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# Simulation of System Dynamics for Improving the Quality of Paddy Production in Supporting Food Security

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***Abstract***

**Background:** The food security policy is an effort to ensure stable food availability and stable access of the community to food. As the population increases, this will affect the fulfillment of food needs in the future. Therefore, increase in rice production is needed to support food security.
**Objective:** Conduct an analysis of the factors affecting the quality of rice production by using a dynamic system simulation that can be used as a basis for formulating policy strategies.
**Method:** Simulation using System Dynamics (SD) is a method used to study and analyze complex systems by modeling non-linear behavior. Then several scenarios were carried out for the best decision-making using a computer.
**Result:** The results of the scenario show that increasing the quality of paddy production in order to meet food needs in the future is doable by boosting the rendement of paddy as it will upgrade rice production which will contribute greatly to rice production.
**Conclusion:** From the simulation results, the study can be used to increase the quality of rice production to maintain food security by improving the harvesting mechanism to increase yields. For further research, the use of Smart Agriculture can be considered to increase production of rice.

***Keywords:*** Food security, Rice production, Rice production, System dynamics

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## I. INTRODUCTION

The ability of a country to guarantee the availability of food and the easy access of the people to food in a stable manner is the notion of food security [1]. Rice is the most important crop in the world because it serves to meet the world's food needs [2]–[4]. The majority of rice is consumed as a staple food for most of the world's population, especially in developing countries [5]. Most people in Indonesia choose rice as a staple food and the main source of carbohydrates [2] [6] . The growing population will certainly affect food needs, and this will require a large enough food supply with better quality [7][8].

The food crop sector is affected by interrelated factors, such as climate change [4], [9], increasing population [10], land conversion agriculture [3], natural disasters [11], and extreme changes in rainfall patterns and climate in several regions [2]. The food and agricultural systems have a predominant feedback complexity structure with test-based robust systems and integrated solutions [12]. To be better prepared for future uncertainties and disturbances, it is necessary to develop efficient policies regarding food security. The success of a policy in an agricultural system certainly requires extensive knowledge and expertise [13]. Developing appropriate and efficient policies will require decision support tools [7]enabling stakeholders to jointly develop strategies. All types of contextual factors have the potential to be modeled through a model approach such as a system dynamic approach to obtain the best agricultural management decisions.

System dynamics can help in understanding, visualizing, and analyzing complex systems with dynamic feedback [1]. Simulations using system dynamics can be used to model dynamic behavior and interactions between interrelated

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factors easily using scenarios or system changes [4], [14]. System dynamics provides an advantage in studying complex systems using system diagrams and simulation models [7] also in the field of agricultural development. Bala's research [11] uses a dynamic system model to provide learning of rice supply chain systems and can be used to design policy options for efficient and sustainable rice supply chain management. Wicaksono's research [15] uses a system dynamics to model variables that can increase rice production. Chung's research [16] used a model system dynamic for rice value chain system in Malaysia, this model was developed for decision-making processes that occur along the rice value chain based on a dynamic structure. Thus, simulation with system dynamics method can be used to describe the interaction between agriculture, environment, food security and livelihoods to obtain measurable output in various scenarios and to formulate a policy that can be implemented into the system [11], [17].

This research uses system dynamics for improve the quality of rice production. The resulting scenario can be used as a instrument to formulate a policy for stakeholders in rice production to maintain food security. This paper is structured as follows: Chapter 1 shows background, chapter 2 is method, chapter 3 is results, chapter 4 the discussion and chapter 5 is conclusions of the research.

## II. METHODS

Simulation with system dynamics was introduced by Jay Forrester. System dynamics can be used to enhance understanding in complex systems [7] and analyzingwith dynamic feedback [18] . An approach using system dynamics can assist decision-makers in formulating policies that can be implemented properly within a certain time period [7], [18]. The study consists of four actions: collection of data , analyze current conditions, identify important variables, design models: causal loop diagrams and develop a basic model in the form of stock flow diagrams , as well as carry out processes simulation with scenario development using Vensim software.

### *A. Data collection*

Primary data used in building a rice production quality model includes data of rice production unit tons, paddy productivity unit tons/ha, paddy field area unit ha, harvested area unit ha and other data related to rice plants obtained from several parties such as Central Bureau of Statistics (BPS) of East Java, Office of Agriculture and Food Security of East Java Province. The primary data in this study are used as a validation instrument and to compare the components in the model with the actual system. Data on harvested area (ha), rice production (tons), rice productivity (tons/ha), and population (millions) are displayed in Table 1.

TABLE 1
COLLECTING DATA

| Year | Harvest area | Rice production | Rice productivity | Population |
|---|---|---|---|---|
| 2007 | 1,736,048 | 9,402,029 | 5.42 | 36,506,003 |
| 2008 | 1,774,884 | 10,474,773 | 5.90 | 37,100,570 |
| 2009 | 1,904,830 | 11,259,085 | 5.91 | 37,310,619 |
| 2010 | 1,963,983 | 11,643,773 | 5.93 | 37,565,706 |
| 2011 | 1,926,796 | 10,576,543 | 5.49 | 37,840,657 |
| 2012 | 1,975,719 | 12,198,707 | 6.17 | 38,106,590 |
| 2013 | 2,037,021 | 12,049,342 | 5.92 | 38,363,195 |
| 2014 | 2,072,630 | 12,397,049 | 5.98 | 38,610,202 |
| 2015 | 2,152,070 | 13,154,967 | 6.11 | 38,847,561 |
| 2016 | 2,278,460 | 12,726,463 | 5.59 | 39,075,152 |
| 2017 | 2,285,232 | 13,060,464 | 5.72 | 39,292,972 |

Secondary data in this study were in the form of previous research on system dynamics and research on increasing quality rice production. These data are used for modeling materials and for scenario model development purposes. Some of the supporting literature in this study was taken from journals, expert opinions regarding the problems and challenges faced in quality rice production.

### *B. Analysis of the Current Conditions of Rice in Asia*

Rice (Oryza Sativa) is a staple food crop in several developing countries. As the population increases, it will affect the fulfillment of food which also increases [4]. The product of rice farming is a material that is easily damaged, so it requires fast and precise handling. Improper handling will cause losses to farmers [9]. The food crisis in 2007–2008 impacted mainly developing countries. The food crisis pushed Asian countries to increase domestic production to reduce imports [19]. Rice production has increased in the last period with rice self-sufficiency, but the availability of rice has not been fulfilled for consumers [11].

*C. Identification of Significant Variables*

Identification of significant variables is used to describe the interaction of several variables in a model. This research uses three component models (sub-models), including: paddy land area and harvested area sub-model, paddy productivity and production sub-model, and population and rice demand sub-model. The sub-model of paddy land area and harvested area consists of important variables such as expansion of agricultural land and conversion of agricultural land [4], [15]. The paddy productivity and production sub-model consists of several influential variables including pests [10], cropping intensity [20], [21], types of rice varieties [22], rainfall [23], and changes in weather [24]. The population and rice demand sub-model consists of several influential variables including rice production [25], population [7], [26], rice price [11]and the need for rice consumption per capita [27].

*D. Computer Model Design*

The following are the steps used in developing a dynamic system model based on Streman [9]. First, understand the system for generating problem articulations. Second, formulate the dynamics hypothesis. Third is simulation model formulation. Four, test the simulation model. Five, is the design and evaluation of policies. At this stage, the CLD is used to represent the system feedback structure. It is used to show the interaction and relationship of variables with the model. Causal relationships in a model are indicated by positive (+) and negative (-) arrows. The Causal Loop Diagram model that will be developed in this study can be seen in Fig. 1.

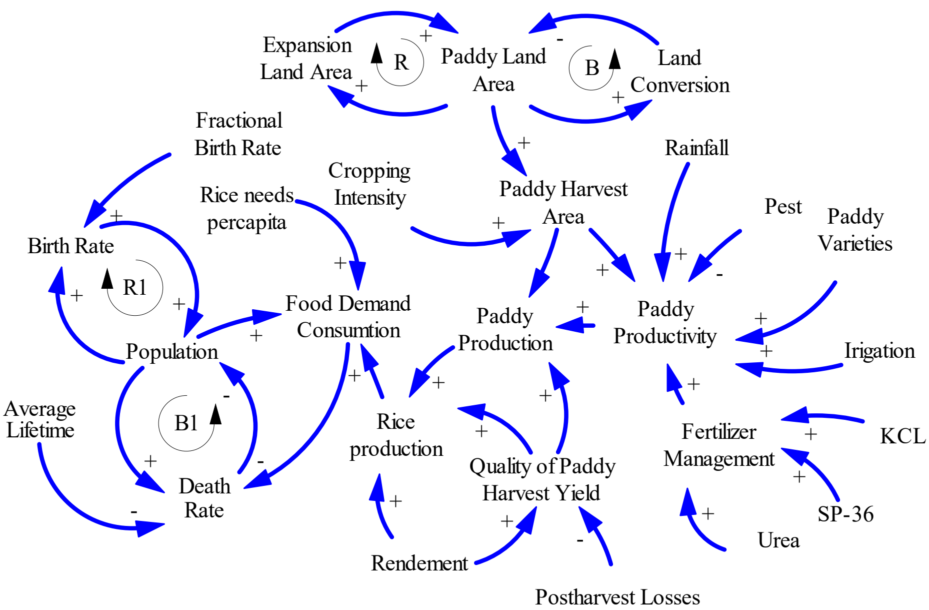


Fig. 1Causal Loop Diagrams

In the sub-model of paddy area and harvested area, a positive relationship (+) occurs when there is opening of new land used as agricultural land, a negative relationship (-) occurs when there is an increase in the conversion of paddy fields to the construction of housing, industry and other facilities. In the productivity and paddy production sub-model, a negative relationship (-) occurs when there are pests and postharvest losses which result in losses to farmers, a positive relationship (+) occurs when there is an increase in cropping intensity, superior rice varieties, irrigation and fertilization done properly will help increase paddy productivity and paddy production. In the population and rice demand sub-model, a positive (+) relationship occurs when the population increases and will affect the rice needs. Population is influenced with a positive (+) relationship in the form of birth rates and a negative relationship (-) in the form of death rates.

For the next step, the basic mpdel is added to the stock and flow diagram to describe the flow structure in detail with a mathematical model. The following is a stock and flow diagram of the sub model of paddy field area and harvested area, the sub-model of productivity and paddy production, and the sub-model of population and demand for rice are shown in Fig. 2.

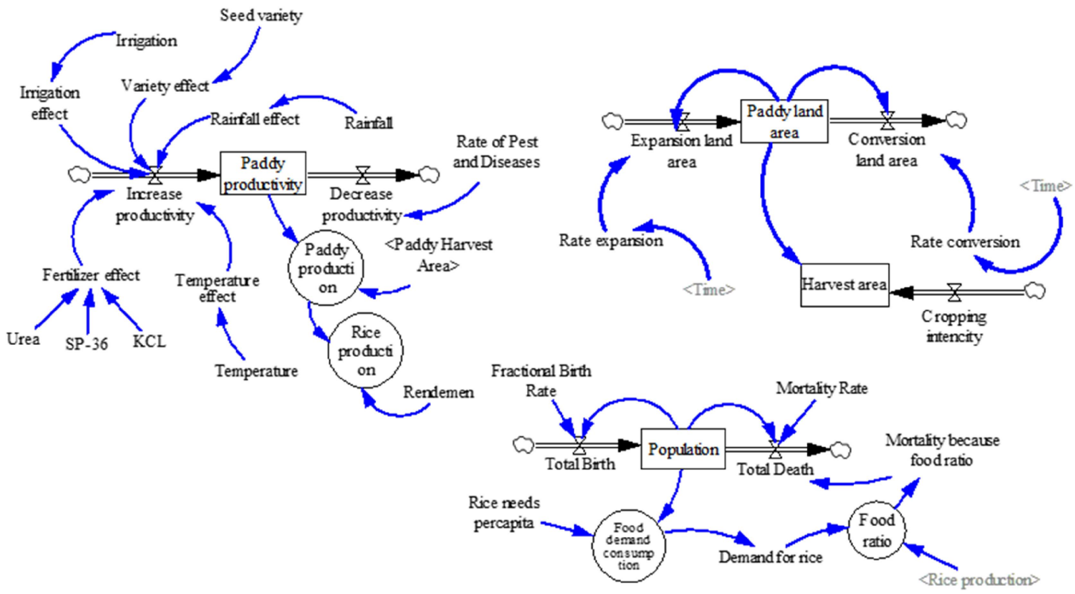


Fig. 2Stock and Flow Sub-Models

To check the accuracy of the model created, validation is needed. The model is said to be valid when the error (E1) is less than or equal to 5% and the error variance (E2) is less than or equal to 30% [18]. E1 and E2 are calculated as shown in equations (1) – (2).

$$E1 = \frac{|(Average\ Rate\ of\ Simulation\ Result) - (Average\ Rate\ of\ Data)|}{Average\ Rate\ of\ Data} \quad (1)$$

$$E2 = \frac{|(Standard\ Deviation\ of\ Model) - (Standard\ Data\ Deviation)|}{Standard\ Data\ Deviation} \quad (2)$$

To predict the possibilities that will occur in the future, it is necessary to develop scenarios by adding new parameters or changing existing structures. Simulations are carried out with insert parameter values or by changing the structure of a model [3]. At this stage, the model that has been created will be modified using three scenarios, including : the first scenario of applying GAP (Good Agricultural Practice) practices [7], [28] to reduce yield losses. In the second scenario, the use of high-yielding seed varieties and improved fertilization management can increase rice productivity [19] [29][22], [23]. The third scenario is the application of Smart Agriculture to increase farmer awareness regarding the adoption of information technology in agriculture [30], [31].

## III. RESULTS

### A. Analysis of Basic Model

The level of productivity and harvested area will affect the level of paady production in East Java. This base model analysis uses the time range from 2007-2017 shown in Fig. 3 below.

### B. Validation Output

Model validation is used to ensure the model can represent the actual system. There are two ways to test the model including structural testing and behavioral validity. In structural testing, examining the stock flow diagrams can be done by experts to assess the relationship between variables and the mathematical equations of each variable [7]. Structural testing is carried out to ensure that all variables are interconnected, and nothing is stopped [32]. Model behavior testing is used to test the substance of the model according to the goals to be achieved. The test was carried out with the E1 and E2 comparison tests. If the results of E1 are less than or equal to 5% and E2 are less than or equal to 30% then the model can be said to be valid [3]. The results of the validation of rice production with a comparison of the average E1 and E2 test results for the comparison of amplitude variations (% error variance) are shown in Table 2

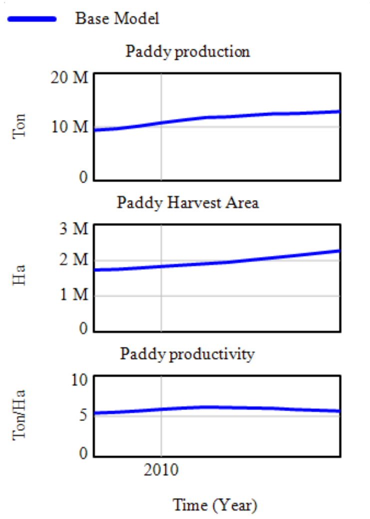


Fig. 3Base Model Analysis

TABLE 2
MODEL VALIDATION OF PADDY PRODUCTION

| Year | Real Data | Model Simulation |
|---|---|---|
| 2007 | 9,402,029 | 9,409,391 |
| 2008 | 10,474,773 | 9,686,409 |
| 2009 | 11,259,085 | 10188235 |
| 2010 | 11,643,773 | 10,800,941 |
| 2011 | 10,576,543 | 11,325,856 |
| 2012 | 12,198,707 | 11,802,480 |
| 2013 | 12,049,342 | 11,925,639 |
| 2014 | 12,397,049 | 12,219,676 |
| 2015 | 13,154,967 | 12,494,466 |
| 2016 | 12,726,463 | 12,541,276 |
| 2017 | 13,060,464 | 12,728,299 |
| 2018 | 12,917,622 | 12,917,622 |
| Means | 11,503,358 | 11,821,735 |
| Standard Deviation | 1,216,610 | 1,133,740 |
| E1 | | 3% |
| E2 | | 7% |

The validation results show a valid model with an E1 value of 3% and an E2 of 7%. This graph shows a comparison of the original data and simulated data in Fig. 4.

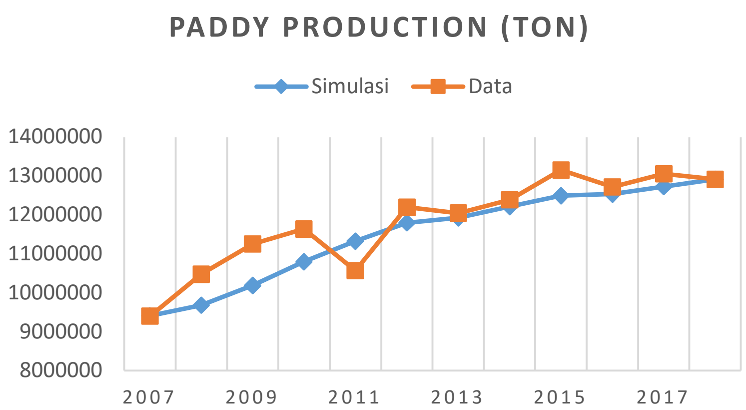


Fig. 4 Validation Base Model Paddy Production

Structural testing is carried out to ensure that the models created are interconnected and have the correct units for each variable. If the structural testing of the model is correct, the notification "Model OK" and "Unit OK" will appear. The following is a view of the model being verified and having the correct units as shown in Fig. 5.

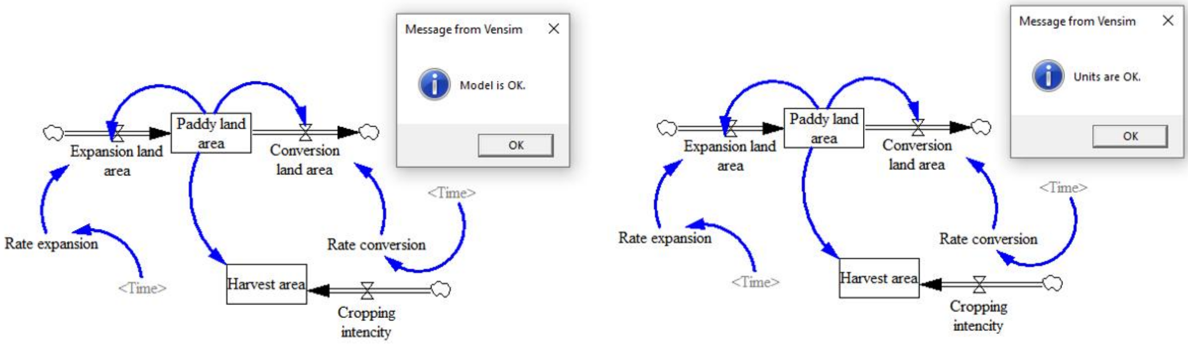


Fig. 5 Models Valid

## *C. Scenario Results*

To predict future possibilities, scenario development is carried out by adding new parameters or changing existing structures. At this stage the model that has been made will be modified using three scenarios as below.

### *1) Scenario of Good Agriculture Practice*

The steps taken are to reduce the amount of yield loss by implementing changes in harvesting, threshing, drying and milling methods through model simulations to reduce the amount of crop and postharvest losses, so that additional rice yields are obtained by saving yield losses. In the first scenario, the postharvest loss scenario is a change in the use of tools or machines in handling harvest and postharvest rice. Harvesting equipment uses a harvester machine, threshing uses a power thresher, drying uses a flatbed dryer and milling uses a conventional method. From the results of the simulation model scenario 1 that has been run, Fig. 6 is a graph of rice production (tons) based on efforts to reduce yield losses

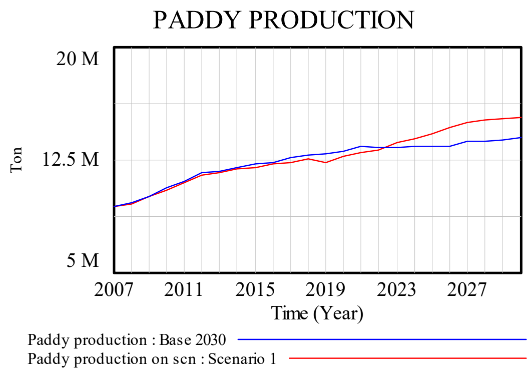


Fig. 6Scenario 1 Good Agriculture Practice

### *2) Scenario of Increased Rendemen*

The yield of rice is a quantity used to determine the quality of grain into rice [22] . National yields averaged 70% in the late 70's. However, every year there was a decrease, to 65% in 1985, and again to 63.4% in 1999 [33] and when referring to the results of the census conducted by BPS in 2012, the average rice yield was 62.42%. Some of the things that affect rice yields include the variety or rice seeds used, the initial handling method, and the mechanism of machine performance used at the post-harvest stage, especially the milling process [24] . However, according to research, the milling configuration does not have a significant effect on rendemen of paddy [25] [34]. The rendemen of paddy scenario model can be seen in Fig. 7.

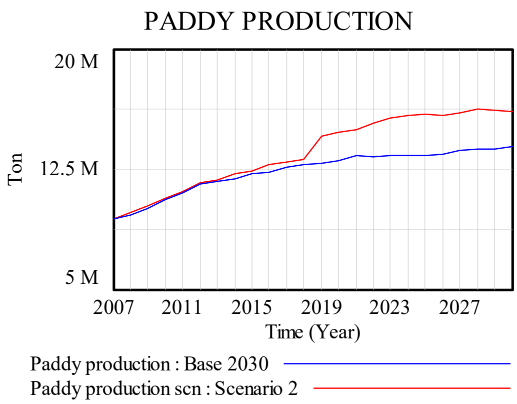


Fig. 7 Scenario 2 Rendemen Rice

*3) Scenario of Smart Agriculture*

In an effort to deal with climate change, the third scenario is carried out by conducting training and learning counseling which is expected to reduce the productivity gap. Training and extension policies for farmers result in higher productivity [26]. Agricultural training and counseling have a good impact on agricultural production for food security efforts in several researches [27]. In addition, the application of "Smart Agriculture" including the adoption of GPS (Global Positioning System) and Wireless Sensor Networks (WSNs) is also believed to be helpful as a potential tool toward the goal of automation in agriculture [28]. Fig. 8 is a table of paddy productivity simulation results and the basic model based on the third scenario

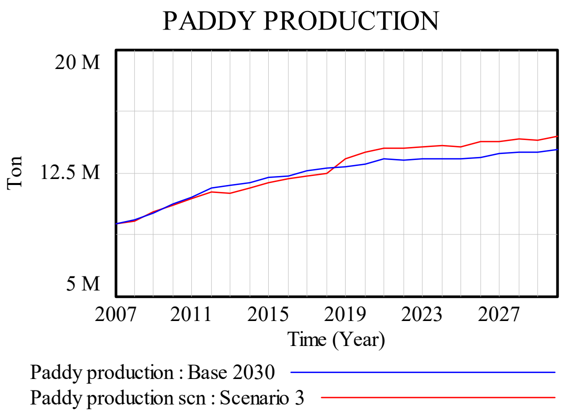


Fig. 8 Scenario 3 Agriculture Intelligent

## IV. Discussion

In this study, simulation used the System Dynamics (SD) method, which is especially suitable for complex dynamic and non-linear relationships [7]. The food and agricultural systems have a predominant feedback complexity structure, with test-based robust systems and integrated solutions [12]. To be better prepared for future uncertainties and disturbances, it is necessary to develop efficient policies regarding food security. Developing appropriate and efficient policies will require decision support tools [7] enabling stakeholders to jointly develop strategies. All types of contextual factors have the potential to be modeled through a model approach such as a system dynamic approach to obtain the best agricultural management decisions. System dynamics is based on the concept of non-loop feedback and multilinearity making it suitable for understanding complex and dynamic agricultural systems [11].

The results of the first scenario simulation, namely the application of Good Agriculture Practice, can reduce paddy yield losses by up to 10.69% in 2030. So that the previously simulated paddy production reached 13,941,723 tons in 2030 increased to 15,328,883 tons in 2030. Increased paddy production has an impact on increasing rice production; previously rice production reached 8,719,350 tons in 2030 after the scenario was increased to rice reaching 9,776,419 tons in 2030 .

The results of the second scenario simulation, namely increasing the yield value which includes the use of seeds from superior varieties and improving fertilization methods and the use of biological fertilizers, can have an effect on increasing rendemen. Before the treatment scenario, the yield reached 62% in 2030. Paddy production reached 13,941,723 tons in 2030,rice production reached 8,719,350 tons and the fulfillment ratio reached 2.52. After the scenario, rendemen reached 69% in in 2030, paddy production reached 16,117,029 tons in 2030 and rice production reached 11,083,319 tons while fulfillment ratio reached3.3.

The results of the third scenario simulation are the application of sustainable agricultural extension to increase the capacity of extension to farmers and the implementation of "Smart Agriculture" to increase agricultural productivity. Before the third scenario, productivity reached 4.5 in 2030 and after the third scenario it reached 4.8 in 2030. Paddy production reached 13,941,723 tons in 2030, rice production reached 8,719,350 tons and the fulfillment of the food ratio reached 2.52.

Our findings show that the challenge faced in increasing the quality of paddy production is soil fertility which continues to decline, which affects the national rendemen and production rice. The decrease in land resources results in a decrease in fertility, and pollution reduces soil fertility due to continuous intensification. In addition, the ever-increasing population has affected the need for food both in quality and quantity. The need for land along with the increase in population will continue to increase. So that the need for land for settlement, trade and conversion of other agricultural land functions will increase. This can cause problems that occur in land conditions in the form of decreased fertility thereby affecting productivity and also the yields produced.

Some alternative policies that can be carried out by the government based on the scenarios that have been implemented are conducting training and counseling to farmer groups regarding the importance of implementing GAP (Good Agriculture Practice)-based agricultural practices and increasing farmer awareness regarding the adoption of information technology through Smart Agriculture to improve quality paddy production.

## V. CONCLUSIONS

It can be concluded that the quality of paddy production is affected by crop loss, small value of rendemen and productivity factors (land management). By improving these factors, the quality of paddy production will increase every year. Increasing the quality of rice yields will affect the rice produced, so as to be able to achieve the goal of supplying surplus rice or being able to achieve food security by meeting the rice needs of the population in East Java. From the simulation results it is considered valid with an E1 value 3% and an E2 validation value 7% so the model can be said to be valid . Based on the potential, constraints and opportunities for success, a rational scenario that can be used as a policy decision making to improve quality paddy production is applying GAP practices, use of super seed varieties, and adoption of Smart Agriculture to increase farmer awareness regarding the adoption of information technology in agriculture.

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