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# Deficit irrigation for rice farming with production risk due to weather variability

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**Abstract.** Deficit irrigation is one of the keys in overcoming the problem of weather variability and limited water resources. Farmers can reduce the amount of irrigation water use without affecting too much on the productivity of rice plants by using deficit irrigation. The level of deviation of rice production increases when the water level changes between the ranges of 0-2.5 cm. The tendency to decrease from the level of deviation of agricultural production is seen when the water level increases in the range of 2.5-10 cm. At a water level of 12.5 cm there is a considerable increase in deviation. However, there was a significant decrease in the level of deviation of rice production when the water level was at 15 cm. Based on this, it can be concluded that the risk management of rice production will be better when the water level is above 2.5 cm and below 15 cm. The results of this study not only can be used for the development of risk-based farmers' decision models but can also be used as input for the development of government policies in resource sharing and development of agricultural insurance

## 1. Introduction

Uncertainty in weather causes a high risk for farmers because crop production is directly affected by rainfall that occurs during the growing season. Meanwhile the ability of farmers to do irrigation in an effort to reduce risk caused by weather uncertainty is limited by the availability of water resources. This limitation of water resources results in a high risk in agricultural cultivation. However, farmers must look for the most effective irrigation strategy where the strategy can overcome the risks caused by weather variability and the limited availability of water resources.

The Government of Indonesia through the Ministry of Agriculture in the Indonesian Development program, especially rice agriculture continues to strive to increase its production, both through intensification and extensification. BPS data shows that 94.52% of rice production comes from lowland rice. To support the program, the Government developed an irrigation system through rehabilitation of damaged irrigation systems and the construction of new irrigation systems. However, in some areas that have irrigation systems are still not able to meet the needs of irrigation water because it is not balanced between the area of land that needs to be dairy with the available water debit, so there is a shortage of water when needed and this condition is referred to as Deficit Irrigation (Irrigation Deficit).

High volatility in weather creates a big challenge for farmers to achieve the desired harvest. Climate change and high climate variability result in high risk of failure in crop production [1, 2]. Farmers can



do irrigation to reduce risks in crop production related to climate change and weather variability [3] However, due to limited availability of water, irrigation applications must be managed efficiently to obtain optimal benefits. Farmers will choose irrigation strategies that provide optimal benefits based on their behavior and preferences for risk.

The negative impact of lack of available water resources for agricultural productivity was greater than the negative impact of change climate. Limitations of water resources can cause farmers to move from irrigation agriculture to agriculture without irrigation. This has a significant impact on reducing agricultural production. Therefore, further efforts must be given to improve the efficiency of water use so that the effects of limited water resources on agricultural crop production can be minimized.

Farmers' decisions in the irrigation strategy will depend on many factors such as water availability, irrigation efficiency and production costs. The intensive irrigation strategy that can be used to overcome the lack of water resources is through irrigation deficits. Deficit irrigation strategies will use less water but still try to avoid plant stress, especially at critical growth stages [4, 5]. Deficit irrigation techniques can be done by adjusting the soil moisture level or irrigation scheduling according to the rate of plant growth [6]. Farmers' attitudes towards risk can affect the irrigation strategy that will be chosen. The irrigation deficit strategy which is affected by weather variability results in higher crop yield variability compared to full irrigation strategies. But deficit irrigation strategies use less water and lower production costs compared to full irrigation. Farmers with high risk preferences may focus more on the choice of irrigation strategies that offer lower profit variability.

Rice is the main food crop in Indonesia which requires intensive irrigation. Rice production is also quite sensitive to the availability of irrigation during the planting season. Variability in extreme weather and climate has caused various production failures and losses for farmers. Various limited water resources owned by farmers often have to be shared jointly by farmers in an area. Distribution of water resources for irrigation often becomes a problem when farmers face seasons where rainfall is limited. Deficit irrigation can be a solution for farmers where farmers do not provide full irrigation but can still minimize crop failure. An important question is the extent to which deficit irrigation can be carried out without causing a large risk of production failure. To overcome the problem of limited water resources it is necessary to develop a strategy or method that can take into account the water needs of wetland crops in deficit irrigation systems, but still be able to get high production as well as the production of lowland rice which has enough irrigation water. This method is by building a deficit irrigation model on lowland rice farming. This model is expected to be able to take into account the water needs of rice paddies in conditions of lack of water but still be able to maintain high production, also can reduce production costs due to the use of water, energy and other cheaper production inputs.

The author did not find previous studies in Indonesia related to economic optimization of agricultural irrigation strategies that are influenced by the availability of water resources. Research on the optimization model which is influenced by the availability of water resources and weather variability is very important to be done mainly due to climate change that is happening at this time. Farmers and policy makers and various related institutions must actively address the problems of climate change and limited water resources for agriculture so that it does not have a large negative effect on agricultural production and food security. The economic model between production and water resources produced from this research can be used and applied to various other irrigation optimization studies. The resulting model can help or facilitate the community or lowland rice farmers to determine the water discharge that is in accordance with the needs of wetland rice. Utilization of deficit irrigation is expected to be able to maintain high production, reduce the cost of production and use of water more efficiently. The results of this study can also be used as a basis for policy makers, especially for resource sharing for water resources shared by agricultural groups that are in one area or across regions.

This study aims to; 1. developing an irrigation optimization model related to weather variability and limited water resources, 2. calculating and analyzing optimal irrigation deficit strategies influenced by limited water resources and risk in weather variability.

### 1.1. Deficit irrigation

Irrigation Deficit means that the irrigation system can only supply part of the water needs needed by rice plants. Deficit irrigation can cause a decrease in rice production because it is in line with the decrease in water debit, energy and other production inputs for the growth of rice plants. However, economically deficit irrigation needs to justify the application / reduction of water under full irrigation (Full Irrigation) decrease in production costs faster than the decline in income (Revenue) [7] The level of water can be lower than full irrigation and produce equivalent production with full irrigation along the slope of the relatively flat (flat) production function, until the production function decreases. Thus in irrigation, it is necessary to determine the level of water supplied, the amount / area of irrigated land, combination of crops cultivated to obtain maximum benefit besides that, planned crop stress during its growth period. for one or more growing seasons, to provide sufficient water during the critical growth stage to maximize water use efficiency. Therefore, to maximize the use of water in deficit irrigation it is necessary to have a method that can combine various parameters that affect the production of lowland rice to still be able to produce high production with low production costs and more efficient use of water.

## 2. Model and methods

The strategy optimization model was developed using a method of maximizing utility means. Research takes into account the risk factors experienced by agriculture due to weather uncertainty. Agricultural production is presented with a random production function [8]:

$$y = f(z, \mu) \quad (1)$$

Where  $y$  is production,  $z$  is a resource (irrigation water), and  $\mu$  is an uncertainty factor (weather). This study assumes that the only resources calculated are water resources. Farmers' estimates of weather probability factors are assumed to be known based on prior experience. Farmers are considered to be making decisions on resources that are used with the aim of maximizing mean utilities [8]:

$$\max_x EU(\pi, r) = \text{Maxx} \{EU([pf(z, \mu) - czi, r])\} \quad (2)$$

Where  $p$  is the price of agricultural products,  $r$  is the coefficient that describes the farmer's risk preference,  $c$  is the input price and  $\pi$  is the net profit. This study assumes that farmers have properties based on Constant Absolute Risk Aversion (CARA), which illustrates that the risk coefficient ( $r$ ) does not depend on the initial conditions of net profit ( $\pi$ ). Based on the assumption utility mean model corresponds to the exponential negative utility model as shown below:

$$EU(r) = \sum (1/T) [-e^{-r * \pi t}], T t = 1 \quad (3)$$

SERF model analysis is shown below:

$$\text{Max}_{\{m,c,t\}} CE(RAC) \quad (4)$$

s. t.

$$CE(RAC) = \ln(1 - E[u(\pi_{ijm})])^{-1/RAC} \quad (5)$$

$$E[u(\pi_{ijm})] = \int u(\pi_{ijm}) dF(z, p_i) \tag{6}$$

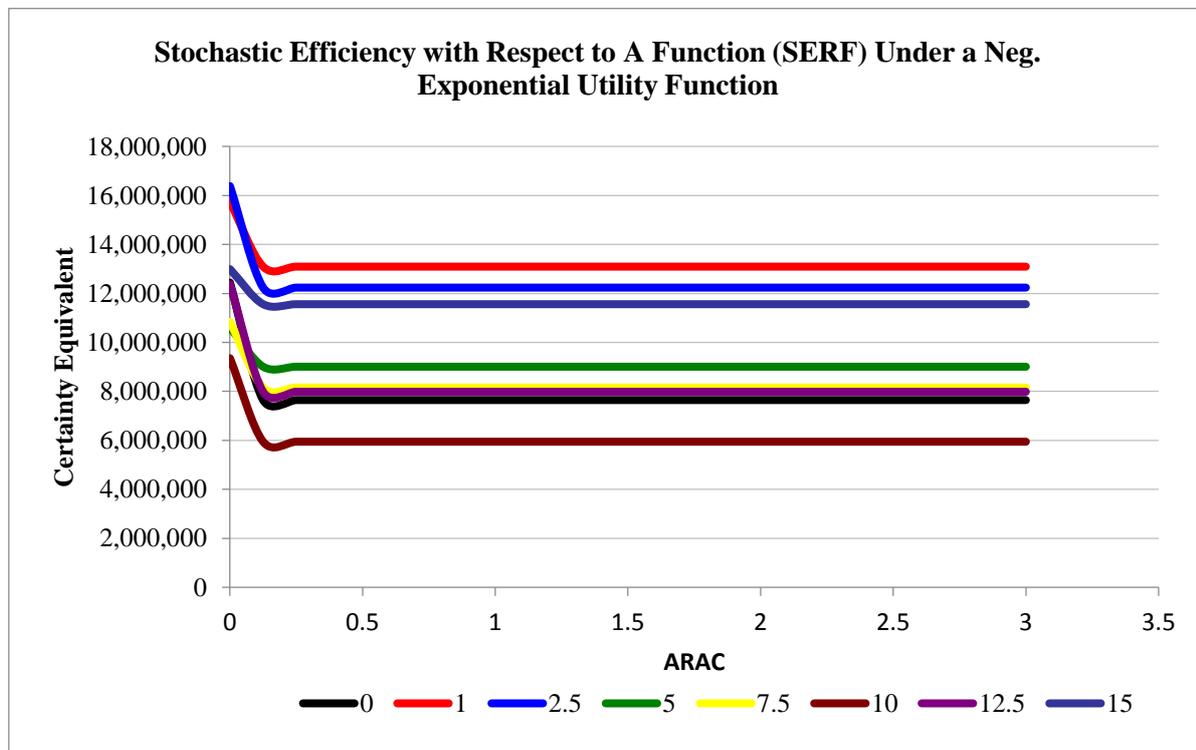
$$u(\pi_{ijm}) = 1 - e^{-r*\pi_{ijm}} \tag{7}$$

$$\pi_{ijm} = p_i * f_{ij}(e * w + z; q, m, i) - c_j(w, pe, d, k; m, i) - v_{ij} \tag{8}$$

SERF analysis is done by considering risk factors and the nature / preferences of farmers against risk. The nature of farmers' preference for risk is done by using risk coefficient (ARAC). The ARAC range used is from 0-3. ARAC number 0 states that farmers are risk neutral and the greater the ARAC number indicates that farmers are increasingly afraid in facing risks (risk averter). ARAC number 4 shows that farmers have very high risk averter properties. The SERF analysis is carried out with the assumption that farmers have a Constant preference Absolute Risk Aversion (CARA) or risk preferences are not affected by the initial conditions of farmer wealth.

**3. Result and Discussion**

The results of certainty equivalent calculations with SERF analysis can be seen in the Table 1 and Figure 1. From both Table 1 and Figure 1, it can be seen that when a farmer is a neutral person against risk (ARAC = 0), the farmer will choose irrigation with a height of 2.5 cm. this is seen as certainty equivalent for irrigation with a height of 2.5 is the highest. However, when a farmer is a person who has a slight risk avoiding nature, the farmer will choose irrigation with a height of 1 cm (macak-macak). This occurs because of the distribution of profits at an altitude of 2.5 cm greater than 1 cm even though the average advantage of 2.5 cm irrigation is greater from 1 cm. However, the advantage of 2.5 cm irrigation is only slightly larger than the average profit of 1 cm.



**Figure 1.** Certainty equivalent with SERF analysis for different irrigation elevation

Farmers are willing to reduce water levels for the purpose of reduce variability in profits even though the average profit is smaller. In the picture above, it can be seen that farmers will avoid 10 cm water level because giving the lowest certainty equivalent compared to the other water level. The picture above also shows that the dominant decision to take is irrigation with a height of 1 cm (macak-macak), 2.5 cm and 15 cm. From the image above it can be concluded that farmers with risk avoidance will make optimal decisions by setting the irrigation height of 1 cm (macak macak).

**Table 1.** Certainty equivalent (in 000 Rp) for different irrigation elevation

ARAC	0 cm	1 cm	2.5 cm	5 cm	7.5 cm	10 cm	12.5 cm	15 cm
0	12,444,000	15,742,000	16,388,000	10,608,000	10,846,000	9,350,000	12,376,000	12,988,000
0.1250	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
0.2500	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
0.3750	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
0.5000	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
0.6250	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
0.7500	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
0.8750	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
1.0000	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
1.1250	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
1.2500	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
1.3750	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
1.5000	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
1.6250	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
1.7500	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
1.8750	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
2.0000	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
2.1250	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
2.2500	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
2.3750	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
2.5000	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
2.6250	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
2.7500	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
2.8750	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000
3.0000	7,650,000	13,090,000	12,240,000	9,010,000	8,160,000	5,950,000	7,990,000	11,560,000

#### 4. Conclusion

The current problems faced by farmers recently are production risks due to weather variability, climate change and limited natural resources. The theme of this study is the development of irrigation optimization models influenced by weather variability and limited water resources. Crop production results are affected directly by the application of irrigation water and rainfall. Limited water resources and poor rainfall conditions require farmers to allocate irrigation water efficiently. The inefficiency of irrigation management will cause crop failure and will widely lead to food security problems. Utilization of irrigation deficit for agricultural production does not get too much attention from previous research in Indonesia. The results of this randomized design will produce an economic model of crop-water

production which will then be used in the irrigation optimization model. The simulation of irrigation optimization model will produce an optimal irrigation schedule model. The level of deviation of rice production increases when the water level changes between the ranges of 0-2.5 cm. The tendency to decrease from the level of deviation of agricultural production is seen when the water level increases in the range of 2.5-10 cm. At a water level of 12.5 cm there is a considerable increase in deviation. However, there was a significant decrease in the level of deviation of rice production when the water level was at 15 cm. Based on this, it can be concluded that the risk management of rice production will be better when the water level is above 2.5 cm and below 15 cm. The results of this study not only can be used for the development of risk-based farmers' decision models but can also be used as input for the development of government policies in resource sharing and development of agricultural insurance

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