Study of Soil Moisture on Coffee Plantation in Dry Land Using Neutron Probe in Malang, East Java

Sugeng Prijono¹, Sahindomi Bana²
1- Department of Soil Sciences, Faculty of Agriculture, University of Brawijaya, Malang
2 –Department of Forest Management, Faculty of Forestry and Environmental Sciences, University of Halu Oleo, Kendari
Email: sugeng.prijono@yahoo.com

ABSTRACT
Water is a limiting factor in the production of dry land agriculture. Improved soil cover and terracing is one of the techniques of water conservation in dryland. The objective of the research was to know the ability of soil profile to retain water for Coffee plantation in relation to the condition of rainfall. The research was conducted on Coffee plantation area of Coffee Research Center Sumber Asin and in the garden of PT. Perkebunan XXIII Pancursari, Sumbermanjing Wetan, Malang. There were two types of Coffee planting i.e. Coffee (A) planted in arranged terrace, free from weeds and Coffee (B) in unarranged terrace, full of weeds. Lamtoro and Glyricidae were used as shade. Field observations are done for soil moisture measurement and rainfall measurement. Laboratory studies was done in the Laboratory of Soil Physics, Faculty of Agriculture, Brawijaya University for analysis pF curve, soil texture, saturated and unsaturated hydraulic conductivity. Results of laboratory analysis showed that increasingly to the bottom layer of soil it will be dominated by clay particles. The bulk density was between 0.82 and 10.6 g cm⁻³ and particle density of 2.48 and 2.61 g cm⁻³ and total porosity of 57.26 and 67.72 %. The field capacity to retain moisture (pF 2) was higher in deeper soil layers. The level of water stress experienced by plants in dry land varies depending on the distribution pattern of rainfall, soil water-holding capacity [11 and 28], crop water requirements, initial soil moisture and water absorption capacity of the soil by plants. [28]. Additionally, the use of agricultural machines also affect the groundwater regime in the drylands [24]. Therefore, water conservation practices in dryland considered very important [31 and 42] especially with the increase of efficiency use of rainfall [42] to reduce the potential risk of water stress, to press erosion potential and increasing soil productivity [31]. Water conservation in dryland can be done by soil tillage practices [17] and utilization of crop residue [17 and 31].

INTRODUCTION
Water is a limiting factor in crop yield of dryland [27, 28, 40,42, 45, 20, and 54]. The water availability from rainfall in dry land is lower when compared with the use of water to evaporation and transpiration [11, 33, 34, 40, and 46], so that charging water storage in the soil commonly through seepage [40]. In addition, the distribution pattern of rainfall on dry land commonly not equal causing water stress in plants and even to trigger high surface runoff and erosion potential on dry land [34]. The level of water stress experienced by plants in dry land varies depending on the distribution pattern of rainfall, soil water-holding capacity [11 and 28], crop water requirements, initial soil moisture and water absorption capacity of the soil by plants. [28]. Additionally, the use of agricultural machines also affect the groundwater regime in the drylands [24]. Therefore, water conservation practices in dryland considered very important [31 and 42] especially with the increase of efficiency use of rainfall [42] to reduce the potential risk of water stress, to press erosion potential and increasing soil productivity [31]. Water conservation in dryland can be done by soil tillage practices [17] and utilization of crop residue [17 and 31].

The terrace is a modifications of soil construction which made to the sloping agricultural land. Some goals of terracing is reduce surface runoff, reduce of erosion potential, increase infiltration capacity, increase soil moisture [9,16, 25 and 55], as a shelter when erosion and surface run off [32] and increasing the nutrient content in the soil [9 and 25]. The terrace can collect and save water for longer so that water infiltration also experiencing more when compared to land without terrace [9]. Therefore making the terrace is a rain harvesting practices [19] and is expected to reduce of soil and land degradation, especially on dryland. Bernas [9] showed that the coffee plantation without terracing, resulting in increased potential for erosion. Results of research by Priatna [36] state that the coffee plantation in
sloping land with a slope of 9-15% erosion of 60 Mg ha\(^{-1}\) year\(^{-1}\) (1-year-old coffee plantation); 37 Mg ha\(^{-1}\) year\(^{-1}\) (3-year-old coffee plantation) dan 5 Mg ha\(^{-1}\) year\(^{-1}\) (6-year-old coffee plantation). Therefore, the terrace application is recommended on coffee plantations with slopes of 15% [9].

Weeding is a common activity undertaken by farmers in order to reduce competition of components of plant growth i.e. water, \(O_2\), nutrient elements, etc. However, weeding the garden the coffee was not recommended because it will increase the potential for erosion, increasing the potential for leaching of nutrients, increase surface temperature of soil and reduce soil moisture status [23]. Increased weed populations can be reduced by planting cover crops. Afandi et al. [3] stated that ground cover with cover crops or weeds is an agricultural conservation practices that can improve the ability of the soil. Ground cover management is a key to water catch in dryland farming [46]. Ground cover by cover crops or weeds can improve soil morphology and affect the character of the soil chemical i.e. increasing soil organic matter content, increasing total N, improve soil pH, increasing the cation exchange capacity (CEC), increasing capacity of Calcium exchange, and to press Al exchange capabilities [3]. Crop residue on the soil surface that acts as a mulch has benefits for protecting soil aggregate by reducing the kinetic energy of rainfall so that soil pore remains intact [46], reduce of evaporation, reduce of surface run off, reduce of erosion [17], increasing of infiltration [1 and 17], and improve soil fertility [1].

Sumbermanjing Wetan is one of the districts in Malang. In Malang District Regulation No. 2 in 2011 [6] stated that the sub-district Sumbermanjing Wetan classified in the region that has a wavy topography. Agriculture in this region included in dryland agriculture which only rely rainfall to meet the water needs of crops. One of the many types of plants cultivated in the district Sumbermanjing Wetan is coffee plants, where water needs are also only rely rainfall. This condition is different with the opinions Kharche et al. [21] that said coffee plants can produce the maximum yield in the region with rainfall of 2000-3000 mm year\(^{-1}\) and dry months of 2-3 months. The objective of the research was to know the ability of soil profile to retain water for Coffee plantation in relation to the condition of rainfall.

**METHODOLOGY**

The research was conducted on Coffee plantation areas of Coffee Research Centre Sumber Asin and in the garden of PT Perkebunan XXIII Pancursari, sub-districts Sumbermanjing Wetan, Malang District. The research was done for a year. There were two types of Coffee planting i.e. Coffee (A) planted in arranged terrace free from weeds and Coffee (B) in unarranged terrace full of weeds. Lamtoro and Glyricidae were used as shade. The research was done in two ways i.e. field research and laboratory studies.

1. **Field research**

   **Soil moisture measurement**

   Three to five aluminium tubes were installed up to 215 cm deep to measure the soil moisture using guide tube method. Calibration checks were made by gravimetric method [8]. Measurement of soil moisture was done using neutron probe type IH III-DIDCOT [52] with intervals of 7-21 days according to the condition of rainfall.

   Reading of the neutron probe was done in each 10 cm interval from 10 to 200 cm deep, each depth was observed 3 times in 16 seconds. Calibration equation was used to measure volumetric water content:

   \[
   \text{VWC} = \frac{R}{R_W} - 0.010
   \]

   Where: \(R\) = reading from the soil (cps), \(R_W\) = standard reading in water (cps), \(VWC\) = volumetric water content (cm\(^3\) cm\(^{-3}\))

   **Rainfall measurement**

   Rainfall was measured daily using rain gauge/umbrometer [8] of the climatological station Sumber Asin (SA-90) located in 8.230S, 1050E and altitude 550 m.

   **Determination of reference evapotranspiration (ETo)**

   Reference evapotranspiration was determined from the climatology data obtained from the climatological station (SA-90) consisting of: air temperature, wind speed, sunshine duration and humidity. The above data would be used to calculate ETo using Modified Penman method [15]. Furthermore the value of potential ET and crop coefficient were used to calculate the crop water requirement.

2. **Laboratory studies**

   From three locations of the experiment undisturbed soil cores and composite soil samples were taken from 0-120 cm depth for the analysis of soil physical properties. The analysis was done in the Laboratory of Soil Physics, Faculty of Agriculture, University of Brawijaya, Malang. The pH curve were analysed using Sand box method [37] and Pressure plate method [49]. The texture/distribution of particle size was measured using pipette method [7]. Saturated hydraulic conductivity was measured using constant head method [12] and unsaturated hydraulic conductivity was measured using Hot Air method [37].
RESULT AND DISCUSSION

TABLE 1: PARTICLE DISTRIBUTION ANALYSIS

<table>
<thead>
<tr>
<th>Soil sample (cm)</th>
<th>Sand (2.00 – 0.05 mm) (%)</th>
<th>Silt (0.05 – 0.002 mm)</th>
<th>Clay (&lt; 0.002 mm)</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 20</td>
<td>12.9</td>
<td>52.0</td>
<td>35.1</td>
<td>Silty clay loam</td>
</tr>
<tr>
<td>20 – 40</td>
<td>10.0</td>
<td>48.2</td>
<td>41.8</td>
<td>Silty clay</td>
</tr>
<tr>
<td>40 – 60</td>
<td>5.4</td>
<td>51.3</td>
<td>43.3</td>
<td>Silty clay</td>
</tr>
<tr>
<td>60 – 80</td>
<td>8.6</td>
<td>47.6</td>
<td>47.6</td>
<td>Silty clay</td>
</tr>
<tr>
<td>80 – 100</td>
<td>6.4</td>
<td>38.2</td>
<td>55.4</td>
<td>Clay</td>
</tr>
<tr>
<td>100 – 120</td>
<td>8.7</td>
<td>37.4</td>
<td>53.9</td>
<td>Clay</td>
</tr>
</tbody>
</table>

From the results of analysis of particle size distribution presented in Table 1. It can be stated that the deeper the soil layer the higher the clay content. This would mean that there was a possibility that the ability to retain the available moisture was greater the deeper the soil, but the movement was very slow. Soil texture has a dominant effect against character of soil moisture [43]. Clays have the ability to hold more water per unit volume if compared with sandy soils [50]. A similar statement is a soil with a clay mineral content it also has a lot more soil moisture retention higher [29]. However, the movement of water in clay particles is very slow, this is in accordance with the opinion Schuhmann et al. [44] stated that the main factor affecting the rate of water movement in the soil is the particle size, clay particles are particles that have a size of < 0.002 mm, where the smaller the particle size, the smaller the pore space so that water movement increasingly hampered.

Table 2 presents the results of analysis of soil physical properties i.e. bulk density, particle density, total porosity and moisture content in different potential. Soil texture, porosity and bulk density affect soil moisture status [8]. The bulk density was between 0.82 and 10.6 g cm$^{-3}$ with particle density of 2.48 and 2.61 g cm$^{-3}$ and total porosity of 57.26 and 67.72 %. In the 80-100 cm soil layer, the bulk density of 10.6 g cm$^{-3}$, while the porosity of 57.26%. In contrast to the 20-40 cm soil layer, the bulk density of 0.82 g cm$^{-3}$, but porosity is high that is equal to 67.72%. The results of the analysis in accordance with some research previous that showed that the bulk density is inversely related to soil porosity [4, 5, 8, 22, 31, 47, 48 and 51]. Increase of bulk density that characterized by soil compaction can inhibits water movement in soil [51], this is in accordance with the soil texture at a depth of 80-100 cm (Table 1).

Absorption of water in the soil is regulated by macro pore space on the surface, where the pore space is influenced by soil aggregate size [46]. High porosity on the surface of the ground is necessary to increase soil infiltration capacity. Fine-textured soil generally has a macro pore space in a small amount so that the infiltration capacity is low [46]. This is in accordance with the results of the analysis on layer of 80-100 cm where the clay texture have a low percentage porosity (Table 1 and 2).

The field capacity to retain moisture (pF 2) was higher in deeper soil layer. This was in accordance with the result of the analysis on particle distribution (Table 1), increasingly to the bottom, a layer of soil more dominated by clay particles that have a high water retention. Soil moisture at field capacity conditions depending on the texture and structure of the soil [31]. In the soil layer of 80-100 cm known soil texture is clay (Table 1) and have the highest field capacity conditions are 59.58% by volume (Table 2). This is in accordance with the statement English et al. [14] which states that the soil with a high clay content has soil-water potential a higher than the soil with a high sand content. A similar statement also was stated by Rab et al. [38] that the condition of field capacity is influenced by the content of clay particles and organic matter in the soil, while the permanent wilting point simply influenced by the content of clay particles in the soil. Results of research Rab et al. [38] to soil in South-Eastern Australia show the soil moisture textured of clay at field capacity conditions of 45% by volume, while the sand soil textured of 8% by volume.

<table>
<thead>
<tr>
<th>Soil sample (cm)</th>
<th>Moisture content at pF 0 % vol</th>
<th>pF 1</th>
<th>pF 2</th>
<th>pF 2.5</th>
<th>pF 3</th>
<th>pF 4.2</th>
<th>Bulk density (g cm$^{-3}$)</th>
<th>Particle density (g cm$^{-3}$)</th>
<th>Porosity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 20</td>
<td>59.09</td>
<td>57.56</td>
<td>44.44</td>
<td>41.11</td>
<td>40.48</td>
<td>31.06</td>
<td>0.93</td>
<td>2.55</td>
<td>63.53</td>
</tr>
<tr>
<td>20 – 40</td>
<td>56.37</td>
<td>46.99</td>
<td>40.57</td>
<td>37.98</td>
<td>37.34</td>
<td>28.53</td>
<td>0.82</td>
<td>2.54</td>
<td>67.72</td>
</tr>
<tr>
<td>40 – 60</td>
<td>60.60</td>
<td>60.55</td>
<td>54.13</td>
<td>51.51</td>
<td>50.85</td>
<td>38.00</td>
<td>0.95</td>
<td>2.55</td>
<td>62.75</td>
</tr>
<tr>
<td>60 – 80</td>
<td>62.22</td>
<td>59.66</td>
<td>55.20</td>
<td>52.81</td>
<td>52.02</td>
<td>36.95</td>
<td>0.99</td>
<td>2.61</td>
<td>62.07</td>
</tr>
<tr>
<td>80 – 100</td>
<td>63.68</td>
<td>62.79</td>
<td>59.58</td>
<td>57.36</td>
<td>56.47</td>
<td>40.48</td>
<td>10.6</td>
<td>2.48</td>
<td>57.26</td>
</tr>
<tr>
<td>100 – 120</td>
<td>58.93</td>
<td>57.76</td>
<td>52.42</td>
<td>50.46</td>
<td>49.61</td>
<td>35.85</td>
<td>0.94</td>
<td>2.59</td>
<td>63.71</td>
</tr>
</tbody>
</table>
Figures 1 and 2 describe the soil profile moisture in the root zone of Coffee plantation (A) and Coffee plantation (B) which represents the beginning of the observation period of the dry season. Coffee plantation (A) or coffee plantation (B), the observations of soil moisture on 1 July is higher compared to that observed 11 August; this happens because 1 July to 11 August did not happen rain so no additional deposits of soil moisture. Total water lost during the period 1 July - 11 August on the rooting zone coffee plantation (A) higher at 165 mm when compared to coffee plantation (B) that is equal to 133 mm. Increased soil moisture status on the coffee plantation (A) is constant when compared to the coffee plantation (B) where an increase in soil moisture status is high on the soil depth of 45-55 cm to 145-155 cm layer. In general, soil moisture status increases with the depth of the soil layer [51]. These results contradict the results of other studies which suggest that the volume of water lost from the land full of weeds Corn is higher when compared with corn land clean of weeds [41] so the soil moisture status on land clean of weeds higher than the land is full of weeds as a result of the high water requirements of plants either by staple crops or weeds. The high water lost in the rooting zone coffee plantation (A) due to the high rate of evaporation, whereas the rooting zone coffee plantation (B) the rate of evaporation is lower because the land covered by the presence of weeds that can serve as a cover crop.
Figures 3 and 4 present the moisture of the soil profile in the root zone of coffee plantation (A) and coffee plantation (B) which represents the beginning of the observation period in rainy season. Figure 3 and 4 show that the current status of soil moisture at observations of 10 December is higher than observations of 14 October, at the rooting zone to treatment of coffee plantation (A) and (B), this occurs because during 14 October - 10 December there is additional deposit of soil moisture through the addition of rainfall. Differences in soil moisture has a correlation with the amount of rainfall received [54]. Total water intake during the period 14 October - 10 December at the rooting zone of coffee plantation (A) is 97 mm a lower when compared to coffee plantation (B) that is equal to 101 mm. The results of this study showed that the low water uptake occur in the root zone of coffee plantation (A) with terracing application. This contrast with the results of previous research that says that the application of terrace can reduce runoff and erosion significant when compared with no terrace [9] so that land with a terrace can collect rainfall more and improve soil infiltration capacity. Terracing can increase soil moisture deposits, especially at a depth of 40-180 cm [25]. Water intake in the rooting zone of coffee plantation (B) is higher than the coffee plantation (A) due to land on a coffee plantation (B) covered by weeds which also functions as a cover crop. The existence of cover crops can increase soil moisture through increased interception of rainfall and its ability to reduce the rate of evaporation. This is in accordance with the opinion Xu et al. [56] that said the influence of precipitation on soil moisture depends on the intensity of rainfall and evapotranspiration. Kuit et al. [23] not recommend weeding clean the coffee plantations because it will
Based on Table 3 and 4 it is known that the volume of soil moisture is highest in January and February. On the treatment of Coffee plantation (A) and Coffee plantation (B) the highest volume of soil moisture found in the 105-155 cm soil layer is 913-918 mm to Coffee plantation (A) and 933-938 mm to Coffee plantation (B). While the volume of soil moisture lowest found in the 00-55 cm soil layer is 727-724 mm to Coffee plantation (A) and 716-720 mm to Coffee plantation (B). Table 3 and 4 showed that the total volume of soil moisture in soil layer at 00 – 200 cm in treatment Coffee plantation (A) as long January – February is highest (3343-3353 mm) when compared to Coffee plantation (B) is 3316-3326 mm.

Soil moisture in the land scale is influenced by factor of the soil, topography [13] and vegetation [13, 54 and 57]. The main orientation of land management practices in the dryland is to improve soil conditions [42] by increasing the capacity of infiltration and reserve moisture in the soil profile, reduces evaporation and create appropriate conditions for root growth thereby increasing the efficiency of soil water use by crop [11] as well as increased crop production in dryland [42].

Making terracing is one land management practices on dry land with a slope Topographic to control erosion, although not directly able to provide water in the soil [53]. However, Widomski [55] said that making terracing done to control erosion, increase soil moisture status through increased infiltration capacity at the soil surface. Results of previous studies concluded that the application of terracing on coffee plantations can significantly reduces surface runoff by 79% and decrease erosion by 78% [9]. Terracing on sloping land with a slope of 50-100 able to improve the status of soil moisture of 20.7%, reduces soil leaching by 57.9-89.8% as well as reduces leaching of nutrient elements by 89.3-95.9% [26]. Making terracing in the Loess Plateau can increase soil moisture reserve and soil fertility status, especially in 40-180 cm soil layer [25]. While the research results of Ramos et al. [39] said that available water capacity (AWC) on terraced land made in Northeastern Spain is very low due to the loss of rock fragments at the time of making the terrace so that reduced soil porosity and pressure the soil infiltration rate.

Based on Table 3 and 4 it is known that the total soil moisture on the land Coffee clean of weeds (Coffee plantation (A) is higher when compared to land Coffee full of weeds (Coffee plantation (B). In some cultivation practices, presence of weeds in fact act as a competitor in the use of water, nutrients and sunlight elements [41] would be harm to the principal crops when weeds are not cleaned. As the results of the study which concluded that the soil moisture content at soil layer 0-20 cm in the plot land that is
clean of weeds higher than the land plots un-weeds [30]. This is because the results of weeding that is returned to the soil acts as organic mulch that serves to improve the infiltration capacity and reduce the rate of evaporation thus increasing soil moisture status. The results of another study stated that the presence of vegetation land cover associated with a decrease in the volume of soil moisture when compared to bare ground [10]. While the results of another study concluded that the deposits of soil moisture in the vegetation-covered land is higher than the land without vegetation (bare soil) in the 0-10 cm soil layer and the difference is more pronounced in the deeper soil layers, where at the soil layer 0-40 cm, soil moisture reserve on land covered vegetation 1.8-2 times higher than the bare soil [20]. Vegetation cover on the soil surface affecting soil moisture status [10]. Improved soil cover is a common treatment to reduce evaporation rate [35], pressing surface runoff and erosion [18]. At previous research results, Afandi et al. [2] concluded that the soil cover using grass (Paspalum conjugatum) and other weeds significantly can suppressed the surface runoff and erosion. Sadeghi et al. [41] concluded that the soil cover significantly can improve the infiltration capacity and reduce the rate of evaporation. Treatment of no-weed control in coffee plantations proven very effective as soil protection because it can protect the soil surface from rainfall kinetic energy, reduce erosion and surface runoff [7] so that improve the soil moisture status.

CONCLUSION

Results of laboratory analysis showed that the bottom layer of the soil particles is dominate by clay particles. The bulk density was between 0.82 and 10.6 g cm\(^{-3}\) with particle density of 2.48 and 2.61 g cm\(^{-3}\) and total porosity of 57.26 and 67.72 %. The field capacity to retain moisture (pF 2) was higher in deeper soil layer. The volume of soil moisture is highest in January and February. In the treatment of Coffee plantation (A) planted in arranged terrace, free from weeds has a total volume of soil moisture is higher when compared to Coffee plantation (B) in unarranged terrace, full of weeds. The total volume of soil moisture layer 00-200 cm in treatment Coffee plantation (A) of 3343-3353 mm, while the total volume of soil moisture layer 00-200 cm in treatment Coffee plantation (B) of 3316-3326 mm.

CONFLICT OF INTEREST: Nil

REFERENCES


CITATION OF THIS ARTICLE