JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 9, Number 1 (October 2021):3165-3173, doi:10.15243/jdmlm.2021.091.3165
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Robusta coffee transpiration rate in smallholder coffee plantations on Inceptisols of Malang, East Java

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Article history:
Received 26 July 2021
Accepted 2 September 2021
Published 1 October 2021

Keywords:
climate change
leaf water potential
soil moisture content
soil water potential
transpiration

Abstract

Climate change and the erratic and uneven rainfall distribution are the causes of reduced water available in the soil for plant needs to the transpiration process. This study aimed to determine coffee transpiration rate on dry land with rain harvesting techniques during the dry season, transition season, and rainy season and the factors that influence it. This study used field observation and laboratory analysis with two treatments, i.e. a bench terrace as a control (P1) and an L-shaped silt pit (P2). The variables observed were soil moisture content, transpiration rate, soil water potential, leaf water potential, and microclimate, especially temperature and sunlight intensity. The results showed that the transpiration rate of coffee plants was significantly different in the two treatments. The highest transpiration rate was found in P2 as much as 13.17 mm week^{-1} or equivalent to 1.88 mm day^{-1} during the dry season. Application of the L-shaped silt pit (P2) increased soil moisture content compared to the control (P1). This increase was followed by an increase in soil water potential and leaf water potential, which could reach the highest values of 0.18 bar and 0.49 bar, respectively. The transpiration decreases with the change of seasons from the dry season to the transitional season and the rainy season. This decrease is caused by changes in the microclimate, especially the temperature and sunlight intensity. Both are the most variables that affect the rate of transpiration.

To cite this article: Saputri, J.Y., Prijono, S. and Prasetya, B. 2021. Robusta coffee transpiration rate in smallholder coffee plantations on Inceptisols of Malang, East Java. Journal of Degraded and Mining Lands Management 9(1):3165-3173, doi:10.15243/jdmlm.2021.091.3165.

Introduction

Malang Regency, especially in Sumbermanjing Wetan, is a coffee production area from smallholder plantations with the type of coffee is robusta. Sumbermanjing Wetan belongs to a dry land agricultural area that is on rainfall to meet crop water requirements. Climate change and the erratic and uneven distribution of rainfall have become problems in the availability of water on dry land causes a decrease in crop production. Coffee production in Malang Regency decreased from 2010 to 2011 by 30%, from 8,588 tons to 5,971 tons. Coffee production in Sumbermanjing District decreased from 2018 to 2019 by 40%, from 1,840 tons to 1,103 tons (BPS, 2020). Water requirement is one of factors affecting coffee growth. If the water requirements are not meet, it will inhibit the flowering process and reduce the productivity of the coffee plant (Cheserek and Gichimu, 2012). The availability of water in dryland is lower than the use of water for plant transpiration.

Transpiration is a process of water loss through the movement of water in plant tissues and loss to the atmosphere (Prijono and Laksamana, 2016). The transpiration rates are influenced by plant physiology, microclimate, soil moisture content, soil water potential (SWP), and leaf water potential (LWP).

According to Wallace and McJannet (2010), the transpiration rates are controlled by the condition of opening and closing of stomata.

Plant roots can affect the amount of water that can be absorbed by plants. If the root penetration is high, the amount of water that can be absorbed and transpired is higher. Transpiration rate increases with increasing sunlight intensity and temperature. Haditiya and Prijono (2018) reported that an increase in temperature of 2 °C to 6 °C increased the air demand by 5-15% from the actual condition of the plant so that it has an impact on the availability of air in the soil which is not sufficient for plant water requirements. The higher the soil moisture content, the greater the amount of water absorbed and transpired by plants. If the amount of water evaporated through transpiration exceeds the amount of water absorbed by the roots, there will be a water deficit that will interfere with plant growth (Wang et al., 2013). The water status of soil and plants is expressed as water potential. Soil water potential is closely related to water availability. The lower the soil water potential, the lower is the availability of water in the soil (Singh et al., 2014). The soil water potential is also related to the leaf water potential. The higher the leaf water potential, the transpired water through leaves is high.

Changes in seasons affect soil moisture conditions. In dry land, efforts to increase soil moisture content can be made by rain harvesting techniques, one of which is a silt pit. Silt pit is effective in controlling surface runoff and increasing soil moisture content in the root zone of plants to meet plant water requirements (Surdianto et al., 2012). The L-shaped silt pit could increase water holding by 3.05% compared to the control (bench terrace). A silt pit is made by cutting the contour to accommodate water from rainfall which will seep into the soil and can be utilized by plants. The amount of infiltrated rainfall that can be directly utilized by plants is called effective rainfall. The amount of effective rainfall will affect the soil moisture content. The application of silt pits on land can increase effective rainfall. Rain harvesting techniques in the form of silt pit and mulch can increase the effective rainfall by 95-96% of the total rain (Noeralam et al., 2003). The water can be used and lost to the atmosphere through the process of transpiration.

This study aimed to determine the rate of transpiration of coffee plants on rain harvesting techniques during the dry season, transition season, and rainy season and the factors that influence it.

Materials and Methods

Research location

The study was conducted at Smallholder Coffee plantations in Argotirto Village, Sumbermanjing Wetan, Malang Regency, from September to December 2020. The plantation is located between 8º16'44.30405" S and 112º44'41.60681" E, altitude 550-600 m above sea level and a slope of 30-35% with soils of Inceptisols. The observation period in this study was divided into three seasons. According to Loo et al. (2015), the monsoon rain pattern has a season division that includes the dry season (May-September), the transition season (October), and the rainy season (November-December).

Soil moisture content

Soil moisture content was measured using the Gravimetric method. Sampling was carried out every observation period in the morning and midday in the rainy season, transition season, and dry season, using a drill at depths of 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, 50-60 cm 60-70 cm, 70-80 cm, 80-90 cm and 90-100 cm. Sampling was carried out at intervals of once a week in the morning and midday in the dry season, transition season, and rainy season to determine differences in soil water content. Soil moisture content was calculated using the following formula:

%SMC= (FW-DW)/DW x100%.............................(1)

The %SMC was then converted into volumetric form with the following formula:

%V = %SMC x BD ……………………….……… (2)

Notes: %SMC: percentage of soil moisture content (%g g^{-1}), FW: fresh weight of soil (g), DW: dry weight of soil (g), %V: volume percent (%v v^{-1}), BD: soil bulk density (g cm^{-3}).

Soil water potential (SWP) and leaf water potential (LWP)

Soil water potential was measured using SPAW (Soil-Plant-Air-Water). The input data needed in this measurement are soil moisture content at the time of measurement, texture, and organic C. Results come out automatically after all data is inputted. Leaf water potential was measured using a pressure bomb with the criteria that the leaf sample was full-grown and must be healthy (Fulton et al., 2014). Sampling was carried out in the morning before dawn and with an interval of once a week in the dry season, transition season, and rainy season. Leaf was put in plastic and stored in a cooler to maintain humidity before being brought to the laboratory. Measurements were made by inserting the leaf stalk or twig upside down into the chamber component and then locking it by tightening the screw. The gas has flowed slowly from the pressurized gas cylinder into the chamber containing the sample. When the liquid started to appear, the gas flow was stopped and read the leaf water potential value on the panel contained in the tool.

Microclimate

Microclimate was measured in the form of temperature and sunlight intensity using an environment multimeter installed 1 meter above the ground level. The data appeared on the monitor screen after the button on the device was pressed. Measurements were carried out at intervals of once a week in the morning at 06.00 and midday at 12.00.

Transpiration rate

The transpiration rate of coffee plants was measured based on the difference in soil moisture content (delta storage/dS) in coffee plants near the root and far from the root. The transpiration rate was obtained from the difference in soil moisture content at the far point from the root (Tt) and soil moisture content near the roots (TR). Based on Prijono and Laksamana (2016), the transpiration was calculated using the following formula:

$T = sTt - sTr$ ……………………………………..(3)

$S = z \times \Theta$……………………………..……………(4)

Notes: T: transpiration of coffee plants (mm day^{-1}), sTt : soil moisture storage far from root (mm), sTr : soil moisture storage near the root (mm), s : soil moisture storage at a certain depth (mm), z : soil depth (mm), Θ : volumetric water content (cm^3 cm^{-3}).

Experimental design and data analysis

This study used field observation and laboratory analysis with two treatments, i.e. a bench terrace as a control (P1) and an L-shaped silt pit (P2). The length of the bench terrace was 3 m, and the size of the L-shaped silt pit was 150 cm x 30 cm x 50 cm. The data obtained were analyzed by T-test, correlation test, and multiple regression using the SPSS program.

Results and Discussion

Soil moisture content

The L-shaped silt pit (P2) treatment had a higher soil moisture content than the control treatment (Figure 1). This can be caused by an L-shaped silt pit that could accommodate more water than control, both from rainfall or accommodate surface runoff which flowed in the direction of the slope as well as the contour so that the soil moisture content was higher in an L-shaped silt pit. Litter that was accommodated in the hole in an L-shaped silt pit also increased input organic matter that could affect the ability of the soil to water holding capacity. This statement is in accordance with Junedi (2014) that organic matter can absorb water up to six times its own weight so that the higher the organic matter content in the soil, the higher the soil moisture content. Soil moisture content that was measured far from the root zone showed a higher value than the zone near the root. This is caused water near the roots is used more for both plants, such as transpiration. This is consistent with the results which showed that the water content far from the root zone had a higher value than the others. Results of the study of Satibi et al. (2019) showed that making a silt pit in the coffee plantation was able to increase soil moisture content by 45.91% when compared to without silt pit by 28.23%.

Soil moisture content in the entire observation period and both treatments (Figure 2) occurred at a depth of 0-30 cm and then gradually increased at a depth of 30-100 cm. Qiu et al. (2001) stated that soil moisture content also varies with the depth of the observation profile. Soil moisture at a depth of 80-100 cm profile was higher than the other profile depths. The moisture content far from the roots (Tt) tended to be higher than the soil moisture content close to the roots (Tr). Bana et al. (2013) stated that the decrease in soil moisture content at a depth of 10-30 cm was due to increased evaporation. The increase in soil moisture content in the lower layer (depth of 40-100 cm) occurs due to an increase in the clay fraction to a depth of 100 cm where the clay has good water retention (Prijono and Bana 2015). The results of the study showed that there was an increase in clay at a depth of 40-100 cm. Bermúdez-Florez et al. (2018) stated that the higher the clay content, the higher the soil moisture content. The results of research by Prijono and Bana (2015) showed an increase in the clay fraction along with the deeper soil layer (40-120 cm); the more soil layers were dominated by clay particles that had high water retention.

Dynamics of coffee transpiration rate in various seasons

Transpiration is a process of water loss through the movement of water in plant tissues and loss to the atmosphere (Prijono and Laksamana, 2016). There were fluctuations in the transpiration rate of coffee plants from the dry season to the rainy season. The results of the T-test showed that the transpiration rate was significantly different ($p<0.05$) between the two treatments. The transpiration rate at P2 was higher than P1, both during the morning and afternoon observations. The highest transpiration rate was obtained in the dry season during midday observations, while the lowest was obtained in the rainy season in the morning observations. The highest transpiration rate at P2 was obtained during the last week of observation (peak of dry seasons) and the lowest transpiration rate at P1 was obtained during the last week of observation of the rainy season.

In this study, the highest transpiration rate was 13.17 mm week^{-1} or equivalent to 1.88 mm day^{-1}, and the lowest was 0.50 mm week^{-1} or equivalent, to a daily average of 0.07 mm day^{-1}. The higher transpiration rate in P2 treatment could be caused by soil moisture storage which was also higher than P1. Increasing soil moisture storage and decreasing runoff reduction were obtained by applying an L-shaped silt pit at the study site. The higher the soil moisture storage, the more water that can be transpired. This statement is in accordance with the research results of

Wang et al. (2013), who stated that the high rate of plant transpiration was influenced by the high content of soil moisture. Soil moisture content and the ability of the soil to carry water to plant roots also determine the rate of plant transpiration. The coffee transpiration rate decreased from the dry season to the rainy season (Figure 2). Based on the results, the transpiration rate in the dry season was higher than in the transitional and rainy seasons, even though the soil moisture content in the dry season was lower than transitional and rainy seasons. The rate of transpiration in the morning was also lower than in the midday. That can be caused by plant factors and climatic factors that affect the rate of transpiration. Climatic factors also are related to plant factors in the form of stomata which affect the rate of transpiration.This statement is in agreement with Renninger et al. (2010) stated that the process of evapotranspiration might be greater in the dry season even though in that season, the soil moisture content was low. This was because there was an increase in temperature and the intensity of sunlight, so it supported an increase in the rate of transpiration.

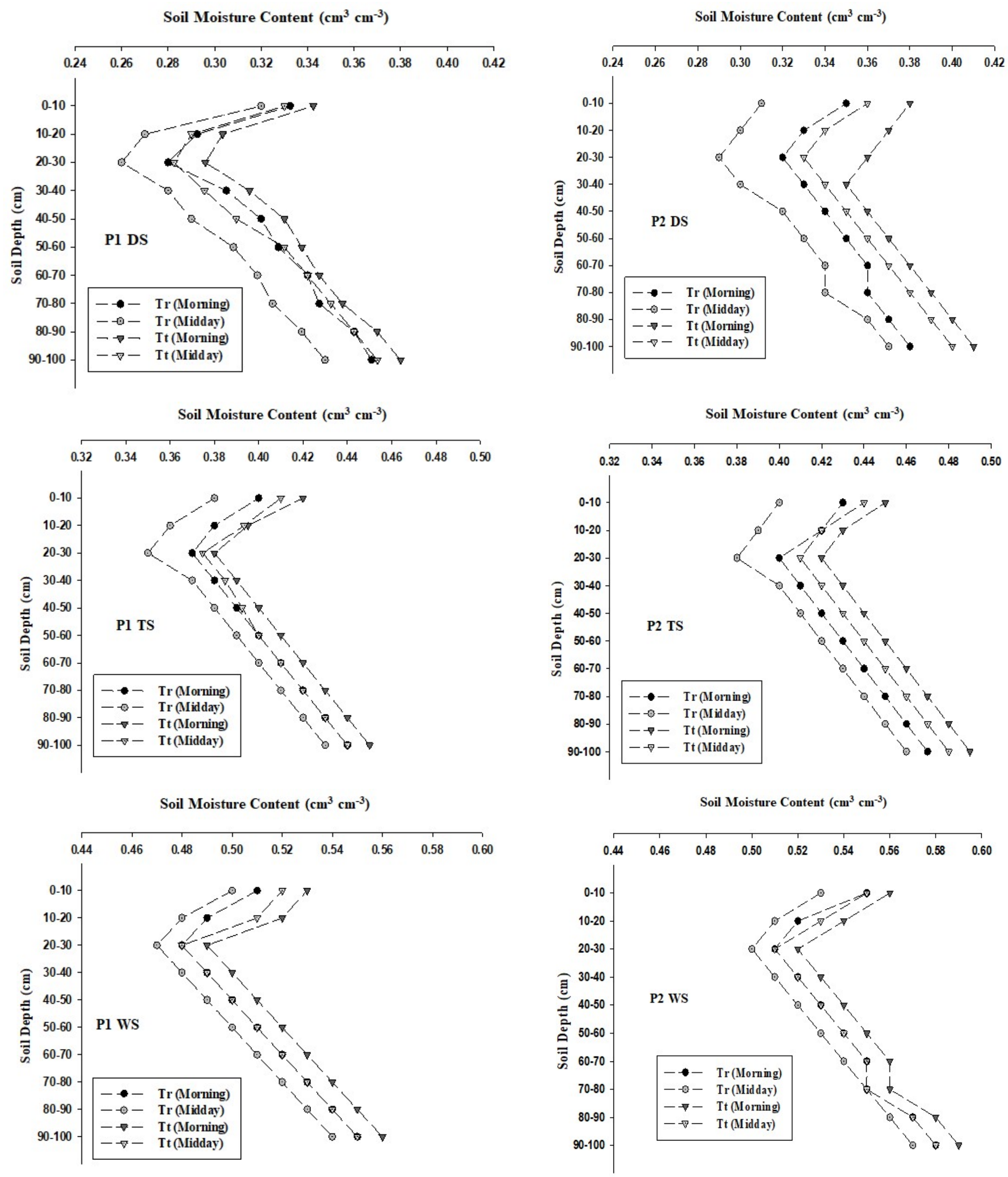


Figure 1. Soil moisture content of control/bench terrace (p1) and L-shaped silt pit (p2) treatments at various observation periods. Tr: soil moisture content near roots; Tt: soil moisture content far from the roots. DS: dry season; TS: transitional season; and WS: rainy season.

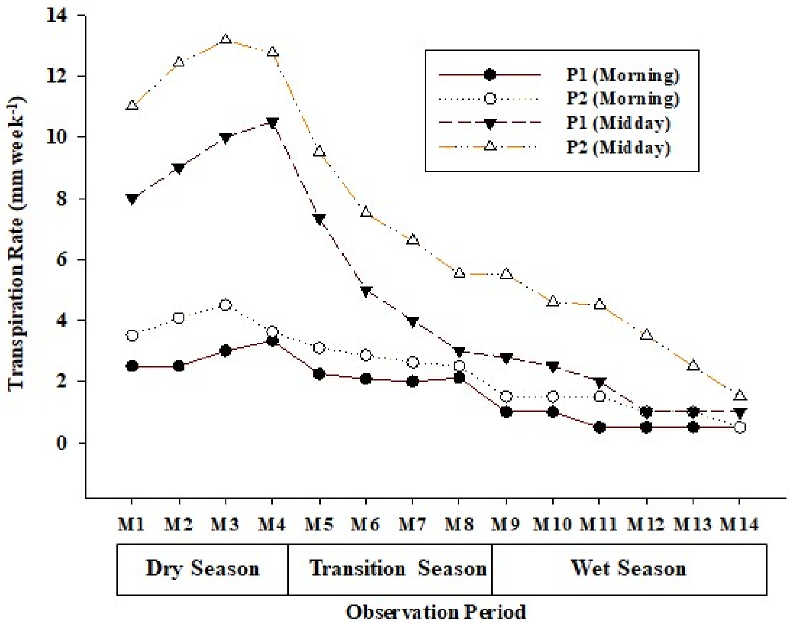


Figure 2. The average transpiration rate of coffee plants in three observation periods. P1: control (bench terrace), P2: L-shaped silt pit.

Effect of microclimate on the coffee transpiration Rate

Transpiration rates were influenced by microclimate, especially temperature and sunlight intensity. The results showed that the increase or decrease in the microclimate was consistent with the transpiration rate in both treatments (Figure 3). The result showed that in the P1 treatment, the highest temperature (33 ℃) and sunlight intensity (35000 Lux) were obtained at midday in the dry season with a transpiration rate of 10.50 mm week^{-1} or an average daily equivalent of 1.50 mm day^{-1}. At P2, the highest temperature (36 ℃) and sunlight intensity (38400 Lux) were obtained at midday in the dry season with a transpiration rate of 13.17 mm week^{-1} or a daily average of 1.88 mm day^{-1}. The results of the T-test showed that the temperature and sunlight intensity had a significant effect ($P<0.05$) on the rate of transpiration.

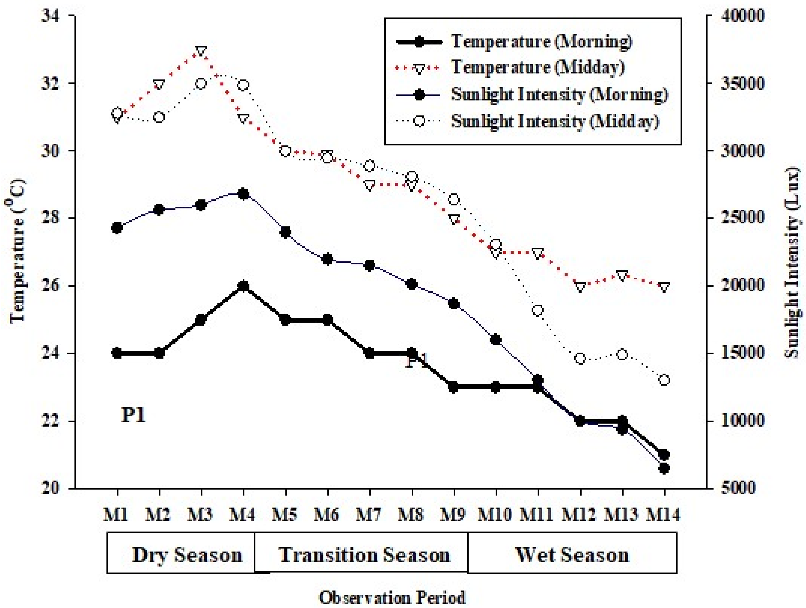
The increase in temperature and sunlight intensity was followed by an increase in the rate of transpiration. On the other hand, the decrease in these two variables was also followed by a decrease in the rate of transpiration. Sunlight intensity will affect the process of opening and closing the stomata; when the stomata are open, there will be gas exchange from the leaves to the atmosphere. Crawford et al. (2012) reported that the transpiration rate at 28 ℃ was higher than at 22 ℃. The correlation test showed that temperature and sunlight intensity had a very strong and positive relationship ($r = 0.92$) to the transpiration rate. This value indicates that an increase in these two factors will be followed by an increase in the transpiration rate. The sunlight intensity determines the opening and closing of stomata as a place for gas exchange from plants to the atmosphere. Guard cells surround each stomatal and regulate CO_2 uptake and water vapour released by opening and closing the stomata (Qaderi et al., 2019).

Soil water potential (SWP) dan leaf water potential (LWP) coffee plant in various seasons

Water potential is the total amount of energy that be expended per unit amount of water to flow. In this research, soil water potential and leaf water potential were measured. Soil water potential refers to soil moisture content. Soil water potential is a criterion for measuring the soil availability water for plants (Singh et al., 2014). The higher soil water potential is indicated by a low value, while low soil water potential is indicated by a large value.

Based on the results of observations in both treatments, it can be seen that the potential for soil water potential is different in each season. Based on Figure 4, the lowest soil water potential (P1 of 10 bar) was obtained during the dry season during daytime observations, while the highest soil water potential (P2 of 0.18 bar) was obtained during the rainy season during the morning observation. This difference in results is thought to be due to differences in soil moisture content. In the dry season, the soil moisture content was lower than in the transition season and the rainy season. The research of Markesteijn et al. (2010) showed that the potential decrease in soil water from 0.2 MPa to 1.4 MPa was at the beginning of the dry season to the peak of the dry season (April to

September). High soil water potential indicates that the water content is more, or it can be said that high water potential is caused by high groundwater content. According to Clermont-Dauphin et al. (2013), the highest water potential (0 bar) is in the rainy season at a depth of 65 cm and continues to increase with the depth of the soil layer. Plant water potential is also an important and widely used indicator for the study of water transport mechanisms, which describe the energy state of water (Wang et al., 2013). Leaf water potential is directly proportional to soil water potential. The higher leaf water potential is indicated by a low value, while the low leaf water potential is indicated by a large value.



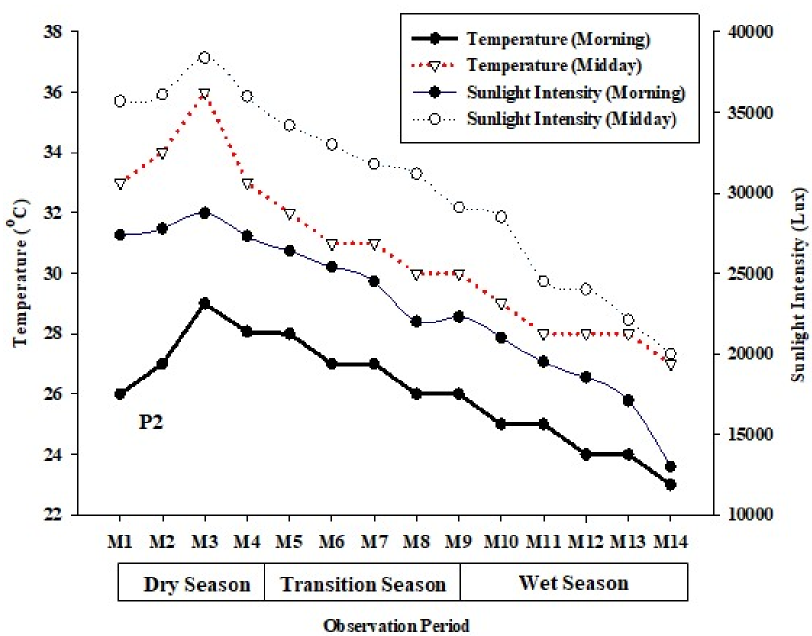


Figure 3. The average temperature and intensity of sunlight at the research site. P1: control (bench terrace), P2: L-shaped silt pit.

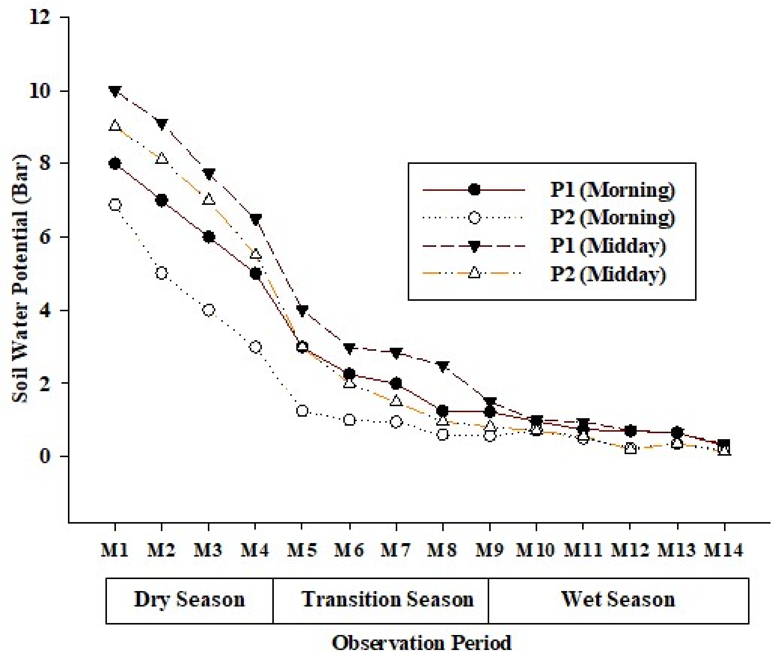


Figure 4. The average soil water potential at various observation periods. M: observation week, P1: control (bench terrace); P2: L-shaped silt pit.

Results of the T-test showed that the leaf water potential was significantly different (p<0.05) in both treatments, where P2 was higher than P1. Based on Figure 5, the lowest leaf water potential was at P1 (3.24 bar in M1 observation) in the dry season, and the highest leaf water potential was at P2 (0.49 bar in M14 observation) in the rainy season. This indicates that the leaf water potential is in accordance with the potential soil water content and soil moisture content. Results of the T-test also showed that the soil water potential had a significant effect (p<0.05) on the leaf water potential. This indicates that the greater the soil water potential (close to 0), the higher the leaf water potential. The lower the soil moisture content, the lower the leaf water potential (LWP) and the plant will experience water stress or stress (Argyrokastritis et al., 2015).

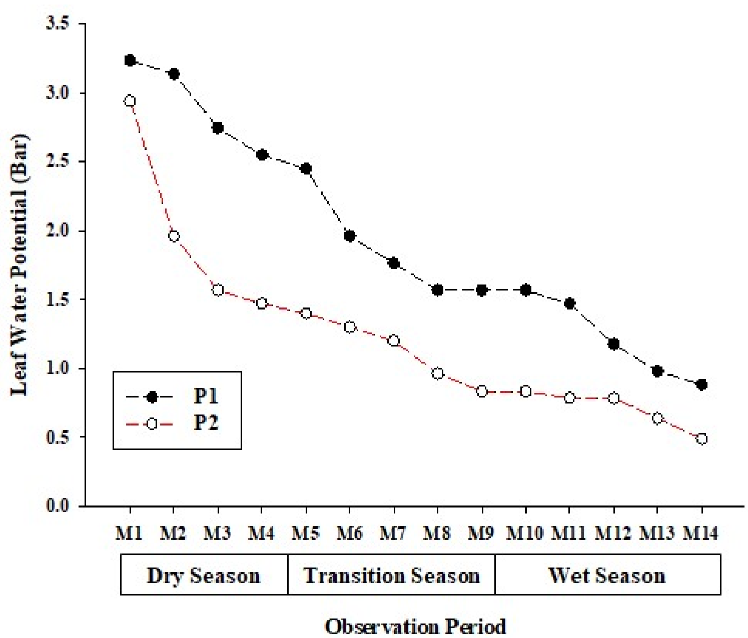


Figure 5. The average leaf water potential at various observation periods. M: observation week, P1: control (bench terrace); P2: l-shaped silt pit.

The results showed that there was an increase in water potential along with the changing seasons from the dry season to the rainy season. The lower the leaf water potential, the plant will lose turgor due to low water availability, so it will be difficult for plants to excrete water because water is bound by water parenchyma tissue; if cell turgor is not maintained, the plant will wither. This condition affects the rate of transpiration. If the leaf water potential is low, the plant will maintain turgor followed by the closure of leaf stomata, where the closure of stomata increases leaf resistance to water loss (Amelework et al., 2015). Soil water potential and leaf water potential have a very strong influence on the rate of transpiration after microclimatic factors. Groundwater potential and leaf water showed a strong and positive relationship to the transpiration rate with the correlation coefficient values (r) of 0.89 and 0.88, respectively. A positive value also indicated an increase or decrease in soil and leaf water potential that was directly proportional to the transpiration rate.

Effect of plant physiology on transpiration rate

Transpiration rate can also be influenced by plant physiological conditions, especially stomata and root length density. According to Prijono and Laksamana (2016), gas exchange between leaves and the atmosphere occurs when the stomata open; under these conditions, photosynthesis and transpiration occur. The rate of transpiration will be influenced by the behaviour of opening and closing stomata. The results showed that the stomata density was higher at P2 (482.49 mm^{-2}) than P1 (312.51 mm^{-2}), but the size was inversely proportional to where P1 was greater than P2 (Table 1). Camargo and Marenco (2011) showed that stomata size had a negative correlation with stomata density. Stomata density in the unit area shows how many stomata are on the leaf. The higher the stomatal density, the higher the transpiration rate. Root length density was calculated to determine the density of root distribution in the soil.

Table 1. The average stomata size and stomata density of coffee plants.

No	Treatment Code	Width (µm)	Length (µm)	Stomata Density (Σ stomata mm^{-2})
1	P1	17.78	24.90	312.51
2	P2	16.21	23.49	482.49

Notes: P1: control (bench terrace); P2: L-shaped silt pit

Water can be absorbed and flowed from the soil to plant parts through roots; therefore, plant roots also have the potential or can affect the amount of water that can be transpired. The distribution of root length density has the potential to affect the transpiration process, but the effect of root length density on the transpiration rate has not been widely carried out, so further research is needed ((Metselaar et al., 2019).

Conclusion

The coffee transpiration rate in the two treatments showed a significant difference. The L-shaped silt pit (P2) had a higher transpiration rate than the control or bench terrace (P1). The rate of transpiration decreases with the change of seasons from the dry season to the transitional season and the rainy season; this can be caused by changes in the microclimate. Temperature and sunlight intensity was the most variables influencing the rate of transpiration. The increase in temperature and the intensity of sunlight is followed by an increase in the rate of transpiration. There is a correlation between soil water potential and leaf water potential on the rate of transpiration which is indicated by a very strong and positive relationship. The increase in groundwater potential is followed by an increase in leaf water and transpiration rate. The L-shaped silt pit treatment had higher soil water potential and leaf water potential than the bench terraces, which was in line with the transpiration rate in the L-shaped silt pit, which was also higher than the bench terraces.

Acknowledgements

The authors wish to thank the Faculty of Agriculture, Brawijaya University, for funding this study through Professor Grant 2020.

References

Amelework, B., Shimelis, H., Tongoona, P. and Laing, M. 2015. Physiological mechanisms of drought tolerance in Sorghum, genetic basis and breeding methods: A review. *African Journal of Agricultural Research* 10(31):3029-40, doi:10.5897/ajar2015.9595.

Argyrokastritis, I., Papastylianou, P. and Alexandris, S.G. 2015. Leaf water potential and crop water stress index variation for full and deficit irrigated cotton in Mediterranean conditions. *Agriculture and Agricultural Science Procedia* 4:463-470, doi:10.1016/j.aaspro.2015.03.054.

Bana, S., Prijono, S., Ariffin, and Soemarno. 2013. The effect of soil management on the availability of soil moisture and maize production in dryland. *International Journal of Agriculture and Forestry* 3(3):77-85, doi:10.5923/j.ijaf.20130303.02.

Bermudez-Florez, L.N., Cartagena-Valenzuela, J.R. and Ramirez-Builes, V.G. 2018. Soil humidity and evapotranspiration under three coffee (coffea arabica l.) planting densities at Naranjal experimental station (Chinchiná, Caldas, Colombia). *Acta Agronomica* 67(3):402-413, doi:10.15446/acag.v67n3.67377.

BPS (Central Bureau of Statistics). 2020. Malang district one data 2020. Malang Regency Central Bureau of Statistics. Malang (*in Indonesian*).

Camargo, M.A.B. and Marenco, R.A. 2011. Densidade, tamanho e distribuição estomática em 35 espécies de árvores na Amazônia central. *Acta Amazonica* 41(2): 205–212, doi.org/10.1590/S0044-59672011000200004.

Cheserek, J.J. and Gichimu, B.M. 2012. Drought and heat tolerance in coffee?: a review. *International Research Journal of Agricultural Science and Soil Science* 2(12):498-501.

Clermont-Dauphin, C., Suvannang, N., Hammecker, C., Cheylan, V., Pongwichian, P. and Do, F.C. 2013. Unexpected absence of control of rubber tree growth by soil water shortage in dry subhumid climate. *Agronomy for Sustainable Development* 33(3):531-538, doi:10.1007/s13593-012-0129-2.

Crawford, A.J., McLachlan, D.H., Hetherington, A.M. and Franklin, K.A. 2012. High temperature exposure increases plant cooling capacity. *Current Biology* 22(10):396-397, doi:10.1016/j.cub.2012.03.044.

Fulton, A. Grant, J., Buchner, R. and Connell, J. 2014. Using the pressure chamber for irrigation management in walnut, almond and prune. UC Agriculture and Natural Resources 1-27, doi:10.3733/ucanr.8503.

Haditiya, F.R. and Prijono, S. 2018. Simulation of impact of climate change on water supply availability for sugarcane in Malang Region. *Jurnal Tanah dan Sumberdaya Lahan* 5(1):663-672 (*in Indonesian*).

Junedi, H. 2014. Effect of china violet (*Asystasia gangetica* (l.) T. Anders.) on the available water capacity and peanut yield at ultisol. *Proceeding of National Seminar on Suboptimal Land,* 26-27 September 2014, Palembang 400-407 (*in Indonesian*).

Loo, Y.Y., Billa, L. and Singh, A. 2015. Effect of climate change on seasonal monsoon in Asia and its impact on the variability of monsoon rainfall in Southeast Asia. *Geoscience Frontiers* 6(6):817-823. doi:10.1016/j.gsf.2014.02.009.

Markesteijn, L., Iraipi, J., Bongers, F. and Poorter, L. 2010. Seasonal variation in soil and plant water potentials in a Bolivian tropical moist and dry forest. *Journal of Tropical Ecology* 26(5):497-508, doi:10.1017/s0266467410000271.

Metselaar, K., Pinheiro, E.A.R. and van Lier, Q. de J. 2019. Mathematical description of rooting profiles of agricultural crops and its effect on transpiration prediction by a hydrological model. *Soil Systems* 3(3):1-16, doi:10.3390/soilsystems3030044.

Noeralam, A., Arsyad, S. and Anas, I. 2003. Effective technique of run off control on sloping upland farming. *Jurnal Ilmu Tanah dan Lingkungan* 5(1):13-16, doi:10.29244/jitl.5.1.13-16 (*in Indonesian*).

Prijono, S. and Bana, S. 2015. Study of soil moisture on coffee plantations in dry land using neutron probe in Malang, East Java. *Bulletin of Environment, Pharmacology and Life Sciences* 4(1):135-143.

Prijono, S. and Laksamana, M.T.S. 2016. Study of *Peltophorum dassyrachis* and *Gliricidia sepium* transpiration rate in fence cultivation systems and their effect on unsaturated hydraulic conductivity. *Jurnal Pembangunan Alam Lestari* 7(1): 5-24 (*in Indonesian*).

Qaderi, M.M., Martel, A.B. and Dixon, S.L. 2019. Environmental factors influence plant vascular systems and water regulation. *Plants* 8(3): 65, doi:10.3390/plants8030065.

Qiu, Y., Fu, B., Wang, J. and Chen, L. 2001. Spatial variability of soil moisture content and its relation to environmental indices in a semi-arid gully catchment of the Loess Plateau, China. *Journal of Arid Environments* 49(4):723-750, doi:10.1006/jare.2001.0828.

Renninger, H. J., Phillips, N. and Salvucci, G. D. 2010. Wet- vs. dry-season transpiration in an Amazonian rain forest palm *Iriartea deltoidea*. *Biotropica* 42(4):470-478, doi:10.1111/j.1744-7429.2009.00612.x.

Satibi, M., Nasamsir, N. and Hayata, H. 2019. Making "rorak" in arabica coffee plantations (*Coffea arabica*) to increase productivity. *Jurnal Media Pertanian* 4(2):74-80, doi:10.33087/jagro.v4i2.85 (*in Indonesian*).

Singh, Y., Kukal, S.S., Jat, M.L. and Sidhu, H.S. 2014. Improving water productivity of wheat-based cropping systems in South Asia for sustained productivity. *Advances in Agronomy* 127:157-258, doi:10.1016/b978-0-12-800131-8.00004-2.

Surdianto, Y., Setiawan, B.S., Prastowo, P. and Saptomo, S.K. 2012. Increasing groundwater infiltration with infiltration channels and "rorak" to increase sweet starfruit productivity (case study in Depok City). *Jurnal Irigasi* 7(1):1-8 (*in Indonesian*).

Wallace, J. and McJannet, D. 2010. Processes controlling transpiration in the rainforests of North Queensland, Australia. *Journal of Hydrology* 384(1-2):107-117. doi:10.1016/j.jhydrol.2010.01.015.

Wang, Y., Zhang, W. and Liu, X. 2013. Daily variations in transpiration rate and water potential of *Robinia pseudoacacia*. *Journal of Food, Agriculture and Environment* 11(1):999-1005.