.4	0.028%
Produktivitas lahan tebu PR	5.27749	5.335	1.007%
Produktivitas lahan tebu PBN	4.635809	4.605	0.66%
Produktivitas lahan tebu PBS	6.782084	6.675	1.6 %

Table 2: Validation (Amplitude Variations Comparisson)

variable	Standart Deviation of Simulation	Standart Deviation of Data	Error variance
Land area PR	14595.14527	16013.166	8.85%
Land area PBN	6468.074057	6459.984235	0.125%
Land area PBS	6533.90412	6536.331679	0.037%
Sugarcane land productivity PR	0.363256989	0.428569974	15.2%
Sugarcane land productivity PBN	0.205723053	0.226089953	9%
Sugarcane land productivity PBS	0.810959425	0.918431634	11.7%

Based on the calculation in table 1 and table 2, all the error rates are less than 5%, and error of variance is less than 30% which means that our model is valid.

5. SCENARIO DEVELOPMENT

Scenario development is carried out to see what might happen in the future by adding new parameters or changing existing structure.

5.1 Land Extensification

In the land extensification scenario, land expansion or expansion will greatly affect the yield of sugarcane in Indonesia. According to the results of an interview with PT. PTPN X, the potential for expansion of the sugarcane area reaches 124,000 ha and only one sugar factory can be established. The potential for land expansion has been studied by the Indonesian Sugar Plantation Research Center (P3GI) and from the aspects of temperature, temperature, soil texture and soil pH it is quite suitable for sugarcane cultivation. With the expansion of land in Madura, it is expected to boost sugarcane production as a raw material for sugar to achieve sugar self-sufficiency in the following year. The land extension scenario model

by adding the potential area for expansion of sugarcane can be seen in Figure 7

Figure 7: Sugar land expansion

The equation of the Total Harvested sugarcane production variable after expansion is as follows:

Total harvested Sugarcane:

$((\text{expansion potential area} + \text{government total area}) * \text{government land productivity}) +$

$((\text{expansion potential area} + \text{private total area}) * \text{private land productivity}) +$

$((\text{expansion potential area} + \text{smallholder total area}) * \text{smallholder land productivity})$

5.2 Land Intensification

Sugarcane land intensification can be carried out for existing plantations by maximizing the factors that affect sugarcane production. The land intensification scenario is a parameter scenario where the modified parameter is the "cane seed" parameter for the use of superior and newest seeds. Superior seeds consist of two types, namely A1 (Quarantine Plant Destruction Organisms) and treatment-free, where there is a guarantee that imported sugarcane seeds to be planted are superior seeds that are safe and free from pests, thereby increasing sugarcane production (Kementerian Pertanian Republik Indonesia, 2020). In addition to improved sugarcane seeds, the intensification scenario is carried out by improving irrigation for water adequacy, fertilizing according to needs so that it will increase the amount of sugarcane production per hectare and will affect the increased productivity of sugarcane.

With equation:

$\text{increasing in productivity} = \text{quality seeds} + \text{rainfall} + \text{temperature} + \text{irrigation effect} + \text{fertilizer use}$

$\text{fertilizer use} = \text{anorganic fertilizer} + \text{organic fertilizer}$

5.3 Sugar Production after land Intensification and Ekstensification

Sugar production scenario is a scenario based on intensification and

extensification. Based on the scenario there is an increase in production in 2020 to 2030 with an increase of around 7% per year. The scenario graph of sugarcane production can be seen in Figure 8.

Figure 8: Chart of Sugarcane production

5.4 Scenarios of Processing the Residual Harvested Sugarcane

Processing of sugarcane residue can be used into silage and biobriquette. Silage is a fermented feed with a high moisture content which is given to ruminants or can be used as biofuel. The bacteria that play a role can provide more nutrition for ruminants. Apart from being used as feed for ruminants, silage can be processed into biofuel.

Figure 9: Residual harvested Sugarcane stockflow diagram

With the scenario of utilization of crop residues, it can increase worker fees due to the results of silage and biobriquettes.

6. CONCLUSION

The highest harvested area is smallholder plantations which contribute to the fulfillment of sugarcane production by almost 60%, but the productivity value is still low compared to large private plantations so that sugarcane production in Java is not maximized. From the intensification scenario on the use of superior seeds, sugarcane productivity increases by 1.03% per year and sugarcane production also increases in smallholder plantations. Sugarcane production at PBN increased by an average of 0.96% per year and PBS increased by an average of 1.52% per year. The expansion scenario in land expansion, sugarcane production increases by an average of 14.10% per year. From the scenario the remaining crop processing into silage can produce an average of 472,500 tons per year of nutritious silage products from sugarcane leaf waste for animal feed, this helps cattle breeders to meet their animal feed needs. Suggestions for further research are to develop scenarios related to water availability, both repairing irrigation and making water containers during the rainy season. In terms of utilization of sugarcane production waste, scenarios of compost fertilizer and other by-products from sugarcane waste can be developed.

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Cite the Article: Hawwin Mardhiana, Erma Suryani, Ully Asfari, Muhammad Nasrullah (2021). System Dynamic Framework: Increasing Productivity of Sugarcane to Support Sustainable Cultivation. *Sustainability in Food and Agriculture*, 2(2): 105-109.