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by M Hasbi Et Al

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The simulation model of rainwater utilization management to fulfill the water requirement of corn feed plants in the slope area of hills: *A Case study of corn feed cultivation for the planting period from March to June in Benteng Gajah village, South Sulawesi, East Indonesia*

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Abstract. Water is a basic need of living things. When its population increased, its water needs also increased. The purpose of this research was to construct an optimal model of rainwater utilization management (RWUM) in the slope area of hills: Case study at corn feed *(Zea mays L.)* plants (CFP) in Benteng Gajah village, South Sulawesi, Eastern Indonesia with simulation method. The data supported in this simulation were: Water need of the CFP during May to June 2019; The average yearly rainfall data of the village; The topography data of the CFP sample location. There were three simulation scenarios of the RWUM model. Those scenarios were differentiated by altitude zones. The first scenario located in the lower zone, the second scenario located in the middle zone, and the third located in the upper zone. The study showed that the optimal RWUM model was the third scenarios. The cost differences of the scenarios mainly lied on the operational cost of pumping, the RWUM infrastructure maintenance, number of employee working hours, and fuel cost of pumping. The ratio of the estimated operational cost among scenario I, scenario II, and scenario III respectively were 9:5:1.

1. Introduction

Water scarcity was caused by the increasing use of water from various sectors, such as agriculture, industry, and households. It was estimated that, by 2025, water scarcity and drought will expand in most parts of Asia [1]. Many studies had been carried out on the utilization of rainwater. Research related to the issues of rainwater utilization in the last few years were the policies and management of utilization of rainwater [2], [3], harvesting and utilization of rainwater in urban areas [4], rainwater utilization for agriculture [5] and [6] rainwater utilization from roof catches in dry areas [7].

One way to deal with the limited availability of water was to harvest rainwater optimally [8]. Harvesting of rainwater was very potential to be developed because Indonesia had high rainfall.

Therefore, harvesting rainwater during the rainy season to be used in the dry season was one of the appropriate steps to overcome the limited availability of water. The rainwater stored in the reservoirs was not only useful for irrigation, the water could also be used as an alternative source of clean water resources [9].

The potential of the slope area of hills in Indonesia was still very wide, which was around 47.45 million ha [10]. This potential was certainly a great opportunity to overcome food shortages in the future. Demand for corn feed in Indonesia was still increasing. The high production of corn processing as animal feed raw material was the main factor that causes increased demand for corn [11]. More than 55% of the corn demand is estimated to be used for animal feed while food consumption is only around 30% and the rest is used for seeds [12].

Benteng Gajah village (BGV) was one of the villages in Indonesia that had a vast area of hills exceeding paddy fields. The BGV had 1,062 ha, there were 544 ha or 51.2% of the hills was very potential for CFP. Today, only around 17 ha or 3.7% of the hills was managed for CFP, and the rest was left stranded because of water scarcity. The hills had been abandoned by their owner, since about the last 10 years, due to lack of water from May to the end of October each year. But on the contrary, rainfall in the BGV was very high which exceeds 3,000 mm year^{-1} [13]. This meant that the problem of the hills land in BGV was not because of the lack of water, but rainwater was not yet managed its utilization. So the purpose of this research was to construct an optimal model of rainwater utilization management (RWUM) in the slope area of hills: Case study at corn feed *(Zea mays L.)* plants (CFP) in Benteng Gajah village, South Sulawesi, Eastern Indonesia.

2. Material and methods

2.1. The description of study area.

The location of this research was carried out in the Benteng Gajah village. Tompobulu Subdistrict, Maros Regency, South Sulawesi, Indonesia. Located at latitude -5.15219 and longitude 119.62602 with altitude above sea level between 40m to180m above sea level (ASL) [14].

2.2. Conceptual framework of rainwater utilization management (RWUM) systems.

The concepts applied to optimize RWUM in feed-corn plants in the slope areas of the slope area of hills were the concept of cultivation systems, rainfall, land slope, law of gravity, optimization, rainwater utilization management, costs, and productivity.

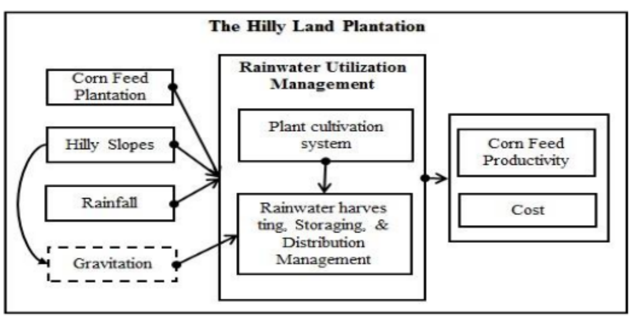

Figure 1. Conceptual Framework of the RWUM Optimization Model

The cultivation system applied to determine water requirements of CFP was a drip irrigation system. The concept of land slope was intended to determine the area of RWUM. The concept of the law of gravity was intended to determine the area of rainwater storage (RWS) that could maximize gravitational power to distribute water from RWS to CFP. The concept of rainfall was intended to determine the optimal of catchment area and capacity of RWS. The optimization concept was intended to find patterns of relationships between RWUM area and the costs of the CFP. The concept of productivity was intended to measure the increased productivity of CFP after its water needs were met. The relationship of each of these concepts was illustrated in the conceptual framework in figure 1.

2.3. The productivity of corn-feed plants (CFP) in Benteng Gajah village.

An intensive CFP in the slope area of hills had not been widely done in Indonesia, it was the case in the Benteng Gajah village. The CFP in the slope area of Benteng Gajah village was generally only done once a year due to water limitations. However, there was a small communitiy in the village, they had tried to cultivate CFP twice planting period a year since 2016. The first period was from November to February, and the second period was from March to June. The CFP that they were grown in the village were superior seeds, such as BISI X, PIONEER XX, with an area of only around 17 ha. Unfortunately, the CFPs production in the second cultivating period was much lower, around 20% to 68% of the first cultivating period.

2.4. The hilly slope and the power of gravitation.

The land slope of CFP cultivation determined the size of gravitational power that could be used to distribute water from RWS to all CFP that were lower than the RWS. The slope of sampled CFPs location could be known through contour intervals (CI) of the location contour line map. The slope of sampled location of the RWUM model was around 20 to 30 degrees.

2.5. The rainfall in Benteng Gajah village.

One of nature's precious gifts for Indonesia was having relatively high rainfall. It means that Indonesia's potential volume of available rainwater was very abundant. In addition, the rainwater advantage could be harvested and stored directly where it falls, so that the rainwater can be managed effectively and efficiently anywhere at the CFP location. The Benteng Gajah village had a high average rainfall of more than 3,000 mm year^{-1}.

2.6. The rainwater utilization management (RWUM).

The RWUM model, in this case, was the management of rainwater harvesting, storing, and distributing the water to the CFP. There were three potential sources of rainwater that can be harvested and stored, i.e. rainwater that falls directly in RWS, rainwater that falls on the roofs of garden buildings that were higher than RWS if any, and rainwater runoff from rainwater catchment areas (RWCA) that were higher than RWS [15]. Management of RWS in this study applied geomembrane technology and the rainwater distribution management (RWDM) to distribute water from RWS to CFP applied a drip irrigation system so that the RWUM was more effective and efficient according to the CFPs requirement.

2.7. Research methods.

This study applied a simulation model to determine a better RWUM model that matched the slope of the CFP land sampled. This simulation model was applied because the RWUM technology infrastructure was relatively expensive for farmers, so its implementation could not be done directly on the CFP of farmers. Indicators for determining the RWUM simulation model that were better based on the total cost of implementation. To calculate the implementation costs, the three RWUM simulation model scenarios were made in accordance with the assuming existing sampled CFP conditions.

Data needed from the sampled CFP location of the RWUM simulation model was: population of the CFP, water requirements tree^{-1} of the CFP from May to June, the slope degree of the CFP area, yearly rainfall average of the CFP area, estimated investment costs of RWUM infrastructure, and operational costs of the RWUM.

The CFP population data and its water requirements corn-feed tree^{-1} were needed to calculate the minimum volume of rainwater that must be managed to meet the water needs of the CFP during May to June. The slope degree of the sampled location was needed to divide the RWUM simulation model zone based on land height. The yearly rainfall average (YRFA) data was needed to determine the RWCA to

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support RWS. The kind of costs involved in the RWUM simulation model was needed to calculate the total cost of each scenario.

2.7.1. The General design of RWUM model. The RWUM model design of the CFP was formulated as in Figure 2. The design model was the result of a reference study, direct observation and discussion with leaders of the CFP farmers community in Benteng Gajah village. The RWUM model consisted of five main subsystem components, i.e. rainwater (*gray colour*) , harvesting (*yellow colour*), distribution (*blue colour*), cost (*red colour*), and CFP of hills land (*green colour*). The figure 2 had shown that the water sources of RWUM model were only from rainwater harvested through a RWCA. The RWCA was designed based on the volume of the CFP water requirement from May to June and the rainfall of the sampled location. Rainwater that falls outside the RWCA was partially infiltrated into the soil and consumed by the CFP, and others become runoff and enter the watershed. If there was an excess volume of rainwater harvested so that it exceeded the capacity of RWS, because the rainfall in certain years was higher than the average, then the excess was channelled to the watersheds.

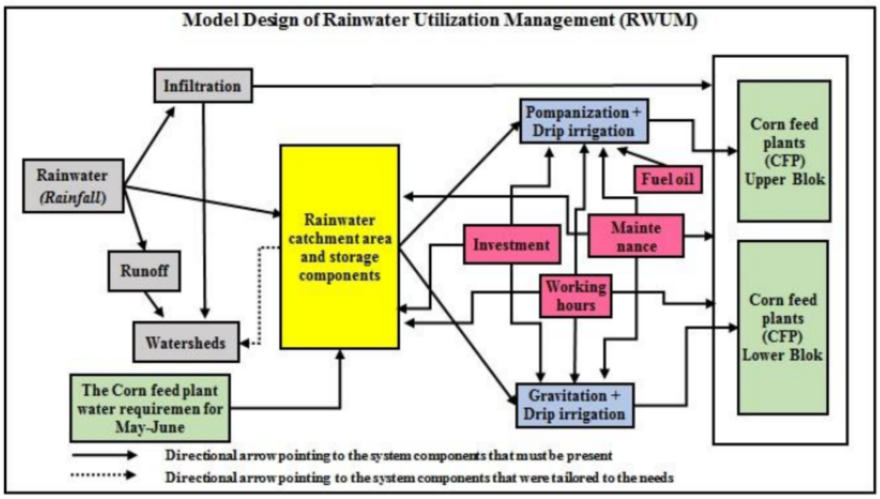

Figure 2. The general design of RWUM model in the hills.

The harvested rainwater was distributed to CFP according to the needs of CFP when there was no rainwater in May to June. The CFP was divided into two blocks, i.e. the upper block and the lower block. The upper block of the CFP had to be irrigated by pump engine power, while the lower CFP block was a block that could be irrigated by gravitational power. In order for the RWUM could run effectively and efficiently, it required investment costs, maintenance costs, labor hours, and fuel oil costs for pumping machines.

2.7.2. Data collection. The location of the sample was purposively selected which had a relatively similar slope, where the length and width were 100 m. The assumptions were intended to make the RWUM simulation model scenario flexible to be placed anywhere in the CFP sampled location. The slope data of the research location was between 50 m to 80 m above sea level.

2.7.3. The RWUM simulation model scenarios. There were three scenarios of the RWUM simulation model that were applied in this study. Each of these scenarios was simulated in different altitude zones at the CFP location. These zones were then called the lower zone, middle zone, and upper zone. The three zones were divided based on 10-meter contour intervals. To determine which scenario was the best of the three was to compare the estimated costs needed for each scenario. These costs were RWUM infrastructure costs and its operational costs which consist of labor costs, RWUM infrastructure maintenance costs, and operational costs of the pumping machine.

2.7.4. Basic assumptions. The assumptions underlying the RWUM simulation model and the analysis of the simulated data resulted were as follows:

- The slope of the sample location was considered relatively the same, so the infrastructure implementation of the three RWUM simulation model scenarios was the same.
- Because of the RWUM simulation model infrastructure was considered the same, then the infrastructure investment costs were also the same. Thus, the costs compared to determine the best RWUM simulation model of the three scenarios were the operational costs.
- The operational costs calculated in each scenario were maintenance costs of all infrastructures by regular workers calculated as working hours and costs of consumables of pumping machine operations. The pumping machine used was considered the same for all three scenarios, namely a gasoline-fueled pumping machine.

3. Results and discussion

3.1. The rainfall in Benteng Gajah village.

Rainfall data were obtained from two sources, i.e. from the Meteorological, Climatological, and Geophysical Agency (BMKG) Maros, and SamSamwater Tools. Data from the BMKGs were the 10-year monthly rainfall average. While the data from SamsamWater Tools was predictive rainfall data in 2019. The two sources of rainfall data indicated that rainfall in the sample location of the RWUM simulation model was high, which exceeds 3,000 mm year^{-1}.

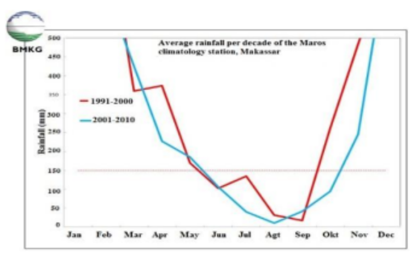

Figure 3. The monthly average rainfall chart for each 10 year period [13].

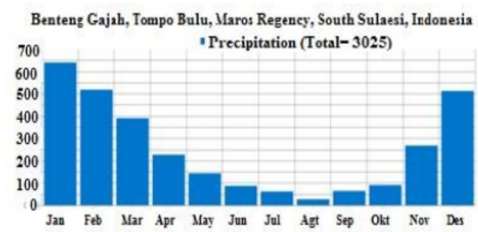

Figure 4. Rainfall prediction chart of Benteng Gajah village in 2019 [14].

The two rainfall charts showed that the rainfall at the sample location of the RWUM simulation model still meets CFP needs, for CFP needs of 0.52 litres day^{-1} tree^{-1} (Table 2), during May, and around 19 days for June. Unfortunately, in addition to rainfall, the productivity of CFP was also determined by the number of days without rain (NDWR) and intervals of days without rain (IDWR). According to their experience, the phenomenon of rain on May in Benteng Gajah village sometimes had more than 22 NDWRs and IDWRs exceeding 10 days. In fact, in June there were sometimes 26 days of NDWR and 12 days of IDWR. If the NDWR phenomenon appeared in those months, then the air temperature also increased significantly, so that CFP and some other crops in of Benteng Gajah village were threatened with a very serious lack of water.

3.2. The Corn-feed Plants in Benteng Gajah village.

The survey had resulted for all CFP farmer community members, from 2016 to 2019, obtained production of CFP as in table 1. The table showed a very significant decrease in production between the planting periods of November to February and March to June each year, which ranges from 20% to.

30%. In fact, in 2019, production was estimated to decline by 68%. The decline in the number of production was very significant, in 2019, one of which was caused by May NDWR of more than 20 days and there was an IDWR of more than 10 days and in June IDWR of more than 12 days which caused CFP lacking water exceeding the tolerance threshold. As a result, the fertilizer provided was not maximally consumed by CFP, even some farmers do not provide fertilizer at all.

Table 1. The average corn-feed production for the last 4 years from corn-feed gardens, in the hills of Benteng Gajah village

Years	Average production ha^{-1} (November-February)	Average production ha^{-1} (March – June)	Production Decline (%)
2016	6,200 kg	4,900 kg	20.97%
2017	5,300 kg	4,000 kg	24.53%
2018	5,450 kg	4,250 kg	22.02%
2019	6,250 kg	≈ 2,000 kg*	68.00%

The CFP had grown through three phases, i.e. the germination phase, the vegetative phase, and the reproductive phase [16]. This study resolved the calculation of CFP water requirements during the reproductive phase of the planting period of March to June. This phase was chosen because the phase of CFP in Benteng Gajah village was always threatened by water shortages due to relatively low rainfall see figure 3, figure 4. At that the phase, the phenomenon of NDWR and IDWR sometimes exceeds the tolerance threshold for CFP. From the survey results of all 15 CFP farmers was found that the average water requirement of CFP per tree was 0.82 liter of $trees^{-1}$ day^{-1} (see table 2).

Table 2. The average water demand $day^{-1}$of corn-feed in Benteng Gajah village based on the growth phase and the source of water to suffice in the planting period March to June

Phase	The Average Water Require ment $tree^{-1}$ day^{-1}	The estimated water source volume		Month	Number of rainy days
		Rainwater	Water Reservoirs		
Germination	0.55 Liter	0.85 Liter	0.00 Liter	March	> 17
Vegetative	0.75 Liter	0.65 Liter	0.10 Liter	March-April	> 12
Reproductive	0.82 Liter	0.40 Liter	0.42 Liter	May	6-8
		0.30 Liter	0.52 Liter	June	4-6

The slope of hilly land varies from one another. Land slope data was needed to determine the RWUM location that meets the requirements of the land. The topography map of the land that sampled could be seen in figure 6. The location of that study sampled was 10,000 m^2 with a length and width of 100 m each, and its slope of about 17 degrees.

Figure 5. The map of topography, the contour lines, and the location of the CFP [17].

3.3. Rainwater Utilization Management (RWUM)
The required volume of RWS depended on at least four variables: the CFP population, the CFP water requirement per tree, the number of watering days of CFP, and the percentage of evaporation of the

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RWS year^{-1} [15]. The simulated CFP area was one ha with a CFP population ranging from 66,000 - 75,000 plants ha^{-1} [18]. The CFP is planted in the planting period from March to June, where during the CFP reproductive phase, it was threatened that there will be a lack of water in May to June because rainfall is not sufficient for water needs. During this phase, the CFP requires an additional water requirement of an average of 0.52 litres tree^{-1} day^{-1} (see table 2) or for 60 days. Evaporation of RWS ponds with a depth of 3.0 m up to the reservoir. 3.5 m is 20% [19] and [20]. By adapting ARWS formula cocoa [15] to CFP as follows:

$$\boldsymbol{Vk} = (1 + e)Vt \tag{1}$$

Where $\boldsymbol{Vk}$: The minimum volume of ARWS (m^3); $\boldsymbol{Vt}$: The volume of rainwater that CFP needed during the dry season (m^3); $\boldsymbol{e}$: The efficiency coefficient of ARWS (%). From the equation (1) was found that the need of rainwater that must be harvested and stored in the RWS for one ha CFP with the population, for example, 66,000 plants, 0.52 tree^{-1} day^{-1}, for 60 days, with a 20% evaporation coefficient was 2,471.04 m^3.

The RWCA depended on the annual average of rainfall and the depth of the ARWS at the sample location. The formula for calculating RWCA was as follows:

$$\boldsymbol{A_{ca}} = \frac{\boldsymbol{Vk}}{\boldsymbol{h}} \tag{2}$$

Where $\boldsymbol{A_{ca}}$: The minimum RWCA (m^2); $\boldsymbol{Vk}$: The minimum volume of RWS (m^3); and $\boldsymbol{h}$: The depth of RWS. Based on the rainfall data, such as at figure 3; figure 4 showed that the average annual rainfall in Benteng Gajah village exceeds 3,000 mm (3m). With the high annual average rainfall, and the volume of rainwater needed by the CFP was 2,471.04 m^3 ha^{-1}, then the RWCA needed was 2,471.04 m^3/3m = 823.7 m^2. Furthermore, the geometric shape of the RWCA was adjusted to the contour of the occupied land.

3.4. An analysis of the simulation result for each scenario.

After the conceptual of RWUM model, as in figure 2, had been designed, then the design of the model was designed with several simulation model scenarios. A decision variable used to determine the best RWUM model was based on a comparison of the estimated cost of each of those scenarios. In this study, the scenario of the RWUM simulation models was limited to only three different scenarios based on the height above the sea level. All the three scenarios apply the RWUM simulation model, where water from RWS is distributed according to CFP requirements. To achieve all CFP, the water can be distributed through two distribution systems, each of which can be through a pumping system or through a gravity system plus a drip irrigation system available. If the position of RWS is lower or equal to CFP, then water must go through a pumping system to the plant, or if the position of RWS is higher than CFP, then the water must go through the gravity system to the plant.

3.4.1. Scenario I. In this simulation scenario, the location of the RWUM model in figure 2 was placed in the lower block of the three RWUM simulation model scenarios. Whereas the CFP block in figure 2 is modified to become 6 sub-blocks. The six CFP sub-blocks consist of the upper part of upper block (U_u), lower part of the upper block (U_l), upper part of the middle block (M_u), lower part of the middle block (M_l), upper part of the lower block (L_u), the lower part of the lower block (L_l).

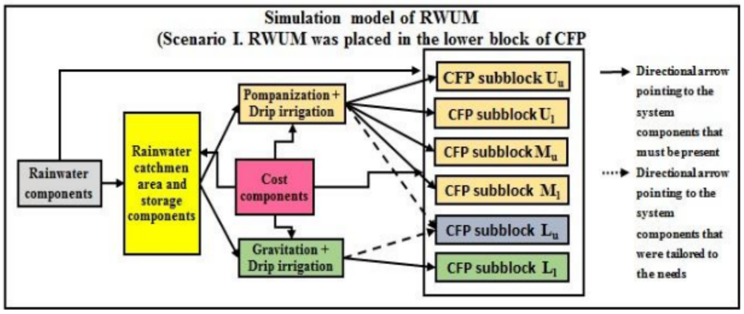

Figure 6. The simulation scenario of the RWUM model that was placedon the upper zone of CFPs sampled.

The relationship between each component in the scenario can be seen in figure 6. The distribution of water from RWS to CFP in this scenario is more through the pumping system than through the gravity system. The scenario I simulation showed that there were four of the six CFP sub-blocks (*brown color of figure 6*) fully receiving water from the pumping system, each of which about half of the six CFP sub block (*purple color of figure 6*) was irrigated from both the pumping system and the gravity system. The only one of the six sub-blocks of the CFP (*green color of figure 6*) fully gotten water from the gravity system. So the ratio of the estimated use of CFPs water between the pumping system and the gravity system was about 9:1.

3.4.2. Scenario II. This scenario differed substantially from the scenario I in two aspects. The first aspect was the placement zone of the RWUM simulation model. The scenario of the simulation was placed in the middle zone. The second aspect was that the utilization of the water distribution system from the RWS to the CFP sub block in scenario II was more through the gravity system than in scenario I. The differences between the two aspects could be seen schematically in figure 6 and figure 7. The two aspects made a very significant difference in operational costs between scenario II and scenario I. Scenario I utilized the water pump machine more than in scenario II, so the operational cost of water distribution from RWS to CFP in the scenario I was higher than the scenario II.

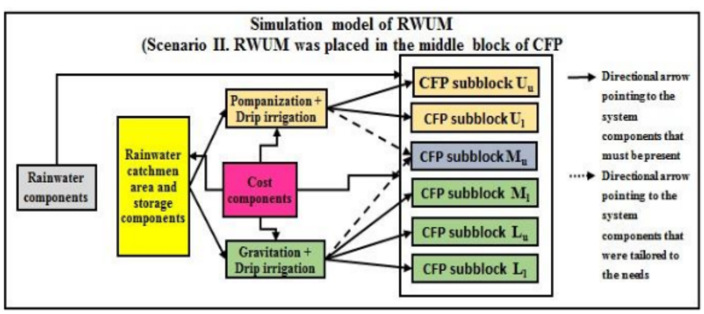

Figure 7. The simulation scenario of the RWUM model that was placed on the middle zone of CFPs sampled.

The scenario II simulation showed that there were two of the six CFP sub-blocks (*brown color of figure 7*) fully receiving water from the pumping system, each of which about half of the six CFP sub block (*purple color of figure 7*) was irrigated from both the pumping system and the gravity system. There were three of the six sub-blocks of the CFP (*green color of figure 7*) fully gotten water from the gravity system. The ratio of the estimated use of a water pump between scenario I and scenario II was about 9: 5.

3.4.3. Scenario III. The scenario differed substantially from scenario I and scenario II in two aspects as well. The first aspect was the zone of placement of the RWUM simulation model in scenario III placed in the middle zone of the CFP. The second aspect was that the utilization of the water distribution system from RWS to the CFP sub block in scenario III was more through the gravity system than in scenario I and scenario II.

The difference between the two aspects could be seen schematically in figure 6, figure 7 and figure 8. Both aspects make a very significant difference in operational costs between scenario III and the previous two scenarios. Scenario I and scenario II use more water pump machines than in scenario III so that the operational cost of water distribution to CFP in scenario I is higher.

The scenario III simulation showed that there were none of the six CFP sub-blocks (*brown color of figure 8*) fully receiving water from the pumping system, each of which about half of the six CFP sub-block (*purple color of figure 8*) was irrigated from both the pumping system and the gravity system. There were five of the six sub-blocks of the CFP (*green color of figure 8*) fully gotten water from the gravity system. So, the ratio of the estimated use of a water pump between scenario I, scenario II, and scenario III was about 9: 5:1.

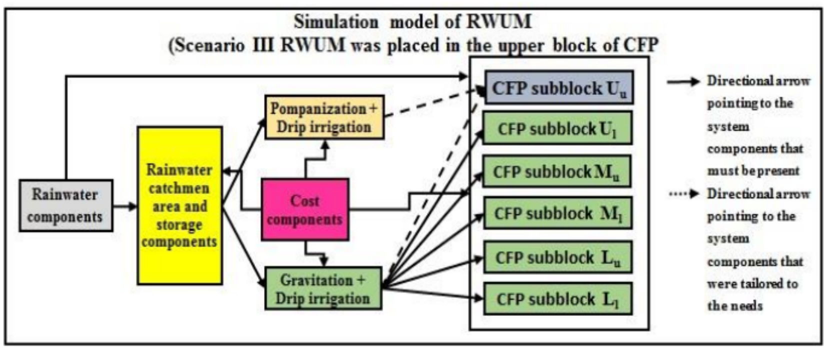

Figure 8. The simulation scenario of the RWUM model that was placed on the middle zone of CFPs sampled.

3.4.4. The cost ratio between the three scenarios. The results of the three simulation scenarios of the RWUM model showed the involvement of the financing components and their estimated number of cost units that must be spent to run each the scenaris (see figure 6, figure 7, and figure 8). From the three scenarios, it could be seen that the comparative investment costs of the RWUM simulation model (storage system, catchment area, pumping system, and drip irrigation system) were relatively the same. The difference between the three scenarios lied in their operational costs.

Table 3. The estimation of unit cost ratio of the three scenarios

Cost / Scenario	Fixed Cost (investment costs)					Variable Cost		
	Harvesting system		Distribution System			Working hours for maintenance		Pumpinization (Fuel Oil)
	Reservoir	Catchment area	Drip irrigation	Pompanization	gravity (Rp 0)	Harvesting	Distribution	
Scenario I	1 unit	1 unit	1 unit	1 unit	0 unit	1 unit	4,5 Unit	4,5 unit
Scenario II	1 unit	1 unit	1 unit	1 unit	0 unit	1 unit	2,5 Unit	2,5 unit
Scenario III	1 unit	1 unit	1 unit	1 unit	0 unit	1 unit	0,5 unit	0.5 unit

These operational costs include the cost of maintaining RWUM infrastructure and operational costs of the pumping system. The operational cost of the pumping system includes the cost of working hours to operate it and the cost of fuel oil. The difference in operational costs as a result of the ratio of the broad coverage of CFP watering through pumping systems also different in each scenario. The ratio of CFP watering area coverage in each scenario is as follows: scenario I covering 4.5 sub-blocks or equivalent to 9/12 ha, in scenario II covering 2.5 sub-blocks or equivalent to 5/12 ha, and in scenario III covering an area of 0.5 sub-blocks or equivalent to 1/12 ha (see Table 3).

4. Conclusion

Based on the comparison of the operational costs of the three scenarios of the RWUM simulation model on CFP in the hilly land of Benteng Gajah village, it could be concluded that the best RWUM model of the three scenarios was scenario III, which was the RWUM model placed in the upper zone of the cultivation park. The operational cost comparison of scenario I: scenario II: scenario III was 9: 5: 1.

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