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Soil Moisture Analysis and Rainwater Management at Clove Plantation to Meet the Water Requirement of Clove Plants During Dry Season

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***Abstract*—In 2015, the clove plants on Ternate Island experienced a drought and dead in the dry season. This study aimed to discover the potential for rainwater and soil moisture as well as the management to meet the water needs of clove plants. This research was conducted from October 2018 to March 2019 on Ternate Islan. The soil data (pF 2.4 and 4.2) and effective depth at 12 land units. The climate data for 2008 to 2017. The data analysis used the water balance approach of the Thornthwaite-Mather method, the Penman-Monteith method, Darcy's law of the SPAW model, and the CropWat 8.0 software. The results showed that the total rainfall was 2307.3 mm/year. The average soil moisture storage (STo) was 134.5 mm. During the dry season, the total rainfall was 1660.4 mm/year. The potential evapotranspiration was 1561.2 mm/year. The water needs for the clove plantation in the tree phase during the dry season was 640.1 mm/year or 53.3 mm/month and increased from the water needs for clove plants in normal conditions which was 607.1 mm/month. The strategies for managing the water needs for the clove plants during dry season were harvesting rainwater during surplus in December and January for storage and increasing soil moisture during water deficit in February and March, using the biopore infiltration hole technology made from organic material from clove leaf litter. Further research on the water needs for clove plants in the vegetative phase.**

***Keywords*— Clove plants; water management; soil moisture; biopore; plant water requirement.**

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I. INTRODUCTION

Cloves (*Syzygium aromaticum* L.) are the main plantation crop for the people of Ternate Island and are native to the Maluku Islands (Moluccas) [1]. Cloves developed for the first time in five small islands in Maluku: Bacan, Makian, Moti, Ternate, and Tidore [1], [2]. The growth and productivity of clove plants are influenced by land quality factors, including the danger of erosion, nutrient retention, root media conditions, plant management, and water availability factors from rainfall and available moisture in the soil [2]. Furthermore, the main environmental factors affecting plant physiological processes are solar radiation, air temperature, and the content and groundwater availability [3]. In normal climatic conditions, water is available annually by rainfall and is lost through evapotranspiration [4].

In 2015, there was a long dry season due to climate change which caused the clove plants on Ternate Island to experience growth disturbances and decreased production [5], resulting in drought and dead. The meteorological drought and the agricultural drought in 2015 were greater than those in 2002. The main plantation crops that experienced drought and dead were 886 cloves, 199 nutmeg trees, and 32 coconut trees. Due to low rainfall and high evapotranspiration. Rainfall is the main source of water for clove plants and then stored in the soil as soil moisture; rainwater can be absorbed directly by the stomata of leaves, branches, and stems through interception or absorbed by plant roots from the soil [6].

The dry season and low rainfall cause soil moisture availability, both in the condition of field capacity or available moisture in the low-root area and moisture absorption by plant roots are also low. Therefore, plants lack water for physiological processes; meanwhile, the transpiration process continues. Therefore, plants wither, then dry, and then die. A decrease in rainfall is always followed by an increase in evapotranspiration due to rising temperatures [7]. The high and low value of evapotranspiration that occurs affects the availability of soil moisture [8]. Soil properties that determine the available moisture content are soil texture, structure, soil pores, organic matter content, and effective soil depth [9].

Rainfall and evapotranspiration fluctuations cause a water surplus and deficit [10]. This happens in clove plantations; therefore, there are months of surplus and deficit in water in one year. If the water deficit is greater, the water needs of the clove plant will not be fulfilled for growth and production due to a large amount of water lost through evapotranspiration. Rainfall <80 mm is called the dry period or month for clove plants [2]. Changes in environmental conditions and plant evapotranspiration influence plant water conditions directly [11]. The evapotranspiration that occurs shows the amount of water needed by plants. This is because plant water needs can be determined based on evapotranspiration and crop coefficients [12].

The amount of water needs for clove plants varies during the growing period, and it is influenced by the amount of water received and lost. This requires a rainwater and soil moisture management strategy in handling water surpluses and deficits. Water management is important in dry land management for agriculture; if water is available, plant productivity will increase and, ecologically, there will be a balance of water in nature [13].

Most of the surplus rainwater is lost from the land through runoff. Therefore, it cannot be used by plants. The amount of surface runoff can reach 30-40% of the rainwater volume that falls to the soil surface [14]. Potentially, if this runoff water can be absorbed and stored in the soil, it will greatly help fulfill the water requirement of plants during the dry season. One of the technologies for harvesting runoff water is the biopore infiltration holes (LRB), installed in rainfed drylands. This research was conducted to analyze the potential for rainwater and soil moisture content for a year and the application of biopore technology with clove leaf litter to harvest rainwater that has run off on the land surface.

II. Material and Method

A. Data and Location

This research was conducted on clove plantations on Ternate Island, North Maluku. Located at coordinates 00°45'11.32" – 00°52'05.10" NL and 127°17'31.76" – 127°23'20.41" EL. The research material were the daily and monthly climate data (rainfall, air temperature, evaporation, humidity, and wind speed) for a period of 10 years (2008 to 2017), obtained from the BMKG Station of Babullah, Ternate. The soil data were soil moisture, field capacity (FC), permanent wilt point (WP) and effective depth, C-organic and soil physical properties. The survey and observation as well as soil samples were conducted in 12 land map units.

B. Data Analysis and Variables Soil Properties and Moisture Levels

The pF2.5 and pF4.2 values of the sand box, kaolin box, and pressure plate methods. The pF curve approach [15]. Soil physical properties, C-organic laboratory analysis.

1) Regional Water Balance: The analysis of regional water balance was done using the Thornthwaite and Mather methods [16]. The components of the water balance analyzed are:

P = average rainfall; PE = Potential Evapotranspiration.
The calculation of the PE value (ETo) used the Penman-Monteith method [7]; the evapotranspiration calculation (ETo) of Penman-Monteith method used the CropWat model software version 8.0 for Windows, developed by the Food and Agriculture Organization [16], [17].

$$APWL = (P - PE)\ difference\ is\ negative \quad (1)$$

$$ST = STo x e^{(+\frac{APWL}{-STo})} \quad (2)$$

Whereas STo is the relationship between the field capacity (FC), permanent wilt point (WP), and the effective soil depth (dz).

AE = PE (for wet months; P>PE),

$$AE == P + \Delta ST\ (for\ dry\ months;\ P < PE) \quad (3)$$

$$\Delta ST = ST2 - ST1 \quad (4)$$

$$D = PE - AE \quad (5)$$

$$S = (P - PE) - \Delta ST \quad (6)$$

P is the precipitation/monthly rainfall (mm). PE is the potential evaporation (mm/month). P-PE is the value difference between rainfall and potential evaporation (mm). APW is the cumulative total deficit in rainfall (mm). ST is soil moisture content (mm). ΔST is the change in soil moisture content (mm/month). AE is the actual evapotranspiration (mm /month). D is the lack of moisture (deficit) (mm/month); S is the excess moisture (surplus) (mm/month). STo is the soil moisture content at field capacity (mm).

2) Plant evapotranspiration (ET) estimation, and crop coefficient (Kc) values.

$$ET = [P + I + U] - [R + D + \Delta S] \quad (7)$$

Plant evapotranspiration (ET) used the water balance approach, where precipitation (P), irrigation (I), upward capillary flow (U), surface flow (R), percolation (D), and changes in soil moisture content (ΔS) were the factors measured in the field based on environmental conditions for plant growth [18]. The values of irrigation and capillary flow upwards = 0 due to the rainfed land and deep groundwater.

$$Kc = ET/ETo \quad (8)$$

Whereas Kc is the crop coefficient, ET is the plant evapotranspiration, and ETo is the standard evapotranspiration [19]. Surface flow, small patch approach [20]. Percolation, Darcy's legal approach, and the SPAW model [21].

III. Result and Discussion

A. Climate Conditions and Water Availability

The climate data from the BMKG of Babullah, Ternate, in 2008 to 2017 (Table 1) showed that, in normal climatic conditions, the clove plantations in Ternate Island were the areas with wet conditions throughout the year. Based on the climate classification of Schmidt and Ferguson, it is classified as the wet climate (B). The highest amount of rainfall occurred in May which was 311.5 mm/month, and the lowest rainfall occurred in September which was 99.9 mm/month; while the average air temperature was 27.2ºC, with a maximum temperature of 31.2ºC and a minimum temperature of 24.5ºC. The average air humidity was 82.3%, the average wind speed was 4.5 km/day, and the solar radiation intensity was 60.6%. Furthermore, the monthly climatic conditions showed that, in October, there was an increase in air temperature (31.7ºC) and solar radiation (70.7%) as well as low humidity (79.8%).

The water availability analysis results (Figure 1) showed that, in normal climatic conditions, the amount of rainfall that occurred was 2307.3 mm; while in the dry season (2014 to 2016), the rainfall that occurred was 1660.4 mm. The highest rainfall was in December (259.7 mm), and the lowest was in March (44.7 mm). In 2015, the rainfall was very low, only 930.0 mm, with 7 dry months (rainfall <60 mm) and only 4 wet months (rainfall >100 mm) and 1 humid month. This shows that, in the dry season, water availability is very low due to low rainfall and higher evapotranspiration, causing loss of soil and crops as well as lack of water, especially in July, August, and September. As according to [22], groundwater content (moisture content) for growth and production of cloves is less available from August to October due to low rainfall and large evapotranspiration.

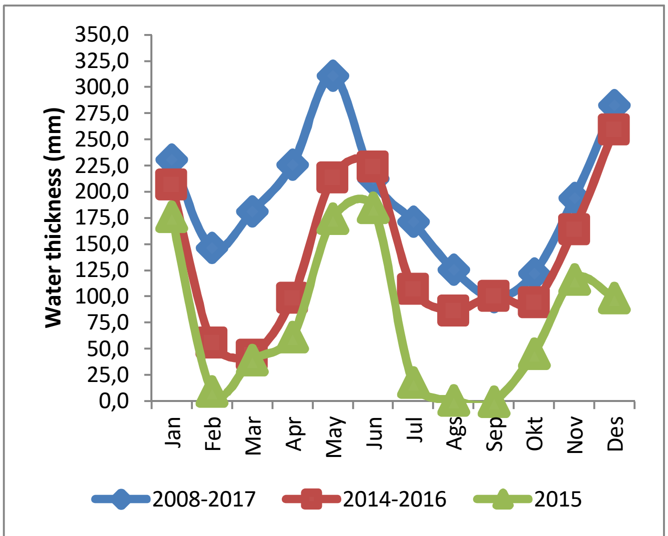

Fig. 1 Total rainfall and water availability

TABLE I
SOIL MOISTURE LEVELS ON CLOVE PLANTATION

Land Unit	FC (pF 2.5) (cm^3/cm^3)	WP (pF 4.2) (cm^3/cm^3)	AM (cm^3/cm^3)	Z (cm)	STo (mm)
SPL-01	0.36	0.13	0.23	75	172,5
SPL-02	0.44	0.23	0.21	70	147,0
SPL-03	0.34	0.22	0.12	75	90,0
SPL-04	0.49	0.28	0.21	69	144,9
SPL-05	0.27	0.17	0.10	60	60,0
SPL-06	0.48	0.30	0.18	78	140,4
SPL-07	0.41	0.23	0.18	80	144,0
SPL-08	0.40	0.31	0.09	65	58,5
SPL-09	0.41	0.26	0.15	125	187,5
SPL-10	0.26	0.12	0.14	115	161,0
SPL-11	0.41	0.27	0.14	90	126,0
SPL-12	0.43	0.22	0.21	87	182,7
Average					**134.5**

Information: FC = field capacity; WP = permanent wilt point; AM = moisture available; Z = effective depth; STo = soil moisture content

B. Soil Conditions and Moisture Availability

Andic lands generally dominated the land in the research site. This was due to the main material (that forms the soil in the research site), which was volcanic ash from Mount Gamalama. Andisols generally dominated the soil in the research site. The research by Umasugi [22], showed that the soil content weight in clove plantations was generally <0.9 g/cm^3, the texture from clay to clay was dusty on the top layer, and sandy on the lower layer, which indicated that the soil was light and developed from pyroclastic and Volcanic ash of Mount Gamalama. Such soil characteristics will result in low available moisture in the soil and around the root area since water is easily lost due to evaporation and percolation. If the roots cannot absorb the water, it is tightly bound and held back by the matrix force between soil particles.

The research results (Table 1) showed that the soil moisture content at the field capacity (FC) ranged from 0.27 to 0.49 cm^3/cm^3. The permanent wilting point (WP) moisture content ranged from 0.12 to 0.31 cm^3/cm^3. Meanwhile, available soil moisture ranged from 0.09 to 0.23 cm^3/cm^3. Soil moisture storage content at the field capacity (FC) in the average root zone (STo) in clove plantations was 134.5 mm. The level of soil moisture capacity depends on the proportion of pore space, soil texture, soil stratification, and organic matter content [9].

C. Water Management Strategy Based on Regional Water Balance

The regional water balance analysis results (Figure 2) showed that the amount of rainfall (P) that occurred was 2307.3 mm. The potential evapotranspiration (PE) was 1480.7 mm. The surplus that occurred was 873.8 mm/year (38% of total rainfall). The highest was in May (188.4 mm), while the lowest was in August (7.9 mm). The deficit occurred in the amount of 7.4 mm, which was in September (2.7 mm) and October (4.7 mm). Such surplus-value showed that if there had not been any management effort for optimal water utilization, then about 38% of the rainwater that had fallen on the clove plantations would have been wasted as surface runoff.

The regional water balance for the dry season in 2014 – 2016 (Figure 3) showed potential evapotranspiration of 1561.2 mm, resulting in an increase in the 7-month deficit, which was 156.8 mm/year (10% of total evapotranspiration) and a 5-month surplus of 448.1 mm/year (27% of total rainfall). The highest deficit occurred in March (62.8 mm), with evapotranspiration of 151.7 mm and rainfall of only 44.7 mm; the lowest deficit was in July (0.6 mm), while the highest surplus was in December (133.5 mm), with a rainfall of 259.7 mm; the lowest surplus was in November (31.8). Therefore, it was necessary to harvest rainwater through a biopore system containing organic material as a technology for catching rainwater and storing it to meet the water needs for clove plants during the deficit period.

Soil moisture content in the root zone or soil moisture storage (ST) in clove plantations in January, February, March, April, May, June, July, August, November and December was 134.5 mm while September and October experienced a decrease of 109.8 mm and 94.7 mm (Figure 2). Meanwhile, in the dry season, soil moisture deposits in January, May, June, November and December were 134.5 mm. In February, March, April, July, August, September and October there was a decrease in soil moisture savings from the average moisture content of the soil. The lowest soil moisture content was in March and April, namely 36.4 mm and 27.1 mm (Figure 3). Increasing the potential for water loss (APWL), the lower the soil moisture storage (ST).

The decrease in moisture savings was due to increased potential evapotranspiration (PE) and a decrease in rainfall. As a result, there is a water deficit for 7 months, so that clove plants lack water to meet their growth and production needs, especially during the dry season. According to Aleixandre-Benavent [5], that climatic conditions, especially a decrease in rainfall, an increase in temperature, directly affects crop production.

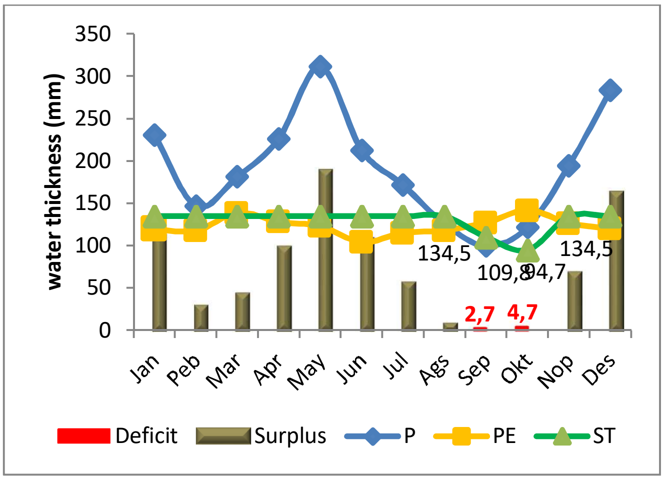

Fig. 2 Regional water balance for 10 years (2008 to 2017) at research site

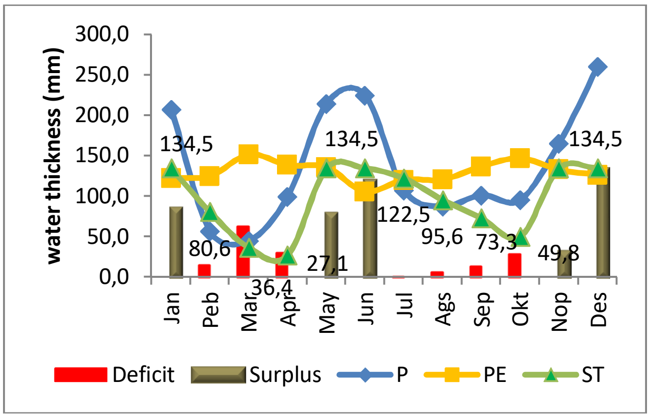

Fig. 3 Regional water balance for dry season (2014 to 2016)

D. *Soil Moisture Content (ST) and Actual Evapotranspiration (EA)*

The amount of soil moisture content in the root zone (ST) in 12 clove plant land units was 1551.2 mm/year, while the actual evapotranspiration that occurred was 1472.4 mm/year, and the actual average evapotranspiration (EA) was 122.7 mm. The lowest soil moisture content was in land units 08 (54.0 mm), and 05 (55.4 mm). The increase in actual evapotranspiration caused water loss in the soil and plants, so that soil moisture content decreases due to a deficit in land units 03, 05, 08 and 11. Soil moisture content in conditions of low field capacity (STo) and shallow soil solum are the contributing factors for the low moisture storage of soil. The surplus occurred in 8 land units, where the highest surplus was in land units 9, namely 59.06 m/month. The size of soil moisture content (ST) and the actual evapotranspiration (AE) for each land unit of clove plantation are shown in Figure 4.

Watering and mulching the surface and litter into the soil, should have been carried out in units 03, 05, 08, and 11 in which the soil moisture storage was low, and the actual evapotranspiration was high in order to maintain or increase soil moisture storage. Mulch can increase soil moisture storage, reduce evaporation, reduce soil temperature, and increase soil moisture [3], [23].

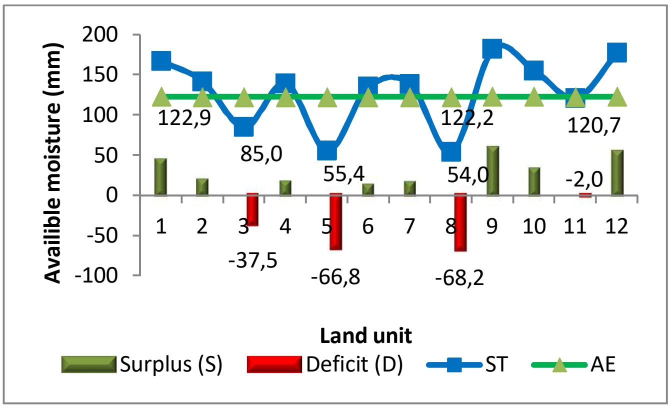

Fig. 4 The soil moisture content (ST) and actual evapotranspiration (AE)

TABLE II
VALUES OF PLANT EVAPOTRANSPIRATION (ET) OF CLOVE AT TREE PHASE

Period (2019)	P	ΔS	R	D	R+D+ΔS	ET
	(mm/d)	(mm/d)	(mm/d)	(mm/d)	(mm/d)	(mm/d)
28/1/	4.0	0.4	0.8	1.8	3.0	1.0
29/1	2.7	-0.2	0.5	1.0	1.3	1.4
30/1	0.0	-0.6	0.0	0.6	0.0	0.0
31/1	0.0	-0.5	0.0	0.0	-0.5	0.5
1/2	1.4	0.1	0.0	0.0	0.1	1.3
2/2	2.7	1.3	0.1	0.7	2.1	0.6
3/2	0.0	-0.3	0.0	0.3	0.0	0.0
4/2	0.0	-0.6	0.0	0.0	-0.6	0.6
12/2	7.8	0.5	0.1	2.6	3.2	4.6
19/2	9.9	0.2	0.2	3.0	3.4	6.6
Total	28.5	0.3	1.7	10.0	12.3	16.6
Average						**1.66**

Information; P = precipitation; ΔS = changes in soil moisture content; R = runoff; D = percolation; ET = plant evapotranspiration.

E. *Water Management Based on Plant Water Requirement Clove Plantation*

The standard evapotranspiration (ETo) calculation using the Penman-Monteith approach for estimating plant water requirements obtained the standard evapotranspiration value of 4.06 mm/day. This showed that there was an average water loss in clove plantations of 4.06 mm/day, with the highest evapotranspiration in October (4.58 mm/day) and the lowest in June (3.48 mm/day). Furthermore, based on the water balance approach, the plant evapotranspiration (ET) value was obtained at 1.66 mm/day (Table 2). The coefficient value of clove (kc) is 0.41, which is the ratio of plant evapotranspiration (ET) and standard evapotranspiration (ETo). The estimation results in normal conditions for the total water needs for the clove plant at tree phase (> 25 years) was 607,1 mm/month (26.3% of the total rain and 40% of the total effective rain) when compared with standard evapotranspiration and plant water requirements, then in the normal condition, the total rain was sufficient to meet the plant water requirements on the clove plantation.

In the dry season (Figure 5), the amount of evapotranspiration increased, and the rainfall decreased by 50%. Therefore, there were more dry months. The amount of effective rain (P-eff) available was 1200.3 mm/year, and the total rain that occurred was 1660.4 mm, while the water requirements for clove plants (ETc) increased by 640.1 mm/year or 52.0 mm/month (53% of the total effective rain). The average water requirements for clove plants were 53.3 mm/month; whereas in February and March, the water requirements for clove plants increased by 51,2 and 62.2 mm/month, and the available effective rainwater was only 51,0 41.5 mm/month.

Clove plantations are dry land agriculture where water availability depends on rainfall. During the dry season the rainfall is low and evapotranspiration is high, as a result, the soil moisture content (ST) is low. As in Figure 5, the increased water demand for clove plants causes a decrease in soil moisture content during the dry month period. Soil moisture content in the root zone (ST) is strongly influenced by the amount of effective rain (r^2=0.80), evapotranspiration (r^2= -0.68), and plant water requirements (r^2= 0.68).

During the dry season, the water availability through rainfall is not able to provide water to meet the needs of plants. As a result, clove plants will lack of water, wither, dry and die due to low water availability, and the soil moisture storage is also unable to maintain the water in available moisture conditions. Therefore, a water management is needed, using rainwater harvesting technology when it is in surplus, and storing it as moisture in the soil to meet the water requirements of the deficit. The biopore infiltration hole with clove leaf litter as organic material is a technology for harvesting rainwater and moisture storage that can be applied during the surplus in December and January for water reserves when there is a deficit in February and March during the dry season.

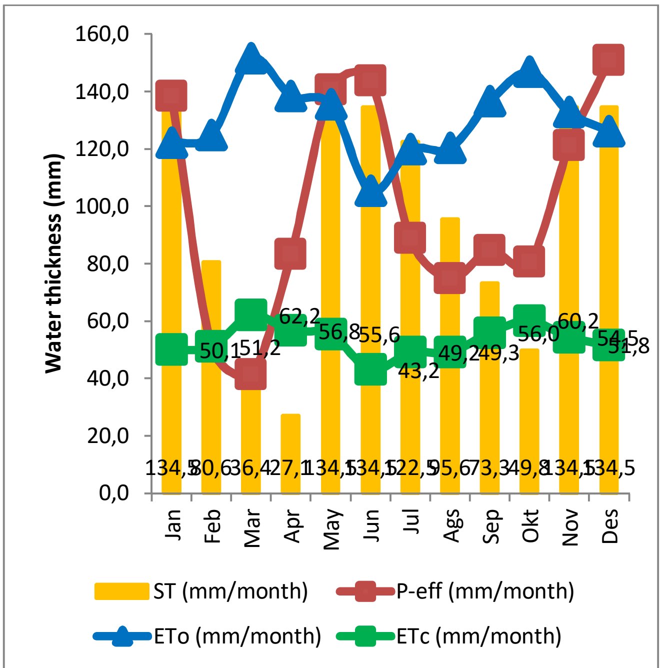

Fig. 5 Plant water requirements during dry season

F. Water Management in Clove Plantation

Clove plantations experience a water surplus in the wet months and a water deficit in the dry months. Based on the incidence of the dry season in 2014-2016, the results of the water balance analysis show that there is a wet period (surplus), namely in January, May, June, November and December and a dry period (deficit), namely in February, March, April, July, August, September and October.

Water management in dry periods uses mulch to reduce evaporation. Straw mulch, plant leaf litter and sawdust are excellent for use in clove plantations. The results of [24] showed that sawdust mulching, spruce and shrub litter increased soil moisture content and decreased soil temperature by 2.5 - 0.0 °C, thereby reducing evaporation in summer.

Wet period water management uses biopore technology for rainwater harvesting and runoff. Biopore infiltration holes and organic matter litter as vertical mulch from the soil surface to the subsoil layer to capture and absorb rainwater and surface runoff during the wet (surplus) period and store as water reserves during the dry period (deficit) in the dry season. As a result of research of Umasugi [22], biopores with clove leaf litter are installed during rain (surplus) in December and January to harvest rainwater and surface runoff and store them, increasing soil moisture storage by 304.93 mm when dry (deficit) in the month February and March.

G. Water Management for Clove Plantation During Dry Season

The subsoil characteristics (depth> 40 cm) on clove plantations have a sand texture, low soil organic matter, and low moisture content in the field capacity (FC) (Figure 6).

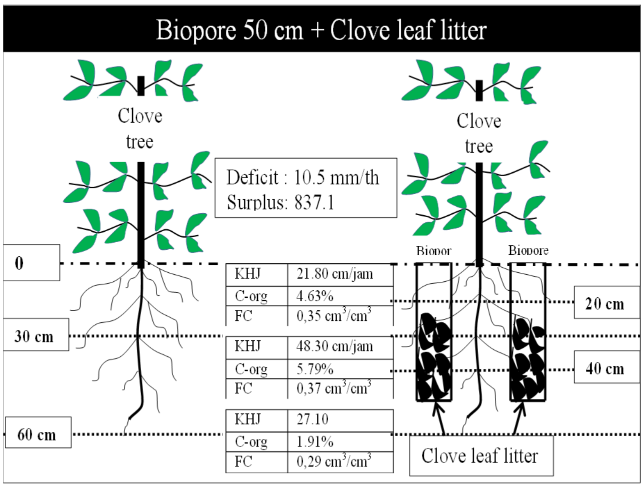

Fig. 6 Biopore technology with leaf litter in clove plantation

There are wet months (surplus) and dry months (deficit) in climatic conditions, so that rainwater harvesting technology is needed during a surplus period for water reserves during a deficit. As the research by Umasugi [22] biopore infiltration holes with a depth of 50 cm with clove leaf litter can reduce surface runoff to 0.1 mm / rain, increase soil organic matter by 4.28% and increase soil moisture storage by 304.9 mm. Plant litter as a source of organic matter can meet the water requirements of plants in the dry season [25]. The biopore infiltration holes can harvest rainwater and surface runoff water so as to reduce surface runoff and increase infiltration, while leaf litter will be decomposed as organic material which is then able to store water and encourage aggregation so as to increase soil porosity and moisture content and is useful as a nutrient enhancer. The biopore infiltration hole (LRB) technology in clove plantations can be seen in Figure 6.

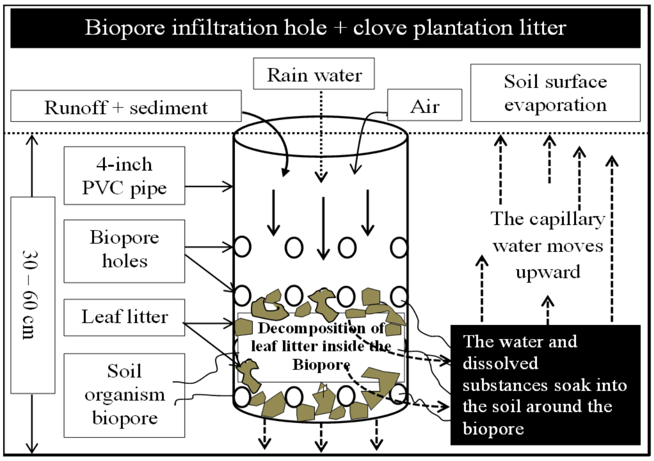

Fig. 7 The mechanism of action of biopores and clove leaf litter

The working mechanism of the biopore with clove leaf litter for rainwater harvesting is through the surface runoff when it rains, infiltration into the soil, and stores it as soil moisture reserves for clove plants when the water is deficient. The biopore infiltration hole is made to cut the slope or parallel to the contour vertically under the canopy of 30 to 60 cm, with a hole diameter of about 10 cm (Figure 7). Furthermore, the biopore hole is filled with chopped clove leaf litter to accelerate the decomposition process and trigger the activity of soil biota such as worms, termites, ants, and plant roots to form cavities (biopores), then form water channels around the biopore hole and the root area of clove plants. The results of litter decomposition will seep into the soil around the biopore hole through biopores formed by soil organisms, increase soil organic matter, and improve the subsoil quality to support the growth of clove plant roots. Research results have shown the importance of the contribution of biopores and organic matter in improving the quality of soil physics, chemistry, and biology [24].

IV. Conclusion

The results of this research on the clove plantation in Ternate Island showed that the total rainfall was 2307.3 mm/year, and the potential evapotranspiration was 1480.7 mm/year. Meanwhile during the dry season (2014 to 2016), the rainfall was 1660.4 mm/year, and the potential evapotranspiration was 1561.2 mm/year, with the available total effective rain was 1200.3 mm/year. The available soil moisture ranged from 0.09 to 0.23 cm^3/cm^3, and the average soil moisture storage (STo) on the clove plantation was 134.5 mm. The water needs for the clove plantation at tree phase (>25 years) was 607.1 mm/month in normal conditions, while during the dry season, it increased by 640.1 mm/year or 53.3 mm/month (53% of the total rain). The management strategy to meet the water requirements of clove plants in the dry season uses mulch and biopore infiltration holes. The biopore infiltration hole and clove leaf litter for rainwater harvesting and runoff during surplus in December and January to increase the soil moisture storage and reserves during the deficit in February and March.

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