Eco. Env. & Cons. 26 (4) : 2020; pp. (1520-1526)
Copyright@ EM International
ISSN 0971–765X

Analysis of soil moisture storage by using various rainwater harvesting methods at people's coffee plantation

Sugeng Prijono[1] and Iwan Parlindungan Sidauruk[2]

Soil Science Department, Faculty of Agriculture, University of Brawijaya, Malang, East Java, Indonesia

(Received 28 March, 2020; accepted 25 April, 2020)

ABSTRACT

Water deficit was able to decrease the coffee productivity. To reduce the risk of water deficit, moisture storage in the soil had to be increased by using rainwater harvesting. This study aimed to analyze the effect of various rainwater harvesting methods on moisture storage and profile moisture content in the soil.This research was conducted from April to June 2019 in coffee plantation of Argotirto Village, Sumbermanjingwetan, Malang, East Java. Three types of rainwater harvesting methods applied were L-shape silt pit, parallel silt pit and Biopore. The observation parameters were moisture content in the soil measured in four observation periods as well as soil texture, bulk density, particle density, porosity, saturated hydraulic conductivity, pF curve, pore distribution and c-organic. The results showed that rainwater harvesting treatments were able to increase the soil moisture storage. L-shape silt pit was able to increase water storage by 3.05 %, parallel silt pit was able to increase water storage by 2.32 %, and biopore was able to increase water storage by 1.54 % compared to the control. Distribution of profile moisture content between the treatments and control had a similar distibution, in which deeper soil layer had higher water content.

Key words *: Coffee plantation, Soil moisture storage, Profile moisture content, Rainwater harvesting*

Introduction

In general, the quantity of annual rainfall in Indonesia is quite high (1500- 5000 mm. Yr-1); however, most of the distribution occurs only during 3-6 months of the year. Concentration of heavy rainfall in a short time will cause the soil becomes saturated and will increase the interception plants rapidly. Thus, when the next rain comes, most of the water will be transferred onto run off and only a small proportion (5-10%) will be stored in the soil (Irianto, 2000). As a result, flood occurs during the rainy season in downstream watersheds. Furthermore,a low percentage of rain water that can be stored in the soil during a rainy season will cause water deficit during the dry season resulting drought.

Sumbermanjing Wetan village is a village located in the Sumbermanjing district of Malang with economic resources are mostly from the agricultural sector. One of plants widely planted is coffee plants. Sumbermanjing Wetan village has a sloping topography. The dominant soil is derived from limestone main material developments with ground Ordo Alfisol. The land use is generally restricted by two factors i.e. slopeness and water absorption ability (Triwanto *et al.,* 2012). According to Elfiati and Delvian (2010), slopeness affects the soil infiltration which means that the steeper slope is, the lower in-

([1]Lecturer, [2]Student)

filtration is. The low rate of water infiltration causes a low soil water storage. According to Suprayogo (2002) the amount of water storage in the soil is determined by the amount of rainwater infiltration. The low soil water storage causes drought when dry season comes. As consequence, it certainly affects on the decline of coffee productivity. According to Shakir and Surmaini (2017), the increase of extreme climate such as droughts may cause a decrease in coffee production reaching 10%.

To increase the land productivity, while reducing the risk of floods and droughts, a half volume of rainwater and runoff needs to be harvested by using the utilization of rainwater harvesting technology. Rainwater harvesting is one alternative of water management technologies with the principle of increasing infiltration and decreasing runoff, in turn, it increases soil water storage (Irianto, 2000). This study aimed to analyze the effect of various rainwater harvesting methods on soil moisture storage and to uncover the distribution of soil moisture in soil profile by using various rainwater harvesting methods in people's coffee plantation.

Materials and Methods

Research Sites

The present research was conducted in Argotirto village, Sumbermanjing Wetan District, Malang. Laboratory analysis was conducted in Soil Physics and Chemistry Laboratory, Soil Department, Faculty of Agriculture, Brawijaya University. The research was conducted at the end of the rainy season (early dry season) from April to June 2019.

The research was conducted in people's coffee plantation under the shady plants such as sengon. The land condition of the entire plot had a similar condition, except for rainwater harvesting method used. Robusta coffee grown had a spacing of 2.5 x 2 meters and sengon with a spacing of 2.5 x 4 meters. The research site had a 50% slope using bench terrace as land management.

Tools and Materials

The tools used in this research were soil sampling tools consisting of ring sample, ring master, knives, hoes, soil drill, plastic and stationery. While, equipment for the measurement of water content were an analytical balance, oven and cup. Materials used were treatment and control soil samples.

Research Design

The research used a randomized block design with four treatments and three replications. The treatments consisted of biopores (B), straight / parallel silt pit (S), L-shape silt pit (L) and control (K). Biopores were made by using PVC pipe 4" with holes and filled with organic compost and put them 50 cm in depth. Straight / parallel silt pit used had 150 cm in length, 50 cm in width and 50 cm in depth. L-shape silt pit used had 100 + 50 cm in length, 50 cm in width and 50 cm in depth with an upright position. Three biopores were applied in each coffee plant and one biopore was among the coffee plants (1500 Biopores per hectare). While, one parallel and L-shape silt pit were applied on each coffee plant (1000 silt pit per hectare).

Measurement of Soil Moisture Storage

Measurement of soil moisture storage was carried out in four different observation periods. They determined a different soil moisture profile at different time period. Soil moisture measurement was carried out at seven different depths, i.e. 10, 20, 30, 40, 60, 80 and 100 cm. Soil moisture value was formulated using the following equation :

$$W = \frac{BB - BKo}{BKo}$$

Note :

W = Moisture content ($g.g^{-1}$)

BB = wet weight of soil (g)

BKo= dried weight of soil (g)

Calculation of Soil Moisture Storage

Soil moisture storage around the root zone was garnered using the equation (Prijono, 2009; Klaus *et al.*, 2013) as follows:

$$\theta = W \times \frac{BI}{\rho w}$$

$$S_{100} = [(15 \times \theta_{10}) + (10 \times \theta_{20}) + (10 \times \theta_{30}) + (15 \times \theta_{40}) + (20 \times \theta_{60}) + (20 \times \theta_{80}) + (10 \times \theta_{100})] \times 10$$

note:

θ´= Volumetric moisture conbtent ($cm^3.cm^{-3}$)

W = Mass moisture content ($g.g^{-1}$)

BI = Bulk density of soil ($g.cm^{-3}$)

ρw = Density of water ($g.cm^{-3}$)

S_{100} = Soil moisture storage (mm)

Data Analysis

The obtained data were analyzed descriptively to compare soil moisture storage on each treatment. The distribution of soil moisture was elucidated by using graphs that soil moisture profiles compared to the water content of permanent wilting point andwater content of field capacity.

Results and Discussions

Soil Characteristics

1. Soil Textures

Depth	% Sand	% Silt	% Clay	Texture
				Silty clay
				Silty clay
				Silty clay

The above table shows that the study area had two classes of texture, i.e. dusty clay (0-60 cm in depth) and clay (60-100 cm in depth). Both percentage of sand and dust tend to decrease following the depth of soil, while a percentage of clay increases following the depth layers of soil. According to Rajamuddin (2009), a various distribution pattern of soil fraction indicates that the pedogenesis process does not work at the same time and also the presence of different environmental factors in the different soil layers.

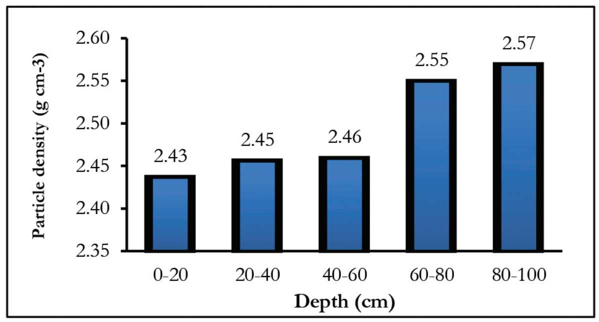
The soil texture is the main physical properties that affect the ability of soil to hold water. Based on soil texture in the research site, the depth of the soil was getting deeper and the soil ability to hold wasgetting higher. Murtilaksono and Wahyu (2004) found that as clay percentage increases, the water content of field capacity also increases, and the increased percentage of clay will also increase the water content of permanent wilting point. While, the percentage of sand is inversely proportional to the water content of field capacity and permanent wilting point. It implies that the percentage of sand is getting higher; while the water content of field capacity and permanent wilting point are getting lower.

2. Bulk Density

The highest bulk density was at 80-100 cm in depth with 1.03 g.cm^{-3}, and the lowest was at 0-20 cm in depth with 0.91 g.cm^{-3}. Bulk density increased following the depth of soil. This is caused by the increased percentage of clay and the decreased percentage of soil organic matter follows the depth

Depth	OM (%)	Class
0-20	0.91	Medium
20-40	0.92	Medium
40-60	0.94	Medium
60-80	1.00	Medium
80-100	1.03	Medium

layer of soil. In the research of Chaudhari *et al.* (2013), it was concluded that organic material has a negative correlation with bulk density(r = -0.8869). It implies that the higher the organic content in soil is, the lower bulk density is. Similarly, Putinella (2011) also stated that the low bulk density was caused by the presence of organic materials that play a role in binding soil particles in order to form a more porous soil.



3. Particle density

The highest particle density was at 80-100 cm in depth with particle density of 2.57 g.cm^{-3} and the lowest was at 0-20 cm in depth with particle densityof 2.43 g.cm^{-3}. Particle density increases following the depth of soil. It is due to the percentage of organic material decreases. Juo and Franzluebbers (2003) supported that the organic matter content in the soil is getting higher, the particle density is getting lower. Organic materials that have a lighter solid mass than mineral solids affect the bulk densityand soil particle density (Soepardi, 1983).

4. Porosity

The highest porosity was at 0-20 cm in depth with a

Depth	Porosity (%)	Class
0-20	62.74	Medium
20-40	62.38	Medium
40-60	61.86	Medium
60-80	60.88	Medium
80-100	59.72	Medium

(*Physics Lab., Department of Soil FP UB, 2006) porosity of 62.74% and the lowest was at 80-100 cm in depth with a porosity of 59.72%. Porosity of the soil is getting lower as the depth of soil is getting deeper. It is due to organic matter decreases as the depth of soil gets deeper. According to Surya et al. (2017), organic material has a positive relationship with the porosity of the soil. It means that the organic matter in soil is higher, soil porosity will also increase. Soil porosity is also influenced by the percentage of soil particles such as clay particles. According to Nita *et al.* (2014), an increase clay particles causes more compacted soil volume, thus the pore spaces in the soil wane. In addition, the porosity of the soil is also affected by bulk density. According to Khodijah and Soemarno (2019), bulk density has a negative correlation with the soil porosity (r = 0.76 and r = -0.90). It implies that the higher bulk density is, the lower soil porosity is.

Depth	SHC (cm.jam^{-1})	Class*
0-20	10,67	Rather Rapid
20-40	6,10	Medium
40-60	4,05	Medium
60-80	0,98	Rather Slow
80-100	0,48	Slow

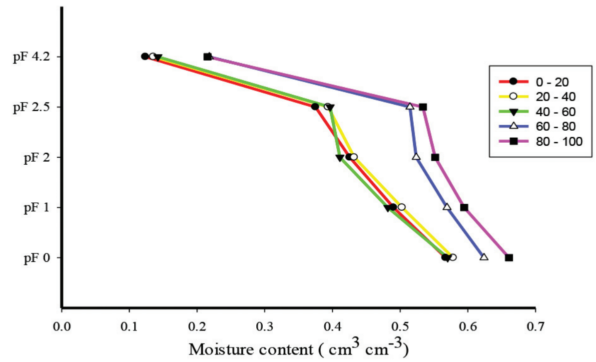
(*Utomo, 1994)

5. Saturated Hydraulic Conductivity

The highest Saturated hydraulic conductivity (SHC) was at 0-20 cm in depth with SHC of 10.67 cm.hourSHC-1. The lowest was 80-100 cm in depth with 0.48 cm.hourSHC-1. SHC had 4 categories, i.e. rather rapid (0-20 cm in depth), medium (20-60 cm in depth), rather slow (60-80 cm in depth) and slow (80-100 cm in depth). SHC in the research site was getting lower as the depth of soil was getting deeper. This is due to the deeper layers of the soil is, the higher percentage of clay is, while the percentage of organic matter and porosity is getting lower. According to Sari and Prijono (2019), soil which has a smooth texture (clay) has a lower ability to flow thewater than coarse-textured soils.

6. Water Retention (pF)

The analysis results of the water retention show that the soil layer was getting deeper, water content of field capacity (pF 2.5) and the water content of the permanent wilting point (pF 4.2) were getting higher. This is caused by the higher percentage of clay following the depth of soil. Based on Murtilaksono and Wahyu (2004), the percentage of



clay has a positive correlation to the water content of field capacity and the water contentof the permanent wilting point. It means that the percentage of clay is getting higher, the water content of field capacity and the water content of the permanent wilting point is getting higher.

Depth	Macro Pore	Meso Pore % volume	Micro Pore
0-20	19.22	25.12	12.38
20-40	18.46	25.82	13.54
40-60	17.36	25.43	14.22
60-80	10.94	29.62	21.82
80-100	12.71	31.81	21.55

7. Distribution of Soil Pore

The analysis results of soil pore distribution show that the percentage of meso pore was higher than the percentage of macropores and micropores on the entire depth. Macropores was found at 0-20 cm in depth with volume of 19.22% and the lowest was at 60-80 cm in depth with volume of 10.94%. Mesopores was found at 80-100 cm in depth with volume of 31.81% and the lowest was at 0-20 cm in depth with volume of 25.12%. Micropores was found at 80-100 cm in depth with volume of 21.55% and the lowest was at 0-20 cm in depth with volume of 12.38%. The depth of soil is getting deeper, the macro pores are getting lower. It is due to the percentage of organic material is getting lower follow-

Depth	OM (%)	Class
0-20	3.47	Medium
20-40	2.78	Low
40-60	2.06	Low
60-80	1.04	Very Low
80-100	0.41	Very Low

(*Hardjowigeno, 1996)

ing the depth layers of soil. According to Widodo and Kusuma (2018), organic material has a positive correlation with the macro pores (r = 0.493). It means that the higher the organic matter is, the higher the macro pores are.

8. Organic Material

The highest organic material was at 0-20 cm in depth with organic material of 3.47% and the lowest was at 80-100 cm in depth with organic material of 0.41%. The organic material was categorized into three i.e. medium (0-20 cm in depth), low (20-60 cm in depth) and very low (60-100 cm in depth). The organic material in the research site was getting lower following the depth of soil. Organic materials can affect the ability of soil to hold water. According to Junedi (2014), organic materials can absorb water up to six times than its own weight, therefore,high organic matter in the soil increasethe amount of soil water.

Soil Moisture Storage

Soil moisture storage with rainwater harvesting treatments (B, S, and L) had higher amount than that of the control (K) in four different observation periods. The highest soil moisture storage was found in L-shape silt pit, followed by staright silt pit, biopores and control with the value of 454.68 mm, 451.47 mm, 448.03 mm and 441.21 mm respectively. L-shape silt pit treatment can enhance soil moisture storage by 3.05%, parallel silt pit can enhance soil moisture storage by 2.32% and biopores can enhance soil moisture storage by 1.54% compared to the control.

Soil moisture storageis largely obtained from infiltrated rain into the soil. The use of rainwater harvesting method aims to improve the infiltration of rain stored in the root of plants.

The percentage of rainwater stored in the treatments (B, S and L) had a higher storage than that of the control (K). The highest percentage of moisture storage was in L-shape silt pit, followed by straight silt pit and biopores 25.26%, 25.08% and 24.89% respectively. While the control was able to store water 24.51%.

Treatments	Soil Moisture Storage (mm)	Rainfall (mm)	Total Storage (%)
K	441.24	1800	24.51
B	448.03	1800	24.89
S	451.47	1800	25.08
L	454.68	1800	25.26

Note: The means of soil moisture storage on K (Control), and treatments of B (Biopores), S (Straight / parallel silt pit), L (L-shape silt pit)

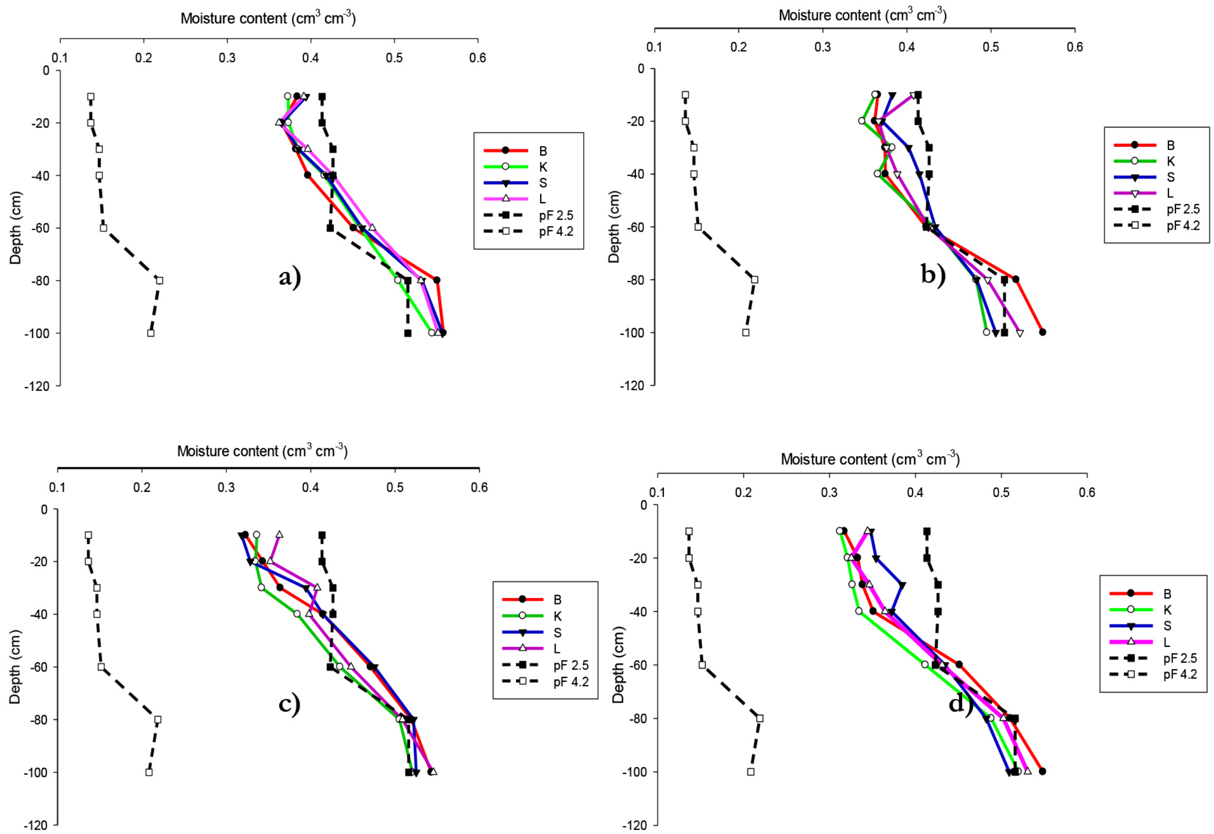
The soil moisture storage increases because of the reduced runoff and the increased water infiltration into the soil during rainy season. Pratiwi and Andi (2013) study revealed that the use of silt pit is able to reduce runoff ranged 0.80 - 2.07% compared to without silt pit. In addition, Yudhistira *et al.* (2014) study found that the use of biopore on sloping lands can reduce runoff ranged 1.70 -3.30% compared to without biopores. The function of biopores and silt pit is to save runoff into the hole. Therefore, water can have time to stay longer on the ground in order the water can infiltrate into the soil slowly. Consequently, the amount of water that flows as runoff reduced. The higher amount of water infiltrate into the soil, the more amount of water is stored in the soil (Arafat, 2008).

Distribution of Soil Moisture Storagein the Root Zone

The distribution of soil moisture in the soil profile in

Treatments	Observation I	Observation II	Observation III	Observation IV
		(mm)		
K	441.24 ± 6.1	415.81 ±16.2	414.40 ± 17.0	393.77 ± 16.1
B	448.03 ± 41.3	433.66 ± 38.4	431.29 ± 47.4	414.56 ± 23.8
S	451.47 ± 27.2	434.14 ± 49.4	430.72 ± 20.7	416.18 ± 44.4
L	454.68 ± 18.7	435.93 ± 13.1	431.37 ± 3.0	413.24 ± 4.9
P-value	0.934	0.743	0.862	0.675

Note: The means value of stored water ± SD (standard Deviation) in treatment K (Control), B (Biopores), S (straight / parallel silt pit), L (L-shape silt pit) on the observation I (on April 27 2019), the observation II (on May 4 2019), the observation III (on May 13 2019) and the observation IV (on June 23 2019)



Note :Graphic profile of soil moisture at: a) Observation I (on April 27 2019), b) Observation II (on May 04 2019), c) Observation III (on May 13 2019), and d) Observation IV (on June 23 2019)

the treatment of rainwater harvesting and control in four observation periods had a relatively similar distribution. The depth of soil is getting deeper, the soil moisture is increasing. This is due to the four treatments has similar soil characteristics in which soil characteristic is as the main factor affecting the dynamics of soil moisture in the soil profile. The high actual soil moisture follows the depth of soil because of the percentage of clay. According to Sojka *et al.* (2009), clay ability to hold water is higher than sand. Soil with a high clay content has the ability to hold higher amount of water. This is due to clay has an electron that is able to bind the proton of the water molecule (Dixon, 1991). Al-Shayea (2001) suggested that clay particles had fine ground particles so that the compound among the particles were very close causing water hardly comes out of the pores.

Conclusion

1. The use of silt pitis able to enhance soil moisture storage around 3.05% for L-shape silt pit, 2.32% for staright silt pit, and 1.54% for biopores compared to control.
2. The distribution of soil moisture in the soil profile is similar between treatments and control. As the depth of soil is getting deeper, the soil moisture storage is increasing.

References

Al-Shayea, N. A. 2001. The Combined of Clay and Moisture Content on the Behavior of Remoled Unsaturated Soil. *Engineering Geology*. 62(4): 319-342

Arafat, Y. 2008. Reduksi Beban Aliran Drainase Permukaan Menggunakan Sumur Resapan. *Jurnal SMARTek*. 6(3): 144 – 153.

Chaudhari, P. R., Ahire, D. V., Chkravarty, M. and Maity, S. 2013. Soil Bulk Density as related to Soil Texture, Organic Matter Content and available total Nutrients of Coimbatore Soil. *International Journal of Scientific and Research Publications*. 3(2).

Dixon, J.B. 1991. Roles of Clays in Soils. *Applied Clay Science*. 5(5-6): 489-503

Elfiati, D. and Delvian, 2010. Laju Infiltrasi Pada Berbagai Tipe Kelerengan di bawah Tegakan Ekaliptus di Areal HPHTI PT. Toba Pulp Lestari Sektor Aek Nauli. *J. Hidrolitan.* 1(2): 29-34.

Irianto, G. 2000. Panen Hujan dan Aliran Permukaan untuk Peningkatan Produktivitas Pertanian Lahan Kering, Penanggulangan Banjir and Kekeringan. *Berita Biologi*. 5(1) : 29-39.

Junedi, H. 2014. Pengaruh Ara Sungsang (*Asystasia gangetica* (L.) T. Anders.) Terhadap Kadar Air Tersedia dan Hasil Kacang Tanah pada Ultisol. *Prosiding Seminar Nasional Lahan Suboptimal*, Palembang 26-27 September 2014. Hal. 400 - 405.

Juo, A.S.R. and Franzluebbers, K.. 2003. *Tropical Soils*. Oxford University Press. New York

Khodijah, S. and Soemarno. 2019. Studi Kemampuan Tanah Menyimpan Air Tersedia di Sentra Bawang Putih Kecamatan Pujon, Kabupaten Malang. *Jurnal Tanah dan Sumberdaya Lahan*. 6 (2): 1405-1414.

Klaus, R., D. Dourado-Neto, A.P. Schwantes and Timm, L.C. 2013. Soil Water Storage as Related to Water Balance. *International Centre for Theoretical Physics*. 1-12

Murtilaksono, K. and Wahyuni, E.D. 2004. Hubungan Ketersediaan Air Tanah dan Sifat-Sifat Dasar Fisika Tanah. *Jurnal Tanah dan Lingkungan*. 6(2): 46-50.

Nita, I., Listyarinidan, E. and Kusuma, Z. 2014. Kajian Lengas Tersedia pada Toposekuen Lereng Utara G. Kawi Kabupaten Malang Jawa Timur. *Jurnal Tanah dan Sumberdaya Lahan*. 1(2): 53-62.

Pratiwidan, A. and Salim, G. 2013. Aplikasi Teknik Konservasi Tanah dengan Sistem Rorak pada Tanaman Gmelina (*Gmelina arborea* Roxb.) di KHDTK Carita, Banten. *Jurnal Penelitian Hutan dan Konservasi Alam*. 10(3): 273-282.

Prijono, S. 2009. *Agrohidrologi Praktis*. Malang: Lembaga Cakrawala Indonesia

Putinella, J. A. 2011. Perbaikan Sifat Fisik Tanah Regosol dan Pertumbuhan Tanaman Sawi (*Bassica juncea* L.) Akibat Pemberian Bokashi Ela Sagu dan Pupuk Urea. *Jurnal Budidaya Pertanian*. 7: 35-40

Rajamuddin, U. A. 2009. Kajian Tingkat Perkembangan Tanah pada Lahan Persawahan di Desa Kaluku Tinggu Kabupaten Donggala Sulawesi Tengah. *Jurnal Agroland*. 16(1): 45-52

Sari, I. L. and Prijono, S. 2019. Infiltrasi dan Simpanan Air pada Jenis Naungan yang Berbeda di Lahan Kopi Desa Amadanom Kecamatan Dampit Kabupaten Malang. *Jurnal Tanah dan Sumberdaya Lahan*. 6 (1): 1183-1192.

Soepardi, G. 1983. Sifat dan Ciri Tanah. Proyek Peningkatan Pengembangan Perguruan Tinggi IPB. Bogor.

Sojka, R.E., Lehrsch, G.A., Kostka, S.J., Reed, J.L., Koehn, A.C. and Foerster, J.A. 2009. Soil water measurements relevant to agronomic and environmental functions of chemically treated soil. *Journal of ASTM International*. 6(1).

Suprayogo, D., Widianto, B. Luasiana and Noordwijk, M.V. 2002. Neraca air dalam system agroforestri. *Bahan Ajar*. 7 : 125-135.

Surya, J. A., Nuraini, Y. and Widianto, 2017. Kajian Porositas Tanah pada Pemberian Beberapa Jenis Bahan Organik di Perkebunan Kopi Robusta. *Jurnal Tanah dan Sumberdaya Lahan*. 4 (1): 463-471.

Syakir, M. and Surmaini, E. 2017. Perubahan Iklim dalam Konteks Sistem Produksi dan Pengembangan Kopi di Indonesia. *Jurnal Litbang Pertanian*. 36 (2) : 77-90.

Triwanto, J., Syarifuddin, A. and Mutaqin, T. 2012. Aplikasi Agroforestry di Desa Mentaraman Kecamatan Donomulyo Kabupaten Malang.

Widodo, K. H. and Kusuma, Z. 2018. Pengaruh Kompos Terhadap Sifat Fisik Tanah dan Pertumbuhan Tanaman Jagung Di Inceptisol. *Jurnal Tanah dan Sumberdaya Lahan*. 5(2): 959-967.

Yudhistira, U. D., Qomariyah, S. and Sobriyah. 2014. Pengaruh Biopores Terhadap Infiltrasi dan Limpasan pada Tanah Lempung Berlanau. *E-Jurnal Matriks Teknik Sipil.* 2(4).