Increasing Paddy Production Through Integrated Farming System Using System Dynamics Modeling

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Abstract: Paddy is a strategic commodity that plays an important role in the economy and national food security. Fulfillment of rice for people's needs is very important for Indonesia because the population continues to increase every year with a wide and spread geographical coverage. This increase in population has an impact on the demand for rice, which also increases. Until mid-2021, Indonesia is still importing rice from various countries to meet rice needs. Therefore, strategies and efforts are needed to increase paddy production so that it does not depend on imported activities which can drain the country's foreign exchange. Agricultural activities around the world can be produced relatively well and sustainably only if there is a large energy input. In a sustainable context, integrated farming systems are considered as a breakthrough for sustainable agricultural systems. Previous research has tackled this problem by focusing on solutions to monoculture farming systems. This study aims to develop a simulation model to increase paddy production by implementing an integrated farming system as a scenario solution using a system dynamics approach. System dynamics was chosen because of its uniqueness which can simulate a complex and dynamic system. The results showed that the system dynamics approach can be used to model the current paddy production system well. Furthermore, through a predetermined improvement scenario, namely the application of an integrated farming system, paddy production and rice production can be increased by 15.26% and 15% respectively for the next 17 years.

1 INTRODUCTION

Paddy is a rice-producing plant, one of the main food needs for most Indonesian people. In recent years, paddy production in Indonesia has experienced instability, where a drastic decline occurred in 2018 (30.54%) caused by weather factors (dry season) which caused agricultural land to become dry and cause crop failure (Suryani et al., 2022). Malang Regency in East Java Province is an area that has great potential in the agricultural sector which produces food crops such as paddy, corn, peanuts, green beans, soybeans, cassava, sweet potatoes and many more. In 2020, Malang Regency produces 481,001 tons of paddy, which is a decrease from the previous year, which was able to produce 498,586 tons, while the level of rice consumption per capita is 114.8 kg/year (B.P.S., 2020). On the other hand, population growth is still faster than the rate of food production in various places due to limited land and water for agriculture and the impact of global climate change (Agus, 2018). The higher the population, the higher the demand for rice food. In addition, an increase in population will also lead to an increase in demand for land for residence, which causes the conversion of land from agricultural land to non-agricultural land which often occurs. With the decreasing agricultural land, of course this will threaten the stability of paddy production. The lack of rice supply has the potential to cause social, economic, and political instability in the country. Therefore, a large supply of paddy is needed to meet the increasing demand for food.

The current agricultural system is dominated by conventional farming which leads to the cultivation of similar crops (monoculture) which forces the continuous use of chemical (inorganic) fertilizers and pesticides. This has the potential to cause ecosystem damage which can cause land degradation and contaminate surface and ground water (Musa et al., 2018). Agricultural businesses around the world can produce optimally and sustainably only if there is a large energy input. In a sustainable context, an integrated farming system is a breakthrough for a sustainable agricultural system. The application of an integrated farming system is an intensification of the agricultural system through integrated resource management

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between crops and livestock. The application of an integrated farming system is highly recommended to increase agricultural production, farmer income, optimal use of agricultural waste to produce environmentally friendly agriculture (Mukhlis et al., 2018).

Previous research stated that increased paddy production could be increased by implementing massive post-harvest harvesting mechanisms together with implementation of GAP (Good Agricultural Practice) according to standards (Aprillya et al., 2019). Meanwhile (Findiastuti et al., 2018) states that expanding irrigation areas and increasing agricultural investment is a sustainable food security solution. This study aims to increase paddy production for food security by implementing an integrated farming system scenario.

The agricultural production system is a complex and dynamic system over time because it can be influenced by many interrelated factors. All types of dynamic contextual factors from time to time can be modeled through system dynamics modeling. System dynamics modeling is a method that can be used to represent the relationship between variables and components in a system such as a paddy production system. This study uses a system dynamics approach to understand the real conditions of the paddy production system. The system dynamics approach is very effective in helping to understand the behavior of complex components. Therefore, this study aims to develop a simulation model for paddy production systems and analyze the simulation results based on the scenarios applied.

2 RELATED WORKS

Conducted an analysis of the factors driving increased paddy production from the cultivation and post-harvest side as a basis for developing policy strategies (Aprillya et al., 2019). There are two scenarios proposed for the strategy to increase the quality of paddy production, namely (1) increasing agricultural equipment and machinery, and (2) increasing seed varieties. The scenario of increasing agricultural equipment and machinery is sufficient to provide a more significant effect. Harvest and post-harvest mechanisms can be improved by replacing traditional tools with modern agricultural tools accompanied by the implementation of Good Agricultural Practice (GAP). Findiastuti et al. (Findiastuti et al., 2018) presents a simulation of an assessment of Indonesian Sustainable Food-Availability (ISFA) to support policy adjustments in achieving sustainability. The simulation was carried out in three stages for seven policy scenario options and six policy scenario combinations to analyze how they affect food availability and agricultural emissions. The ISFA ratio and food availability score were defined as objective performance. Scenarios that mediate government policies carried out during the 2015–2019 period which are then simulated until 2025. Scenarios were developed to represent Indonesian government policies to achieve sustainable food availability in 2015–2019. The result is a combination scenario of expanding irrigation areas and increasing investment policies is the best policy for ISFA. Sekaran et al. (Sekaran et al., 2021) explores the beneficial properties and contribution of integrated crop-livestock systems (ICLS) to food security, along with their social and economic benefits, and proposed strategies for adopting ICLS in low income countries, medium, and high. This study assesses the production of more plant residues under ICLS that can be used as animal feed. ICLS can influence household dietary diversity and support subsistence farmer incomes and reduce economic risk. Reinventing crops and livestock systems could have many potential benefits such as higher socio-economic returns and better environmental conditions. In low, middle, and high-income countries, success in implementing ICLS requires organizational and/or institutional support to form new marketing opportunities and the application of ICLS can be increased if government policies can provide markets, capital, and educational service assistance for subsistence farmers. However, adopting ICLS requires deep commitment and knowledge of crops and livestock.

3 RESEARCH METHODS

To overcome the problems in this study, a system dynamics approach was used because of its ability to deal with various complex problems. System dynamics is a continuous simulation technique introduced by Jay Forrester from MIT around the 1960s. System dynamics focuses on the structure and behavior of the system consisting of interactions between variables and feedback loops (Suryani, 2006). System dynamics is an approach to study the dynamics of the behavior of the observed system. System dynamics modeling is considered suitable to be applied in this study because it is based on feedback on each structure of the system that affects other structures. There are 5 stages that need to be carried out in developing a system dynamics model (Sterman, 2000), namely problem articulation, dynamic hypothesis, formulation, testing, and policy formulation.

3.1 Problem Articulation

In this process observations are made of systems in the real world that are the object of observation. After that, the key variable is determined. Defining the problem is also done through literature study, by digging up information through the literature as a source of basic concepts or previous research that has been done regarding the object of the problem in the form of journals, books, theses, or online references. The data obtained from the literature is used as a material consideration in determining the significant variables and additional variables that influence each other in the system. In this study, the data used was obtained from several related government agency sites such as the Central Statistics Agency (BPS) (B.P.S., 2020; B.P.S., 2019; B.P.S., 2018); the Ministry of Agriculture (Balitbangtan, 2019; RI, 2019); the Office of Agriculture and Food Security of East Java Province, as well as news portal sites to understand the latest developments regarding the situation in paddy farming. Historical data on paddy and rice production were used in this study from 2008 to 2020 for simulation purposes and their validation.

3.2 Dynamic Hypothesis

After the process of problem articulation, the next step is to develop a dynamic hypothesis to account for the problem behavior. Several internal/endogenous and external/endogenous variables that affect rice production are obtained based on the results of the previous stage. In addition, at this stage a casual structure description is also carried out based on a literature study adapted to the system object. Modeling begins by creating a Causal Loop Diagram (CLD). This diagram contains a series of variables (components) that each represent a process or status and form a series of processes with an emphasis on causal aspects (Prahasta, 2018). Each relationship describes the causality between these variables. Each relationship also has a positive (+) or negative (-) polarity to describe how the relationships between these variables influence one another. CLD has two types, namely reinforcing loop (R) which shows the strengthening of a cycle, and balancing loop (B) which shows the stability/balance of a cycle.

3.3 Model Formulation

The next step in developing a system dynamics model is to build a simulation model formulation through a Stock Flow Diagram (SFD). This stage tests the dynamic hypothesis of CLD. The development of SFD is CLD oriented, but in SFD new components and information flow (cause-effect relationships) can be added, without changing the big picture of the system that has been described in the CLD structure (Soesilo and Karuniasa, 2014). This stage also determines the formulation of the equations of each variable as well as the estimation of the initial values and parameter values.

3.4 Testing

According to (Barlas, 1989) the system statistical validation process can be carried out in two ways of testing, namely statistical model validation by testing the average error rate $(E1)$ and model validation by testing the comparison of amplitude variations or error variances (E2). The model is said to be valid if $E1 \leq 5\% and E2 \leq 30\%$. The equations for model validation are shown in Equations 1 and 2.

$$E1 = \left| \frac{S - A}{A} \right| x100 \tag{1}$$

Where $E1$ is the average comparison, S is the average value of the simulated data, and A is the average value of the actual data.

$$E2 = \left| \frac{Ss - Sa}{A} \right| 100 \tag{2}$$

Where $E2$ is the variance error, Ss is the standard deviation of the simulated data, and Sa is the standard deviation of the actual data.

3.5 Policy Formulation

Policy design involves creating entirely new strategies, structures, and decision rules. Because the feedback structure of a system determines its dynamics, most of the time policy will involve feedback loops effecting by reshaping the stock and flow structure, release the time delay, change the flow and quality of information available at the primary decision point, or substantially reinvent the decision-making process of key players in the system. Based on the objectives of this study, the scenario that will be applied is the application of an integrated farming system to lowland rice farming to increase paddy production, by changing the SFD structure that has been developed and declared valid.

4 RESULTS

In this section, a case study of a paddy production system simulation with a system dynamics approach will be presented. This study begins with the articulation of the problem. In this research, the object of the system to be observed is the paddy production system in Malang Regency, East Java, Indonesia. Malang Regency in 2020 produces 481,001 tons of rice, a decrease from the previous year, which was able to produce 498,586 tons, while the level of rice consumption per capita is 114.8 kg/year (B.P.S., 2020). Simulations were performed using Vensim PLE 9.1.1 x64 simulation software. According to a number of studies, increased paddy production can be influenced by several important factors, such as the use of fertilizers; the use of superior seeds (Aprillya et al., 2019; Ishaq et al., 2016); availability of irrigation water (Suryani et al., 2022; Bashir and Yuliana, 2019); and cropping index (Suryani et al., 2022; Aprillya et al., 2019). In this study, the focus of increasing attention is paddy production and rice production.

4.1 Base Model

Based on the results of the problem articulation, a dynamic hypothesis was developed through CLD which represents the system according to the case in this study, namely the paddy production system. Modeling in CLD also simulta neously displays the proposed scenario, where in this study the proposed scenario is the application of an integrated farming system (green arrow line) to increase paddy production. CLD that has been developed is shown in Figure 1.

Paddy production yields are influenced by the harvested area and the level of productivity per hectare. The harvested area is influenced by the area of paddy fields which has a reinforcing loop (R1) for land expansion and a balancing loop (B1) for land expansion. While productivity is influenced by several factors such as seed varieties, fertilization, availability of irrigation water, and rainfall which have a positive effect on paddy productivity. On the other hand, yield loss from harvesting and threshing, as well as pest and disease attacks on paddy reduces productivity.

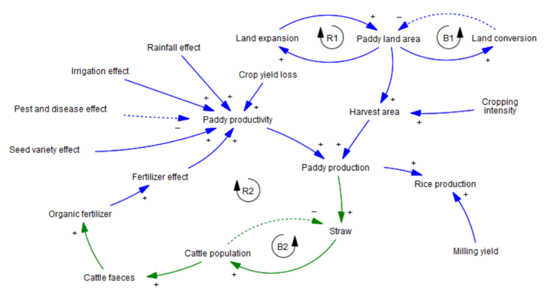

Figure 1: CLD of Paddy Production Systems and Scenarios of Integrated Farming Systems.

The rate of paddy productivity will affect the resulting paddy production. In general, paddy production experienced an increasing trend. Meanwhile, Rice production is the result of converting the productivity of harvested dry grain into dry milled paddy multiplied by the harvested area. Paddy that has been harvested still has to go through several stages to be consumed into rice. Milling is the process required to process harvested paddy/dry milled grain into rice. During the milling process shrinkage will occur. The ratio of the weight of rice to the weight of paddy due to shrinkage is called milling yield. Figure 2 displays a graph of paddy and rice production.

From agricultural activities, agricultural waste can be obtained in the form of rice straw. Straw, which is a waste of paddy plants, is a potential material and is easy to obtain so that it can be reused as an alternative animal feed. Meanwhile, from animal husbandry activities, the resulting livestock manure can be processed into organic fertilizer which is useful for increasing rice productivity and production.

After conceptualizing the system through CLD, SFD development is carried out for model formulation. Figure 2 is the SFD for the base model of a paddy production system.

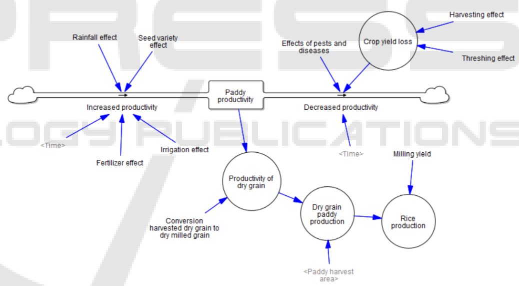

Figure 2: SFD of Paddy Production System.

In general, paddy production in Malang Regency has an increasing trend with an average production of 448224 tons or 1.39% per year. However, in 2019 and 2020 paddy production decreased by 0.28% and 3.53%. Figure 3 shows a graph of current paddy production. Likewise with rice production, the average rice production is 285088 tons or 1.32%. Figure 4 shows a graph of current rice production.

The model that has been developed in the form of SFD will be validated based on Equations 1 and 2. Model validation was carried out in the 2008–2020 period for a better understanding of the system based on available data. Here is some variable validation:

- Paddy Production
  $E1 = 0.60\%$
  $E2 = 18.62\%$

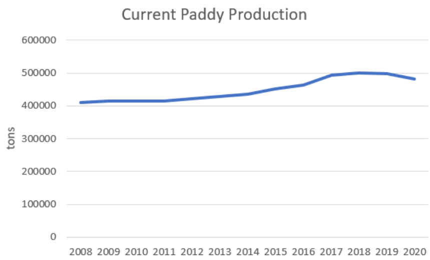

Figure 3: Current Paddy Production.

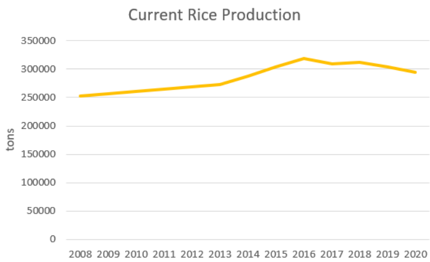

Figure 4: Current Rice Production.

- Rice Production
  $E1 = 1.95\%$
  $E2 = 23.58\%$

Based on the results of validation calculations, the error rate (E1) is $\leq$ 5% and the error variance (E2) is $\leq$ 30%, which means that the model can be said to be valid.

4.2 Scenario Model

After the model is said to be valid, then policy scenarios are formulated to optimize the running system. In this study, the scenario that will be applied is the application of an integrated crop and livestock farming system. An integrated farming system is an intensification of the agricultural system through integrated resource management between crops and livestock. Integrated farming systems are assessed as being able to maintain organic elements in the soil that are always available to create sustainable agriculture (Musa et al., 2018). The scenario model is projected during the 2008-2040 period.

Figure 5 is a model scenario that represents an integrated farming system scenario. Rice farming will produce rice straw. The weight of rice straw is 1.4 times that of dry grain paddy yields (Kim and Dale, 2004). Paddy straw is used as the main fibrous feed for cattle, given as much as 6-8 kg per day. This means that every year it takes 2190-2920 kg or 2.19-2.92 tons of straw for animal feed. After that, feces will be produced from the livestock which can be processed into organic fertilizer which is produced through the formation of biogas. One cow can produce 10-15 kg of manure, where 1 kg of cow manure has the potential to produce 0.03 m3 of biogas (Jimmy and Hudha, 2011). From the processing of livestock manure to producing biogas through the digester, biogas residue will be produced. The biogas residue is used to produce organic fertilizer to return to the field to increase agricultural productivity (Paulus et al., 2022).

Based on the research objectives, this research will focus on the analysis of paddy production and rice production. The simulation results show, first, the scenario results from 2020 to 2040 paddy production are stable with an average production of 567337 tons per year. Whereas in the basic model during this period, paddy production was stable with an average production of 492241 tons per year. A comparative graph of the simulation results of the basic model and scenarios for paddy production is shown in Figure 6. Overall, the scenario of implementing an integrated farming system can increase paddy production by 15.26%.

Second, it can be seen in Figure 7, the scenario results from 2020 to 2040, rice production is stable with an average production of 355947 tons per year. A significant increase occurred in 2016 of 13.88%. Meanwhile, in the base model during this period rice production was stable with an average production of 308832 tons per year. Overall, the scenario of implementing an integrated farming system can increase rice production by 15% until 2040.

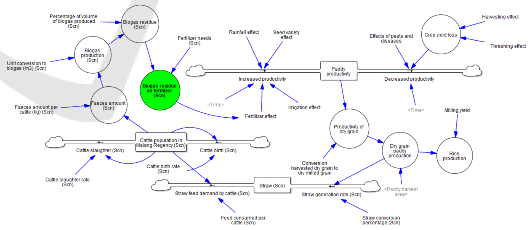

Figure 5: Current Paddy Production.

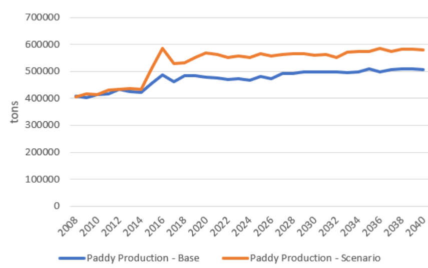

Figure 6: Current Rice Production.

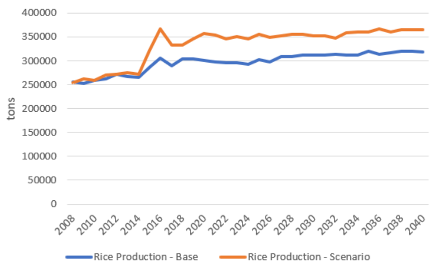

Figure 7: Current Rice Production.

5 CONCLUSIONS

The paddy production system is a system with complex problems with various variables that are interrelated to each other in it. In this study, paddy production was influenced by harvested area and paddy productivity per hectare. The system dynamics approach is used in this study to find solutions to increase paddy production. Causal Loop Diagram (CLD) was developed to visualize the relationship between variables in the paddy production system, which was then developed with a Stock and Flow Diagram (SFD) to simulate the current paddy production system. Several validations were also carried out to prove that the simulation represented the current system based on the available data. The simulation results on the basic model are considered valid because the validation results obtained are $E1 \leq 5\%$ and $E2 \leq 30\%$. Through the scenario of the integrated farming system implemented, paddy production (15.26%) and rice production (15%) can be increased for the next 17 years. Overall, from 2008 to 2040 the average of paddy and rice production increased by 15%.

The system dynamics approach is useful for providing insight for stakeholders to find solutions in increasing the production of paddy or other agricultural commodities. This study focuses on the analysis of the integration of agriculture and livestock on paddy and rice production behavior, but other aspects of integrated farming systems are not considered. Another limitation of this study is the increase in paddy production from fertilization intensification, while postharvest handling was not considered. Further research can be carried out by focusing on the quality of postharvest handling or it can also focus on other aspects of integrated farming systems such as the energy produced for community energy efficiency.

REFERENCES

Agus, C. (2018). *Pertanian terpadu untuk mendukung kedaulatan pangan nasional*. UGM PRESS.

Aprillya, M., Suryani, E., and Dzulkarnain, A. (2019). System dynamics simulation model to increase paddy production for food security. *Journal of Information Systems Engineering and Business Intelligence*, 5:67.

Balitbangtan (2019). *Menuju balitbangtan terdepan dalam penelitian pangan dan pertanian*. IAARD Press.

Barlas, Y. (1989). Multiple tests for validation of system dynamics type of simulation models. *European journal of operational research*, 42:59–87.

Bashir, A. and Yuliana, S. (2019). Identifying factors influencing rice production and consumption in indonesia. *Jurnal Ekonomi Pembangunan: Kajian Masalah Ekonomi dan Pembangunan*, 19:172–185.

B.P.S. (2018). Survei konversi gabah ke beras 2018 (skgb. Badan Pusat Statistik (BPS),.

B.P.S. (2019). Luas panen dan produksi padi di indonesia 2019. Badan Pusat Statistik (BPS), 2019).

B.P.S. (2020). Luas panen dan produksi padi kabupaten malang tahun 2020.

Findiastuti, W., Singgih, M., and Anityasari, M. (2018). Indonesian sustainable food-availability policy assessment using system dynamics: A solution for complexities. *Cogent Food & Agriculture*, 4:1455795.

Ishaq, M., Rumiati, A., and Permatasari, E. (2016). Analisis faktor-faktor yang mempengaruhi produksi padi di provinsi jawa timur menggunakan regresi semiparametrik spline. *Jurnal Sains Dan Seni ITS*, 5.

Jimmy, J. and Hudha, M. (2011). Potensi pemanfaatan biogas di kabupaten malang, jawa timur. *Spectra*, 9:35–47.

Kim, S. and Dale, B. (2004). Global potential bioethanol production from wasted crops and crop residues. *Biomass and bioenergy*, 26:361–375.

Mukhlis, M., Noer, M., Nofialdi, N., and Mahdi, M. (2018). The integrated farming system of crop and livestock: a review of rice and cattle integration farming. *International Journal of Sciences: Basic and Applied Research(IJSBAR*, 42:68–82.

Musa, Y., Syam'un, E., Pomalingo, E., Bahwi, S., and Rusli (2018). Peningkatan produktivitas lahan dan pendapatan petani melalui integrasi tanaman dan ternak. *Integrated Farming System*, page 3–9.

Paulus, J., Lengkey, L., and Najoan, J. (2022). Penerapan teknologi biogas sebagai sumber bahan bakar dan pupuk organik untukmeningkatkan kesejahteraan petani di desa pinaling minahasa selatan. *Agrokreatif: Jurnal Ilmiah Pengabdian kepada Masyarakat*, 8:220–227.

Prahasta, E. (2018). *Systems thinking pemodelan sistem dinamis*. Penerbit Informatika.

RI, K. (2019). *Buku outlook komoditas peternakan sapi potong daging sapi*. Pusdatin Pertanian.

Sekaran, U., Lai, L., Ussiri, D., Kumar, S., and Clay, S. (2021). Role of integrated crop-livestock systems in improving agriculture production and addressing food security–a review. *Journal of Agriculture and Food Research*, 5:100190.

Soesilo, B. and Karuniasa, M. (2014). *Permodelan system dynamics untuk berbagai bidang ilmu pengetahuan kebijakan pemerintah dan bisnis,"(Lembaga*. Penerbit Fakultas Ekonomi Universitas Indonesia.

Sterman, J. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Jeffrey J. Shelstad.

Suryani, E. (2006). *Pemodelan dan Simulasi*. Graha Ilmu.

Suryani, E., Hendrawan, R., Muhandhis, I., and Indraswari, R. (2022). A simulation model to improve the value of rice supply chain: A case study in east java–indonesia. *Journal of Simulation*, 16:392–414.