Development of Scenarios for Increasing Maize Production In Changing Weather Conditions Using A System Dynamics Approach

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Abstract

Changes in weather have an impact on current agricultural conditions. Weather changes occur due to the large number of human activities that have an impact on the occurrence of extreme weather conditions that are uncertain. Weather is a determining variable that is closely related to agricultural production capacity. The problem of the gap between demand and supply that occurs requires preventive actions that need to be taken to reduce the impact of losses that occur. The aim of this research is to develop a climate change scenario to increase corn production. This study of production problems is approached by mathematical modeling to simulate policies that might be applied to solve the problem. In the approach to increasing maize production, a model is built consisting of 3 sub models, namely the production sub model, the demand sub model, and the profit sub model. The formed model is adjusted to real conditions by verifying and validating it. The models that have been validated and then carried out scenario development based on weather conditions that affect the level of maize production. The scenario development is based on variables that experience the risk impact of weather changes. The weather conditions used are based on normal rainfall, high rainfall, and low rainfall. The scenario development is based on variables that experience the risk impact of weather changes. The weather conditions used are based on normal rainfall, high rainfall, and low rainfall. The scenario development is based on variables that experience the risk impact of weather changes. The weather conditions used are based on normal rainfall, high rainfall, and low rainfall.

Keywords : Weather, Rainfall, Corn, Production, System Dynamics

1. Introduction

The occurrence of the phenomenon of erratic weather changes in recent years. Weather changes occur due to increased human activity which has an impact on global warming (Khan, 2012). This weather change results in unpredictable rainfall, number of rainy days in a year, dynamics of temperature changes, relative humidity, solar irradiation and unpredictable wind speed (Hegerl et al., 2019). The uncertainty of the impact of this weather change presents risks that need to be anticipated (Prăvălie et.al., 2020). This impact greatly affects several sectors, especially the food sector. The food sector, which is supported by agricultural commodities, is highly dependent on good weather conditions (Rahman and Anik, 2020).

The agricultural sector in its sustainability process is influenced by internal and external aspects. Weather is an external factor that plays a very important role in cultivation activities, maintenance and final results (Mendelsohn, 2014).The agricultural sector in certain commodities has a high level of vulnerability to weather changes.Especially in developing countries that are lacking in the application of harvest and post-harvest technology. Weather changes that occur without preparation can affect the level of production and income of farmers (Chavas et al., 2009).

Weather changes have a positive or negative effect on agricultural yields depending on the location and the mitigation actions that need to be taken (Cappelli et al., 2015). There is a possibility that the impact of weather changes on climatic and weather characteristics, such as the length of the growing season, water availability, levels of fertilizers, and the effects of weeds, insects and diseases among other factors (Bhattarai, Secchi and Schoof, 2017; Liu et al. al. , 2020). The side effects of this condition are inevitable, but they can be reduced by the possible risks.

The impact that may arise due to changes in weather on the agricultural production sector is an increase in temperature, an unfavorable rainfall distribution and an increase in the frequency of extreme weather events (Anyamba et al., 2014). In countries with high levels of agricultural consumption it is a challenge in itself to be able to meet supply needs even in uncertain weather conditions. Developing countries especially in overcoming this phenomenon have various obstacles, especially on technological readiness.Indonesia is one of them is a developing country which faces conditions of uncertain weather changes. The decline in the level of production of several commodities in the agricultural sector occurred over several periods (Ruminta, Handoko and Nurmala, 2018). This of course requires a prediction to determine conditions that may occur and actions that need to be taken in certain weather conditions (Samimi and Zarinabadi, 2011).

Mathematical modeling is one of the tools that can be applied in predicting a problem (Srivastava, 2007; Rebs, Brandenburg and Seuring, 2019). There are dynamic changes that occur in existing weather conditions, causing the importance of consideration in taking into account dynamic variables. Modeling with the dynamics system is used to approach the prediction of existing conditions. Modeling with system dynamics has been carried out on various aspects of agricultural commodities. Aspects of production, storage, supply chain and industrial activities use a system dynamics approach in finding problem-solving solutions (Minegishi and Thiel, 2000; Rahmanifar, Shirazi and Fazlollahtabar, 2014; Li, Ren and Wang, 2016; Bastan et al., 2018).

The use of system dynamics modeling has been widely used to support agricultural activities.When devoted to corn, several similar studies have been conducted. Research conducted by Putra, Mukaromah and Kusumantara, (2018), simulated a maize production model by developing land extension scenarios, improving irrigation quality and improving seed quality to increase maize production. Similar research was conducted by (Natalia et al., 2016) with the aim of a simulation model to maintain the continuity of corn production. Similar to other research, namely the application of a scenario system dynamics to increase maize production, in research conducted by Church (2018) and

Sanga, Olabisi and Liverpool-Tasie (2018) using variable weather conditions that have an impact on production levels. So that the system dynamics model is used to determine actions that can be taken to reduce the risks that may arise. Departing from the previous research, this research will carry out the development of a weather change scenario to increase corn production.

2. Materials and Methods

This research was conducted by taking cases in the province of Gorontalo, Indonesia. The research location is in Gorontalo Province because it is one of the largest suppliers of maize in Indonesia, where the corn commodity is an alternative source of carbohydrates for the Indonesian people. Apart from being food, corn is the main composition in making animal feed. The availability of abundant maize commodity in Gorontalo Province is sufficient to meet the needs of the province, even if the excess is able to be exported to several other countries.

In the preparation of this research, the method approach taken is a mathematical model approach, which transforms existing problems into mathematical models and formulations (Arwani et al., 2018). In the mathematical model approach, theoretical approaches are used as supporting materials for modeling. This theoretical study is then continued to the context of the interpretive approach, where the research paradigm is based on the assumption that social reality is not single or objective, but is shaped by human experience and social context (ontology) (Santoso et al., 2019). The research stages in this study:

1. Initial collection of information and data including media reports, historical and statistical records, policy documents, previous studies, and stakeholder interviews that confirm the seriousness and clarify the scope and magnitude of the problems / concerns identified.
2. The next stage is a systemic structure that reveals how the patterns of the data relate to and influence one another. After identifying the main problem that exists, the formulation of thinking is directed at using the approach of "Causal modeling or described in the causal loop diagram (Banson et al., 2020). Thus, systemic structures break down complex relationships in complex systems into more detailed systems.
3. Structural modeling. Stock flow diagrams are a way of representing the structure of a system with more detailed information than is shown in a causal pie chart. Stock (Level) is the basis for generating behavior in a system. Stock and flow diagrams are the most common first step in building simulation models because they help determine the types of variables that are important in causing behavior (Qiu, Shi and Shi, 2015). In this study, a model will be built with 3 research sub-models, namely the demand sub-model, the production sub-model and the profit sub-model. The model that has been formed is then verified and validated to determine the credibility of the model in representing the real conditions.

4. The last stage is scenario development. The scenario development is based on logical assumptions under certain conditions. This research uses scenario development in changing weather conditions, namely normal rainfall, high rainfall and low rainfall. These conditions then give rise to a model development scenario that may be carried out to increase production or reduce risks that may impact the level of maize production.

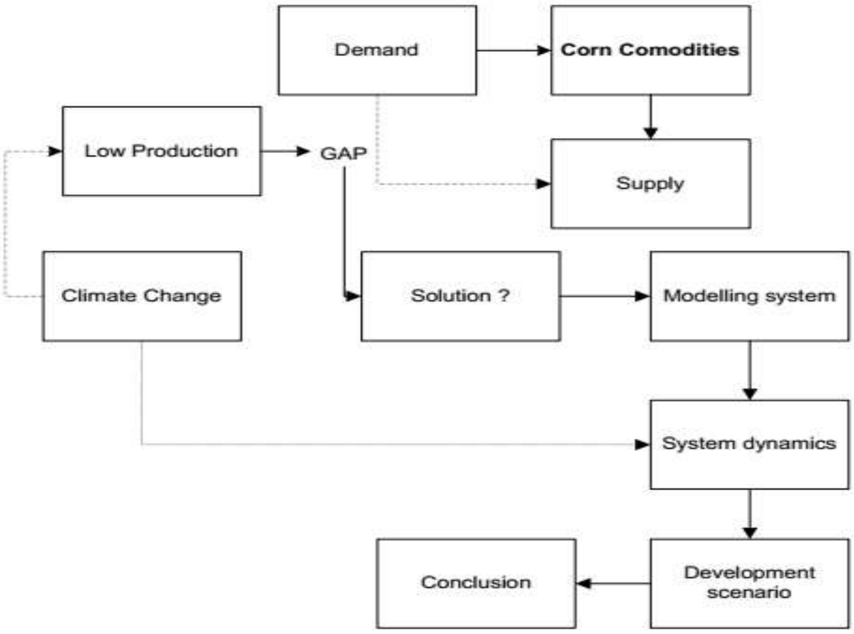

Figure 1 . Research conceptual framework

3. Results and Discussion

3.1. Identification of problems

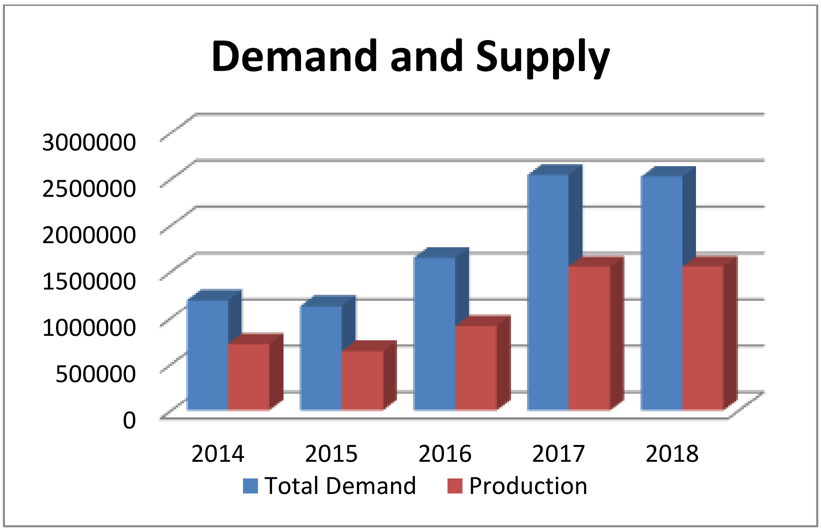

Figure 2. Graph of demand and supply of corn production in Gorontalo Province

The ability of farmers to produce corn to meet demand is quite high. It can be seen from Figure 2, from 2014 to 2018 the average maize production capacity was 1,076,278.92 tons. The highest level of production was in 2017 and 2018, with more than 1,500,000 tonnes capable of being produced. The increase in production is directly proportional to the increase in demand for corn.There were 5 In 2015 there was a decrease in rainfall which resulted in the productivity of maize in Gorontalo Province so that export activities were eliminated during 2015 and 2016 to meet the needs of corn production in the province and nationally.

In that year, there was no change in land use or a decrease in the planting capacity of corn. The existing phenomenon is low rainfall, resulting in decreased production. The types of seeds planted in Gorontalo Province are less resistant to high temperature conditions, resulting in the flowering and fertilization processes of maize. The planting land that uses the irrigation source from the dam, during the dry season has to pay additional costs to transport water from the dam or pump water from dug wells. Of course, this condition requires anticipatory action to maintain the continuity of corn production to meet domestic and export needs.

3.2. Causal loop diagram

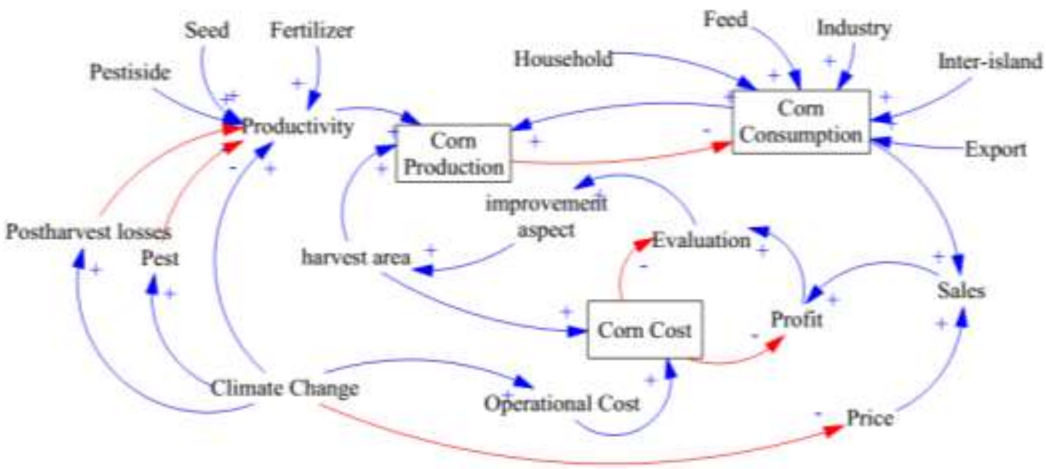

Figure 3. Causal Loop Diagram of Corn Production in Gorontalo Province

Figure 3. shows a causal diagram of maize production activities in Gorontalo Province. Corn production is influenced by several variables that support its increase, namely harvested area and productivity. When the harvested area and productivity increase, corn production will increase, and vice versa if the productivity and harvest area decreases, the production will decrease (Suryani et al., 2010; Caldarelli and Gilio, 2018).

Productivity is generally defined as the ability to produce output from the required input ratio. In the maize production system the influencing variables are seeds, fertilizers, pesticides, weather effects, the influence of pests and post-harvest damage. The effect of pest attacks and post-harvest damage has a negative relationship with productivity levels, so the higher the level of pest attack, the lower the production level (Bhandari, 2016; Donatelli et al., 2017).

Changes in weather can have a positive effect on productivity levels because when the weather is high, it will increase pest attacks and post-harvest damage, thereby reducing productivity (Magfiroh, Zainuddin and Setyawati, 2018). High or low rainfall can affect production costs and selling prices. Low rainfall can reduce production costs, especially post-harvest activities, while low rainfall will increase production costs, especially in drying corn (Kurniawan et al., 2019). Rainfall can also affect the selling price of corn. Corn with a high moisture content will result in a decrease in selling prices (Bachtiar et al., 2014).

Talking about weather changes, the variables that affect the damage to maize leaf disease almost always involve humidity and temperature in the corn planting area during the growing period of maize (Ascough, Fathelrahman and McMaster, 2008). During storage or post-harvest, which is carried out with high rainfall intensity can cause high water content, so that it can be at risk of rotting, fungal growth and other quality degradation (Volenik et al., 2007).

3.3. Stock Flow Diagram

Stock Flow diagrams (SFD) are defining a mathematical formulation (equation) which is the definition of a mathematical relationship between one variable and another. These mathematical relationships are based on information, data and assumptions that can be explained and accepted rationally. The formation of the SFD model consists of several sub models consisting of the production sub model, the demand sub model, and the profit sub model. The sub models that are formed are interrelated with each other to build unity in modeling existing problems so that they can be simulated according to the objectives of the study.

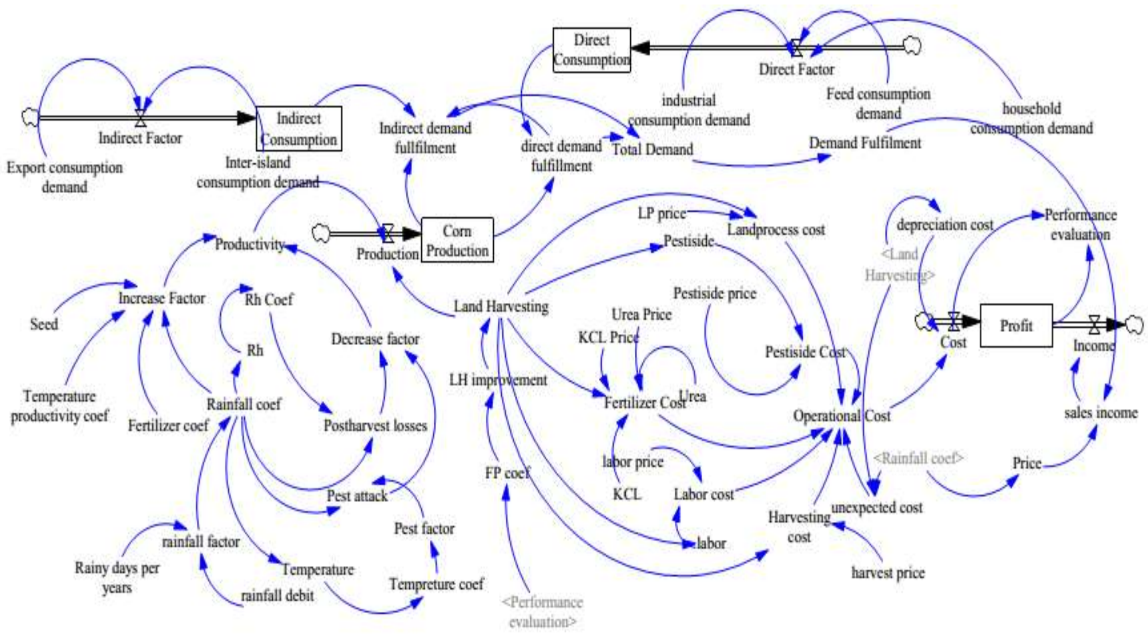

Figure 4. Stock Flow Diagram of increasing maize production in Gorontalo Province

3.4. Scenario Development

The model that has been built is then verified and validated using the syntax error in the program. Model running on Vensim PLE 7.2a software. The basic model that has been verified and validated, the next step is to develop a scenario from the model. Scenarios are created by changing the parameters that have an influence on the model. In this study, as previously described, the influence of weather changes, especially on rainfall, will be simulated to determine the best possible scenario for these conditions. The conditions taken into consideration are normal rainfall conditions, high rainfall, and low rainfall. Normal rainfall ranges from 250-5000 mm, high rainfall> 5000 mm, and rainfall <250 mm.

The development of policy scenarios in the modeling of the corn commodity farming system is carried out with the aim of analyzing the possibility of an increase in productivity by considering weather changing conditions. This then becomes one of the bases for developing a simulation model with a dynamics system using a rainfall change approach. There are three types of weather that

will be used as the basis for scenario development, namely normal rainfall, high rainfall and low rainfall. Each rainfall condition will develop a different scenario according to the decreasing variable due to weather changes.

3.4.1. Policy Scenario Without Change (Normal)

The conditions in this scenario are a general description or normal conditions of maize cultivation. In the context of the weather approach, rainfall conditions are in the range of 250-5000 mm, with rainy days ranging from 180 - 222 days per year. In normal weather conditions, scenario development is aimed at increasing production and increasing income for farmers. Scenarios were formed in addition to maintaining continuity of production and improving the welfare of farmers.

3.4.1.1. Normal 1 - Increased Productivity

Departing from the description and modeling using CLD and SFD, increased production can be achieved by increasing productivity and harvested area. It is possible to increase the harvested area, but it will have an impact on increasing production costs. So by assuming cost minimization, a scenario development approach is carried out with increased productivity. Increasing the productivity of agricultural products can be done by improving the quality of seeds (Cui, 2020). Seed quality improvement can be done by using varieties that are resistant to pests, diseases, or those with higher yields (Saadah et al., 2019). By using these assumptions, the ability of the seeds to initially be 5.5 tons per hectare of harvested area is then increased to 6.5 tons. This can be realized with real conditions in the form of equal distribution of the corn seed varieties used. As many as 30% of farmers in Gorontalo Province still use old varieties and 70% use superior varieties. The superior varieties have a large production capacity of 5.5-6 tons per hectare, while the older varieties are less, namely 5 tons per hectare. With the assumption of equal distribution of superior varieties and the number of seeds given, it can increase seed capacity by 6.5 tons per hectare.

3.4.1.2. Normal 2 - Decrease in production prices

Apart from the purpose of increasing maize production capacity, it is important to study the economic factor in the form of increasing farmer profitability. So that one other approach in scenario development is carried out using the principle of lowering production prices. The production costs involved in maize production activities in Gorontalo Province cover the need for maintenance and harvesting of maize. Corn seed is a government program in the form of seed subsidies, so that farmers do not have to pay for seed procurement. The highest cost in production activities is the procurement of fertilizers and pesticides. Fertilizers and pesticides are the main expenses for farmers to support the safety of the production process until harvest. About
40% of the total production costs come from the procurement of fertilizers and pesticides. So that in this development scenario, there is subsidies for fertilizers and pesticides as much as 10%.

3.4.1.3. Normal 3 - Combination of increased seed productivity and subsidized fertilizers and pesticides

In developing this scenario, the development of scenarios 1 and 2 was carried out in the form of increased seed productivity and subsidized production costs. This combination approach is applied with consideration of cost minimization efforts, so that by minimizing costs, you will get more profit.

3.4.2. Policy Scenarios when rainfall is high

Changes in extreme rainfall from normal rainfall to high or low rainfall can affect productivity. This can occur due to the influence of rainfall on several other factors related to productivity levels (Knox et al., 2012). Rainfall variable is closely related to the factors that affect the productivity of existing maize. Sufficient rainfall will have a good impact on plants, but if it is excessive, it will have a bad impact on plants. High rainfall will increase temperature and humidity, so
the possibility of pests and insects that can damage crops will be higher (Ruffo et al., 2015). This then becomes one of the considerations to maximize productivity-enhancing factors.

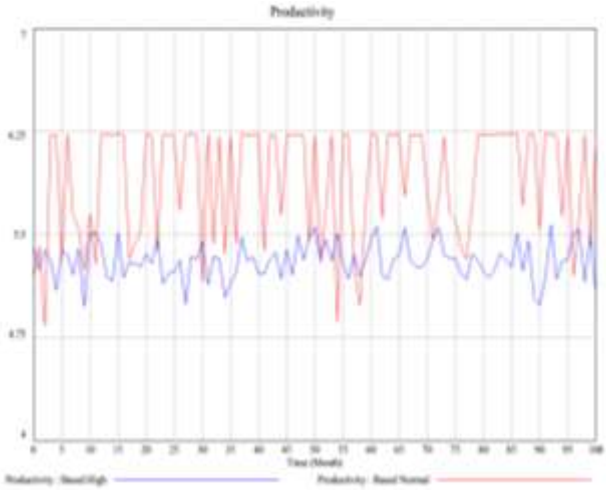

Figure 5. Productivity simulation with high rainfall

It can be seen in Figure 5 that therei s a decrease in the level of maize productivity in the simulation of high rainfall conditions. The level of productivity can be influenced by factors reducing and adding. When the reducing factor is greater, a decrease in the level of productivity may occur. In Figures 6 and 7 it can be traced as a variable reducing the level of productivity has increased.The increase occurred in the percentage of damage that may occur due to disease or decreased quality of maize and the percentage increase in pests and diseases. Excessive rainfall results in increased humidity and decreased temperature, thus allowing the moisture content in agricultural products to increase. This triggers the emergence of pests, fungi and diseases that can damage crops (Roesch-McNally, Arbuckle and Tyndall, 2018).

Figure 6. Simulation of postharvest losses with high rainfall

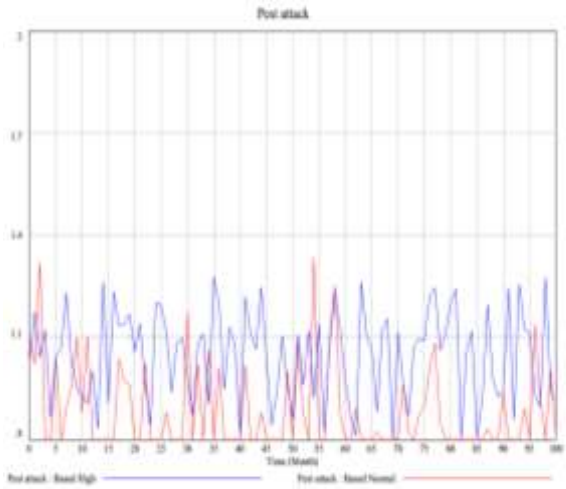

Figure 7. Simulation of pest attack with high rainfall

The increase that occurs in a decrease factor on productivity will have an impact on the amount of productivity. So that it will also have an impact on the level of production. High rainfall will also reduce the selling price. This is because the water content in the maize is still high and reduces the selling price by 500-1,000 rupias per kg from the existing selling price. The decline that occurs in the productivity level will also have an impact on other variables that are integrated with the productivity level. The level of production decreases when compared to conditions where there is no change in weather with high rainfall. This high rainfall has an unfavorable impact for farmers. Rainfall that is higher than under normal conditions allows for less losses.

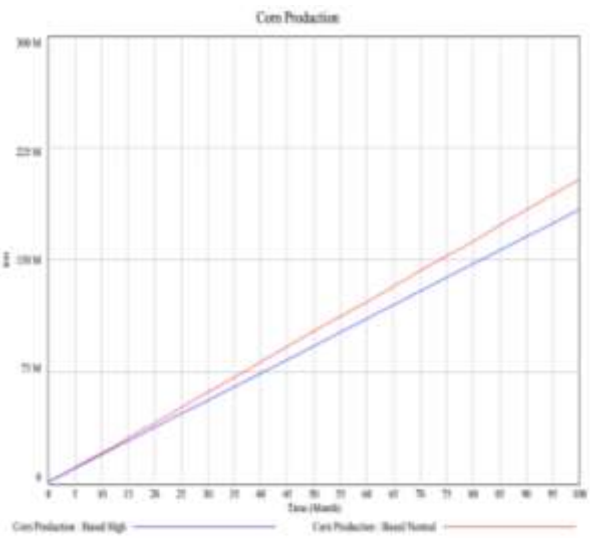

Figure 8. Production simulation with high rainfall

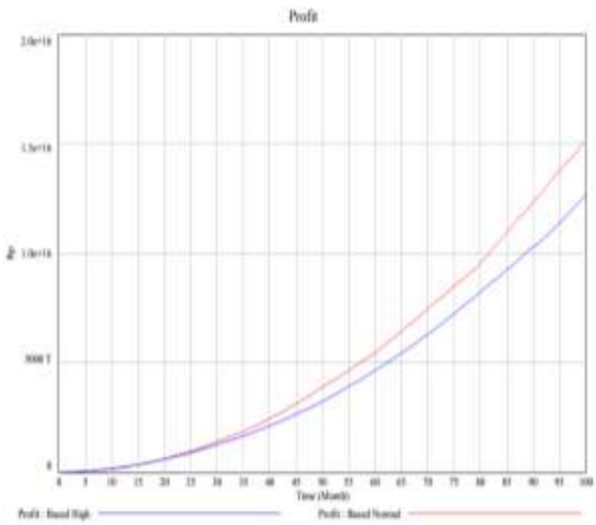

Figure 9. Profit simul ation with high rainfall

3.4.2.1. High 1- Pest attack reduction

As previously described, the increasing number of pests and diseases arising from high rainfall. Pests attack both flowers, leaves, seeds, and roots can cause crop failure or decrease the quantity of corn harvest. efforts to anticipate these events by providing additional protection to plants when there is high rainfall. This prevention step can then be used as a basis for developing scenarios in the form of increased pesticide use and pest management. It is assumed that this preventive measure is able to reduce as much as 10% of the damage that occurs.

3.4.2.2. High 2 - Post harvest losses reduction

This scenario development is carried out when it is assumed that the corn has entered the period of harvest and post-harvest. High rainfall can increase the water content contained in corn. in rainfall conditions, the intensity of the sun decreases, so the corn drying process is not effective. The incomplete drying process has an impact on the quality and selling price of corn. Quality degradation occurred due to non-conformity of standards in the form of corn moisture content by 17%. The reduction of water content in maize at the farmer level is done traditionally using solar power, so that when the rainfall is high with less solar radiation it will have an impact on corn drying activities. In this scenario, a drying device was added so that the corn that had been harvested could be optimized for quality.

3.4.3. Policy scenario when rainfall is low

Similar to the occurrence of high rainfall conditions, low rainfall will have an impact on the level of existing corn commodity production and operational costs of water supply. Extreme weather has greatly impacted the level of agricultural productivity and could have an impact on production costs and farmers' income (Choirun et al., 2020). With the number of rainy days halved and the water discharge low, maize production decreased significantly. Low or dry rainfall with high intensity of sunlight has an impact on plant health and the quality of the maize produced. Low humidity and high temperatures have an impact on the growth of maize leaves and kernels, so this can have an impact on the amount of production and farmers' income as

depicted in Figures 10 and 11.

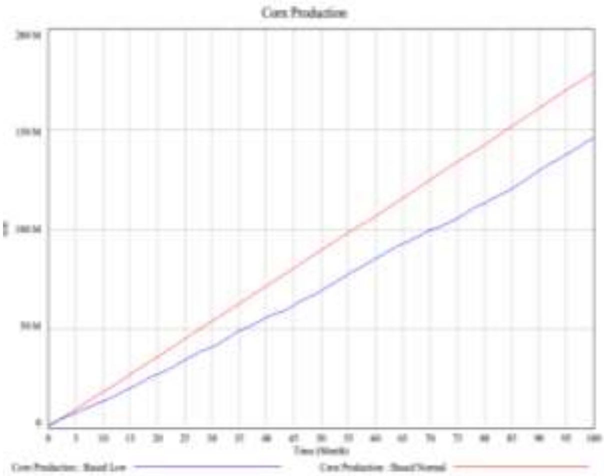

Figure 10. production simulation with low rainfall

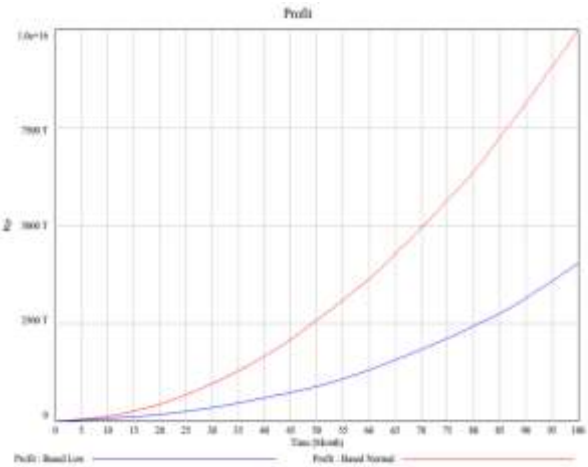

Figure 11. Profit simulation with low rainfall

Figure 11. provides an illustration that conditions when the rainfall is low gives a very significant loss to the level of production and profit of corn farmers. This is very important considering the availability and welfare of farmers is a top priority. For further efforts to reduce the impact of risks that may arise when compared with normal rainfall conditions. In contrast to the case of high rainfall, the variable will be very influential is the emergence of unexpected costs due to a lack of water for irrigation, so farmers have to provide additional fuel to collect water from the reservoir.

3.4.3.1. Low 1 - Productivity increase

As in normal conditions, at low rainfall, the main obstacle is availability as the most influencing factor on maize production. So an approach to increase productivity is carried out by increasing the quality of the seeds (Septifani et al., 2019). The selected seeds are superior varieties that can survive conditions of high sun intensity. Initially, the seed capacity was 5.5 tonnes per hectare of harvested area and then increased to 6.5 tonnes. This can be realized with real conditions in the form of equal distribution of the corn seed varieties used. As many as 30% of farmers in Gorontalo Province still use old varieties and 70% use superior varieties. The superior varieties have a large production capacity of 5.5-6 tons per hectare, while the older varieties are less, namely 5 tons per hectare.

3.4.3.2. Low 2 - Seed + Fuel subsidy for irrigation

An adverse condition for farmers when rainfall is low is the additional cost of water supply as previously explained, in conditions of low rainfall, the highest unexpected cost rate appears.Unexpected cost is the cost of procuring fuel for the water pump engine. In developing this scenario, the scenario is developing in the form of 100% fuel subsidies and the use of seeds.

Table 1. Summary of weather conditions and scenarios applied in the study

Conditions	Scenario 1	Scenario 2	Scenario 3
Normal rainfall	Seed quality improvement	Cost subsidies	Combine scenario 1 and 2
High rainfall	Pest attack reduced	Post-harvest Losses reduced	
Low rainfall	Seed quality improvement	Unexpected cost reduce	

3.5. Scenario Development Impact Analysis

The development of scenarios that arise due to changes in rainfall will certainly have an impact on the calculated variables in the model. Several aspects are considered in the comparison of the scenario development results, namely the demand-supply and economic aspects. Aspects of demand-supply can be seen from the level of production, productivity, and demand fulfillment. The productivity aspect was raised because changes in rainfall had the most impact on the productivity conditions of corn. The economic aspect is seen from profit, cost, and income.

3.5.1.Normal Rainfall conditions

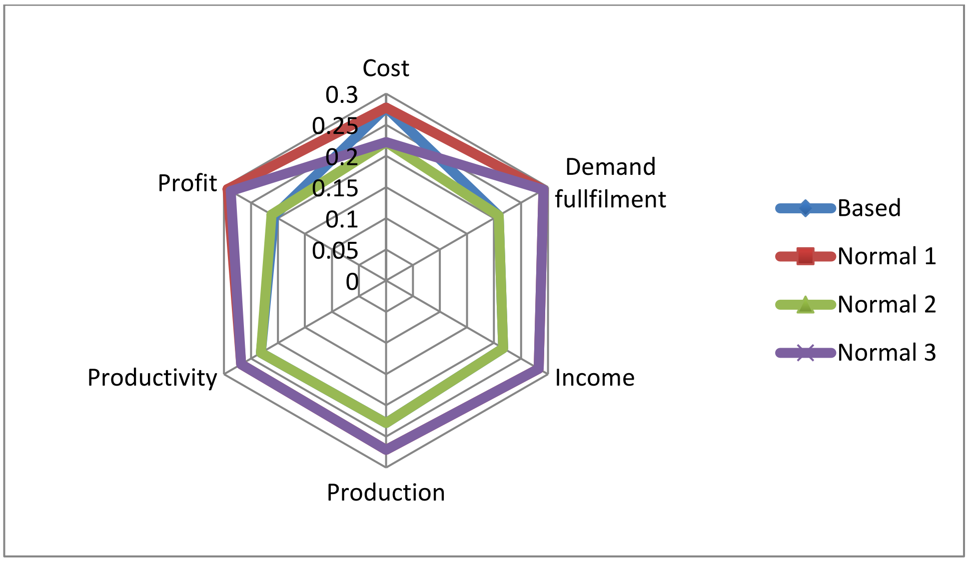

Figure 11. Comparison graph of the results of developing a normal rainfall scenario

In Figure 11. Scenario-based is the initial condition without any scenario development. The purpose of the simulation in normal rainfall conditions is a high level of production and a high profit. Scenario-based and normal 2 had a fixed level of production when compared to the production in scenarios 1 and 3 which increased by 15.8%. this can occur because of an increase in productivity. When viewed from the costs incurred in the scenario-based and normal 1 has the highest level of costs compared to other scenarios. There was a reduction in production costs in the normal 2 and 3 scenarios by 19% from the scenario-based. When viewed from Figure 11 the scenario with the highest production level, minimum cost, and increased profit, the normal scenario 3 development is the best compared to other existing scenarios.

3.5.2. High Rainfall Conditions

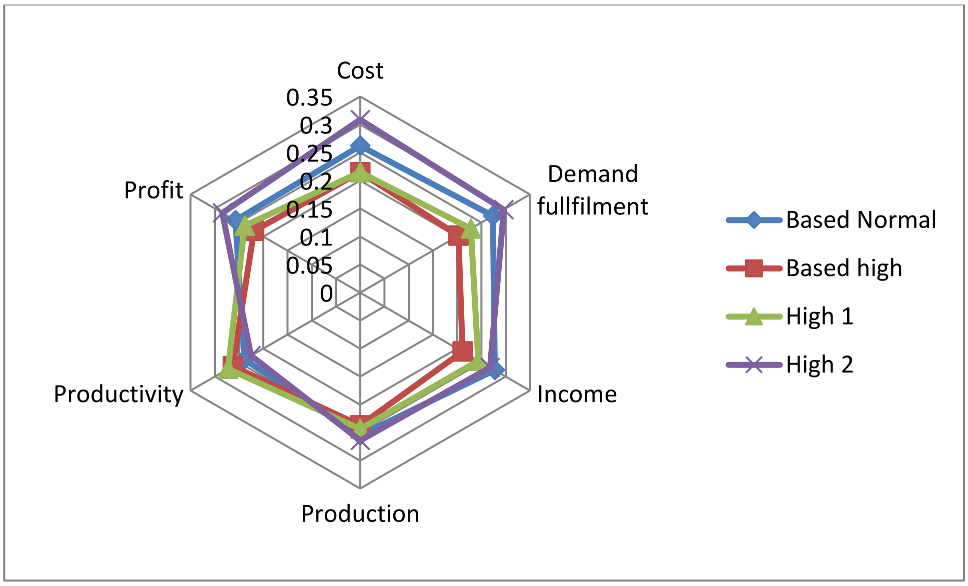

Figure 12. Comparison chart of the results of high rainfall scenario development

In Figure 12. Scenario-based normal is a normal rainfall condition, and based high is an initial scenario of high rainfall conditions. The purpose of the simulation in high rainfall conditions is to maintain production stability and reduce the impact of high rainfall. At 7%, it is simulated to experience a decrease from scenario-based normal. High scenarios 1 and 2 can increase production losses by 3-11% from the scenario-based high conditions. When viewed from the high 1 scenario, the level of profit obtained is almost in the scenario-based normal conditions. In the application of the high 2 scenarios, the production level increases from the scenario-based normal condition resulting in a higher profit level. This occurs because there is a difference in the selling value in the high 1 and high 2 scenarios. In high 1 conditions, the quality level of the corn produced is lower because the moisture content in the corn is higher which results in a low selling price. Whereas in the high 2 scenarios, the selling price is in the scenario-based normal condition. So, when compared to the development scenario in high rainfall, the high 2 scenario has advantages in the level of production and the profits that farmers get.

3.5.3. Low rainfall conditions

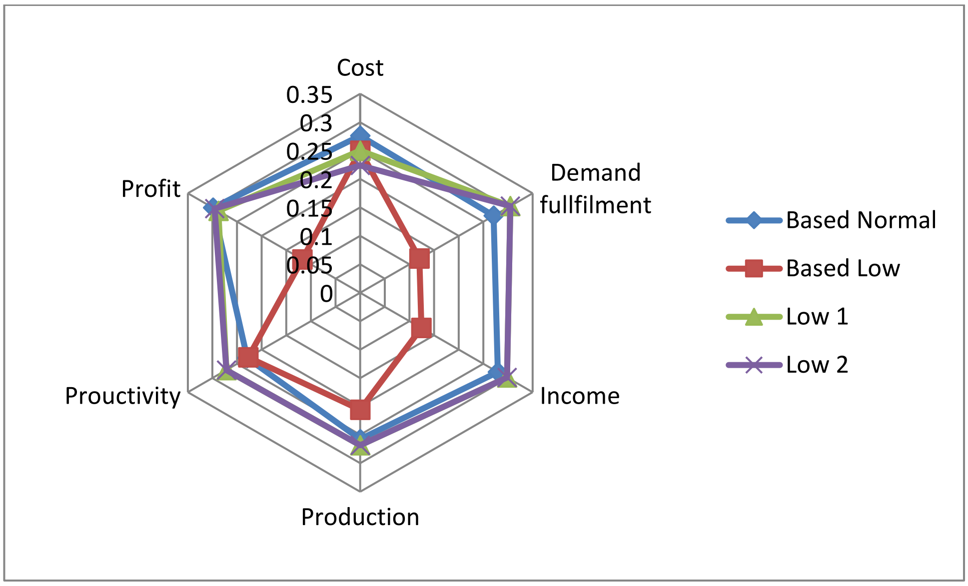

Figure 13. Graph of comparison of the results of developing a low rainfall scenario

In Figure 13, it can be seen that the scenario-based normal compared to the based low condition is the benchmark for developing a low rainfall scenario. The based low scenario is the initial scenario of low rainfall conditions. The simulation in high rainfall conditions aims to maintain production stability and reduce costs arising from these conditions. The condition-based low is the simulation result that is the least profitable for farmers because of the decline in production and farmer profits. As much as 20% of the total simulated reduced production results due to low rainfall conditions. By simulation the development of a production scenario can increase the level of production as in normal scenario-based conditions. Low Scenarios 1 and 2 have levels of production and profit that are almost the same as normal scenario-based conditions. The low 1 scenario has a higher cost level than the low 2 scenarios. The compared, the low 2 scenario has a better level of excess than the low 1 scenario.

4. Conclusion

The problem of the gap between demand and supply that occurs requires preventive actions that need to be taken to reduce the impact of losses that occur. The system dynamics modeling approach is used to simulate existing problems. In the approach to increasing maize production, a model is built which consists of 3 sub-models, namely the production sub-model, the demand sub-model, and the profit sub-model. The formed model is adjusted to real conditions by verifying and validating it. The validated and verified models have then carried out scenario development based on weather conditions that affect the level of maize production. The scenario development is based on the variables most affected by weather changes. The weather conditions used are based on normal rainfall, high rainfall, and low rainfall.

Development of a scenario in normal rainfall conditions considering an increase in production and in profitability is simulated with an increase in productivity and subsidized production costs, which have the most significant impact on maize production development activities in Gorontalo Province. Development of scenarios in high rainfall conditions considering the impact reducing the risk of production reduction and farmer profits is simulated by adding pesticides and post-harvest handling facilities to increase production in high rainfall conditions. In developing scenarios in low rainfall conditions, the highest risk in the production simulation is a decrease in production, and an increase in costs. So the scenario approach is carried out by increasing the productivity of maize plants in low rainfall and subsidizing production costs.

5. Suggestions

Modeling with the dynamics system does not escape several variables that are not included in the system. So that for future model development, it can be developed by considering other variables. Other variables in this study that were not included, such as irradiation intensity, wind speed, and other extreme weather phenomena that could affect agricultural activities. The gap can be another development material in further research.

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