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The rain water management model on an appropriate hilly area to fulfil the needs of cocoa farm during dry season

M Hasbi[1,2], R Darma[3], M Yamin[2], M Nurdin[2] and M Rizal[2]

[1] Department of Computer Science, Mathematics, Hasanuddin University, Jalan Perintis Kemerdekaan KM 10, Makassar, 90245, Indonesia.
[2] Doctoral Program, Department of Agricultural, Hasanuddin University, Jalan Perintis Kemerdekaan KM 10, Makassar, 90245, Indonesia.
[3] Department of Agicultural Socio-economics, Hasanuddin University, Jalan Perintis Kemerdekaan KM 10, Makassar, 90245, Indonesia.

E-mail: *hasbi.unhas@gmail.com*

Abstract. Cocoa is an important commodity because 90% farmers involved, easily marketed, and potentially harvested along the year. However, cocoa productivity tended to decrease by an average of only 300 kg hectare^{-1} year^{-1} or away from the potential productivity of two tons. Water management was an alternative method to increase its productivity by harvesting rainwater on the hilly cocoa farm area and distributing the water based on the gravity law. The research objective was to describes how to manage rainwater at the hilly cocoa farm area, so that the water needs of cocoa farm were met during the dry season. The important implication of the management was the water availability that supports the cocoa cultivation during the year. This research used qualitative method with descriptive approach to explain the appropriate technical specification of infrastructure to support the rainwater management. This research generated several mathematical formulas to support rainwater management infrastructure. The implementation of an appropriate rainwater utilization management for cocoa farm will ensuring the availability of water during dry season, so the cocoa farm allowed to produce cacao fruit during the year.

1. Introduction

Water was one of the main needs of cocoa plant to produce good bean quality. Therefore, lack of water that exceeds the threshold of the cocoa plant needs would cause the cocoa plant to suffer. Rainwater was one of the water resources in an area that faced water shortages [1]. Studies in several cities in Australia suggest that rainwater use could save up to 29.9% (Perth) and 32.3% (Sydney) water supply [2]. In Jordan, the use of rainwater by residents as an alternative source of clean water reduces water consumption by up to 19.7%.

Cocoa (*Theobroma cacao L.*) is a cultivable plant in the tropics, such as Indonesia. The population of cocoa per hectare ideally is around 1,000 trees with the size of planting of 3 m x 3 m. The specialty of cocoa plants was that they could bear fruit during the year if their water, nutritional and environmental needs were met. Cocoa plants could produce an average of 3 kg of dry beans per tree per year or about 3000 kg year^{-1}.

The main problem of cocoa crops according to the cocoa farmers, from the results of our survey since 2012 to 2014 in Bulukumba and Wajo District, was insufficiency of water to fulfill the needs of cocoa plants durig the dry season. According to them, most of cocoa diseases were caused by the lack of water.

The many aspects associated with rainwater management, this study was limited only to rainwater management using small artificial reservoirs at the hilly area or artificial-mini-hill-basin (AMHB) that applied geomembrane technology. The problem formulation of this research is how to manage rain water in the hilly areas of cocoa farm so that the water needs of cocoa plants are fulfilled during the dry season. The research objective is to describes how to manage rainwater in the hilly areas of cocoa farm so that the water needs of cocoa farm were met during the dry season. With proper water management and utilization would ensure the availability of water for cocoa farm during dry season, so that cacao could produce fruit throughout the year.

2. Literature review and Logical Framework

2.1. Literature Review

Rainwater harvesting system (RHS) was one of the rainwater utilization management (RUM) component. Rainwater harvesting (RH) was a method implemented to collect rainwater that fell on the roofs of buildings, the ground, the street, or the rocky hills that would be used as a source of clean water supplies [3].

RHS components depend on RH objectives. RHS for the purpose of clean water or drinking water consists of the following components: rainwater catchment area (RCA), rainwater channel (RCh) that drains rainwater from rainwater catchment to conveyance, rainwater filter (RF), rainwater storage tank (RST), rainwater sewer (RS), and a rainwater pump (RP) [4, 5].

The rainwater catchment area (RCA) component was where the rainwater were captured and the materials were used in the construction. The materials affected the efficiency and quality of rainwater collection. The materials used for the rainwater catchment surface should not contain toxins and materials that could degrade the quality of rainwater. Generally, the materials used were anti-rust material such as aluminum, galvanized iron, concrete, fiberglass shingles, etc. [3].

RHS implemented after the tsunami disaster in Banda Aceh was a simple, easy and inexpensive RHS constructed. This system was very helpful for the people affected by the disaster and the difficulty of clean water after the tsunami [6]. The rainwater drainage system usually consists of collecting channels or pipes that drain rainwater down on the roof to the storage tank. The collector or pipe channel had the size, slope and mounting in such a way that the maximum volume of rainwater could be accommodated [4]. The size of the container channel depends on the area of the catchment area, usually the diameter of the catching channel measuring 2.0 to 5.0 inc. [4].

According to UNEP [3], there were several types of RHS that could be applied: (1) RHS with roof system, this system uses the roof of the house as a rainwater catchment area. If the system was applied to individual homes, then the possibility of collected water was not significant, but if the system was massively applied, then the water collected was very abundant; (2) land surface catchment areas. this system uses the ground surface with a very simple method to collect rainwater. Compared with the roof system, RWH with the ground surface system allows more collecting rainwater because of its wider catchment area. Rainwater collected with ground-level systems was more suitable for agriculture because of low water quality. The rainwater collected with this system could be accommodated in a farm basin. However, some of the water contained in the farm basin was likely to sink into the soil [3].

The volume of rainwater that could be utilized by cocoa farm depended on the efficiency coefficient of the rainwater storage. The rainwater storage efficiency coefficient was the percentage of rainwater that could be utilized effectively. This coefficient depends on the RHS and its utilization to meet water needs. For indoor utilization needs (such as: shower, washing, toilet, leakage), the efficiency coefficient was (75-90) %, while for outdoor needs (eg irrigation, reservoir (liter / day) was about 50% [3].

2.2. Logical framework

Management of rainwater utilization (MRU) for cocoa farm was the management of rainwater based on the need of cocoa farm. The management model was defined in equation (5). The aim of MRU was to optimize the productivity of cocoa farm throughout the year from an average of 500 kg ha^{-1} $year^{-1}$ to more than 3000 kg ha^{-1} $year^{-1}$.

Farmers' cocoa farm were generally located in hilly areas. The contours of the hilly cocoa farm led to high runoff coefficients. As a result, cocoa farm in such location would quickly dehydrated. On the other hand, one of the advantages of a hilly cocoa farm was that the rainwater could be managed on the highest area. Thus, the water distribution system throughout the cocoa farm was applying the law of gravity.

3. Research methods

The research was a preliminary study of the application of AMHB that were carried out for one week, at the beginning of November 2016. The research areas were conducted in AMHB at "*Sentra Pemberdayaan Tani"* (SPT), Genting Village, Semarang and AMHB Nglanggeran, Nglanggeran Village, Patuk, Gunung kidul, Yogyakarta. The researchers took this location only as an example representing the AMHB built with the SPT concept developed by "*Obor Tani"* foundation.

In this study, researchers used in-depth interview techniques with two technical supports of the two AMHB as the informants, the first was Mr. Pratomo as a senior technical enginer support, and the second was Mr. Cahyo as an assistent of technical enginer. Researcher also use technical documentation of the AMHB to get written data which was considered relevant with this research. This research used qualitative models and some mathematical formulas used to analyze and describe the information obtained logically.

4. Results and Discussion

Based on in-depth interviews conducted by researchers on both informants on how the management of rainwater utilization using AMHB could be applied. Both informants, complement each other, explained systematically and comprehensively the advantages, disadvantages, technical requirements, organization, empowerment, and community assistance associated with the application of the AMHB. From the very comprehensive explanation, in this paper the researcher would only focus on discussing the aspects of advantages and disadvantages in general, the application of main technology aspects, and the required technical specifications of AMHB in more detail.

4.1. Advantages and Disadvantages Aspects

According to the two informants, the implementation of rainwater management using a AMHB relatively required more expensive for initial investment compared to the mini-valley-basin (MVB). The advantage of deploying AMHB was that there is no need for additional investments in water pumps and its operational costs, such as fuel, oil, maintenance costs, and skilled human resources to handle the agricultural machinery system. According to the experience based calculation of the two informants that the additional machinery investment and its operational costs of MVB for three years was equivalent to the investment of AMHB. Thus, the AMHB investment would be cheaper after more than three years.

4.2. Technology and Its Supporting Infrastructure

Management of rainwater utilization using AMHB requires additional technology, which should not be used in MVB, in order for rainwater stored in reservoirs to be controlled and avoid potential landslides. There are two major types of investments needed to construct the AMHB, which was its own development investment and its infrastructure. The investments in the construction of AMHB such as cut and fill, soil compaction using heavy equipment with certain specifications, and other supporting facilities. The main infrastructure investment in additional technology required to complete the AMHB is a geomembrane, some devices for rainwater management system technology.

4.3. Required Technical Specifications

According to the two informants, there are three main technical factors that must be met to build and manage the appropriate AMHB, which are the suitability of the volume of rainwater to be managed, the annual rainfall at the cocoa farm area, and the adequacy of the hill area to meet the needs cocoa farm. The need for rainfall volume to be managed in AMHB is calculated based on the accumulation of maximum volume of water of each productive cacao trees during the dry season, the average evaporation factor throughout the year, and other water requirements. The rainfall factor is needed to calculate the rainwater catchment area to meet the capacity of the AMHB. While the location determination is based on the height of the location and the wide area of available rainwater catchment area.

4.4. Rainwater Utilization Management

The management of rainwater utilization intended in this paper is the management of rainwater based on the needs of the cocoa farm during the dry season. Therefore, the underlying factors of management are the volume of rainwater that falls in the cocoa farm location throughout the year, the percentage of rainwater required by the cocoa farm during the dry season, the percentage of rainfall evaporation from the AMHB for a year. Thus, the volume of rainwater that should be managed in AMHB was the accumulation of cocoa farming needs and evaporation throughout the year.

4.4.1. The water Requirement of Cocoa Farm

The volume of rainwater required to manage a cocoa farm during the dry season depended on the population of the cocoa farm and the maximum water requirements of the most productive cocoa plant at the same environmental conditions. Mathematical formula for determining the volume were as follows:

$$\boldsymbol{Vc} = \boldsymbol{N} * \boldsymbol{n} * V_{max} \quad (1)$$

Where **V**c : The volume of water needed by the cocoa farm during the dry season (m^3)
N : The Length of dry season at the area of cocoa farm (day)
V_{max} : The maximum water requirement of the most productive cacao plant at the same environmental conditions during the dry season (liters)
n : The number of cocoa plants.

For example: A cocoa farm had an area of 2 ha, population of 2135 trees, with an average age of 5 years. The cocoa farm was located in village X which had a dry season for 7 months. Suppose the most productive cocoa tree needs an average of 5 liters of water tree^{-1} day^{-1}. For this case, then each cocoa plant for 7 months of dry season required 7 x 30 days x 5 liters tree^{-1} day^{-1} was equal to 1050 liters tree^{-1} or 1.05 m^3 per tree. So the need for rainwater that have to be stored in the AMHB during the year to meet the needs of cocoa plant during the dry season was equal to 2135 trees x 1.05 m^3 per tree or equal to 2241.75 m^3.

4.4.2. The Efficiency Coefficient of AMHB

The efficiency coefficient of AMHB determined the volume of rainwater that must be harvested during the rainy season. In general, there were three main factors that could affect the efficiency coefficient of AMHB, the first was the infiltration factor or permeation of the AMHB, the second was the evaporation factor of the AMHB, and the third was the damage factor of AMHB. The implementation of AMHB system could minimize the water infiltration or permeation factor of the AMHB and the damage factor could be well controlled. In other words, the evaporation factor of AMHB was the only major factor affecting the efficiency coefficient. According to Pratomo [7], the evaporation factor of AMHB was estimated at about 20%. Thus, the efficiency coefficient of the AMHB was about 80%.

4.5. Management of Artificial-Mini-Hill-Basin (AHMB)

There were three types of rainwater catchment area (RCA) that could support the AMHB in cocoa farm, the first was the AMHB itself, the second was the building roof (BR) of the cocoa farm which was higher than the AMHB, and the third was the cocoa farm at the higher level of cocoa farm area (HCFA) than the AMHB.

4.5.1. Volume of AMHB. For example, the volume of water need of a cocoa farm during the dry season was **Vt** (m^3), then the mathematical model for determining the volume of AMHB needed to meet the needs of the cocoa farm was as follows:

$$Vk = (1 + e)Vt \quad (2)$$

Where Vk : The minimum volume of AMHB for a year (m^3)
Vt : The volume of rainwater that cocoa farm need during the dry season (m^3)
e :The efficiency coefficient of AMHB (%)

By knowing *Vk*, the AMHB could be determined its area and depth. According to (Pratomo, 2009), the water depth within the AMHB was about 3m. Factors needed to consider for determining the depth of the AMHB were the physical security of the AMHB itself and its evaporation (Pratomo, 2009).

*4.5.2. Rainwater Catchment Area (RCA) Management.*Types of RCA that could be utilized to fulfill **V**k were the AMHB itself, BR, or HCPA: The first priority to fulfill the AMHB was the AMHB itself, the second priority was the building roof (BR) of cocoa farm which was higher than AMHB if any, and the third priority was the HCFA.

The mathematical model for determining the rainwater volume of RCA cached from the AMHB was as follows:

$$Vtk = \boldsymbol{P} * \boldsymbol{L} * \boldsymbol{Ch} \quad (3)$$

Where Vtk : The rain water volume from AMHB as RCA for a year (m^3)
P : The Length of AMHB (m)
L : The width of AMHB (m)
Ch : The average annual rainfall (mm)

The mathematical model for determining the rainwater volume of RCA cached from the BR was as follows:

$$Vta = \boldsymbol{Pa} * \boldsymbol{La} * \boldsymbol{Ch} \quad (4)$$

Where Vta : The rain water volume fromBR as RCA for a year (m^3)
Pa : The length of BR (m)
La : The width BR (m)
Ch : The average annual rainfall (mm)

The mathematical model for determining the rainwater volume of RCA cached from the HCFA was as follows:

$$Vts = \boldsymbol{Ps} * \boldsymbol{Ls} * \boldsymbol{Ch} * \boldsymbol{R} \quad (5)$$

Where Vts : The rain water volume from HCFA as RCA for a year (m^3)
Ps : Length of HCFA (m)
Ls : The width of HCFA (m)
Ch : The average annual rainfall (mm)

Thus, the total area of rainwater catchment required is the accumulation of AMHB, BR, and HCFA areas.

5. Conclusions

- With the right management of AMHB, rainwater can be optimally utilized as a source of cocoa farm water to overcome the lack of water during the dry season.
- Rainwater management, by applying AMHB, had to apply geomembrane and water-controling-system technologies.

- Rainwater management, by applying AMHB, must meet the requirements of the wide areas of each available RCAs in the cocoa farms.
- The mechanism to identify the volume of rainwater management in cocoa farm, by applying AMHB, was started with identifying the total of cocoa plants, the maximum water requirement of the most productive cocoa in the same environmental conditions, the average annual rainfall, the duration of the dry season and the AMHB evaporation coefficient at the cocoa farm area, and AMHB volume, and finally, determine carefully according to the mathematical equations (1) through (5) above.
- The volume of rainwater utilization for cocoa farm was different at each of the different cocoa farm environmental conditions, it was primarily dependent on the annual rainfall average, the duration of the dry season, and the maximum water requirement of the most productive cocoa at the same area during the year.

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