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# Impact of Reforestation After Forest Fire on Infiltration and Other Soil Physical Properties

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## ABSTRACT

Forest fires have become a vital issue causing various hydro-meteorological disasters. Many parties have carried out efforts. This study aimed to analyze the impact of land covers due to reforestation on infiltration rate and other soil physical properties related to hydrological conditions. The research was conducted in the Cempaka Forest area. There are four observed land covers, i.e., Timber Forest Products (TFP), Non-Timber Forest Products (NTFP), Pine, and Shrub. The results showed that land cover significantly affected the infiltration rate ($p < 0.05$). The infiltration rate of Pine was not significantly different from NTFP but significantly different from TFP and Shrubs. The infiltration rate of Pine, NTFP, TFP, and Shrub land cover was 76.2 cm $hr^{-1}$, 48.1 cm $hr^{-1}$, 32.7 cm.$hr^{-1}$, and 40.0 cm $hr^{-1}$, respectively. The infiltration correlated with soil bulk density at two depths (0-15 cm and 16-30 cm) with r values of 0.614 and 0.595, respectively. Infiltration rate also significantly correlated with water content at pF 0 and pF 2.5 in the second soil depth. Additionally, soil bulk density is correlated with soil particle density with r = 0.621. Soil particle density also correlated with clay content with r equal to 0.726.

***Keywords***: Forest fire, infiltration, land cover, reforestation, soil physical properties

## INTRODUCTION

Forest fires have been a global issue in recent times, such as in Australia, America, German, Russia, and Amazon. In the current time, wildfire has become a catastrophe event, and it is in line with NIFC (National Interagency Fire Center) publication data that revealed 20% of wildfire area from 2017 to 2021 from the total wildfire area since 1983. The fire brought several impacts, both economic and environmental problems. Lee et al. (2015) stated that environmental failure may be a prominent part of directly measured costs for the impact of wildfires generated by climate change. The harshness of forest fires reported by Heydari et al. (2017) set disserve impact on natural ecosystems regarding soil properties. In Indonesia, wildfires, both in lands and forests, have become a significant challenge. The area of forest and land fires shows an increasing trend. Indonesia's Ministry of Environment and Forestry reported that the total burned forest area in 2019 was 1,649,258 hectares. However, a study reported a double number which hit 3,1 million hectares (Bhawono et al., 2022). In East Java, Indonesia, the area of land and forest burned in 2019 increased by around five times from 4,975 hectares in 2014 to 23,655 hectares. Forest fires can occur in mountainous areas, categorized as upstream areas, and have a recharge area function to drain water through the existing river system (Markovich et al., 2019). In addition, forests hold an essential role as a conservation area for biological resources (Ifo et al., 2016).

Forest fire, particularly in the mountains area, has led to the derivation of hydrological and biodiversity functions and ultimately impacts the surrounding community's livelihood. In East Java, forest fires engulfed almost all of the forests in the mountains area. At least 7 (seven) mountains in East Java experienced forest fires at the end of 2019, including Mount Arjuna, Welirang, Kawi, Wilis, Semeru, Bromo, and Ijen (Purnomo, 2019). A series of forest fires in mountainous areas which began to occur around 2013, has shown an impact, especially on the hydrological function of the area around the mountains. Floods, landslides, and other hydro-meteorological disasters recur every year (May 2020; Ishomuddin, 2019; Perdana, 2018; and Pusat Krisis Kesehatan Kemeterian Kesehatan RI, 2017). Many parties have carried out efforts to improve the condition of plant biodiversity in burnt forests. Cempaka Education Center Foundation was one of the parties conducting the forest replanting (reforestation) in 2018. The reforestation location was in the Cempaka Forest area, which was burned around 2017 and the years after. This study aimed to analyze the impact of land cover from reforestation on infiltration rates and other soil physical properties. The results expected can be a means of monitoring and providing information for the improvement of forest replanting strategies by all relevant parties, especially the Cempaka Education Center Foundation.

## MATERIALS AND METHODS

The research was conducted from March to July 2022 in Dayurejo Village, Prigen District, Pasuruan Regency, East Java, Indonesia. The research was located in the protected forest area of the Perhutani in Curah Tangkil Block, which Cempaka Education Center Foundation manages. Geographically, the research location has 7°43'33.3" of South Latitude and 112°39'57.3" of East Longitude coordinates. Soil sample analysis was carried out in the Laboratory of the Department of Soil, Faculty of Agriculture, Brawijaya University. The forest area used as the research location is a protected area delegated to the Cempaka Education Center Foundation as a social organization in the nearest area. A survey was conducted to determine the land cover types in the research location. Preliminary survey activities were conducted by collecting land cover information from available maps, followed by field surveys (ground checks). The survey found four land covers were grouped according to their function, i.e., Non-Timber Forest Products (NTFP), Timber Forest Products (TFP), Pine, and Shrub. Several parameters of soil physical properties were measured and observed from the four land covers, including infiltration, soil bulk density, soil particle density, soil texture, porosity, and soil water retention at saturated conditions (pF 0) and field capacity (pF 2.5). Observations of litter and understorey biomass are expected to be able to elucidate the results of soil physical properties measurement. Soil bulk density and soil porosity were measured using the gravimetric method through cylindrical ring equipment. Soil particle density was measured using the pycnometer method, soil texture was measured using the pipette method, and soil water content at pF 0 and 2.5 were analyzed using a kaolin box.

Meanwhile, infiltration was measured using a double-ring infiltrometer, and the infiltration rate was calculated using Horton's equation. Litter and understorey samples were measured using a frame of 50 cm × 50 cm size. All parameters were measured in 3 replication for each land cover.

The normality test was conducted on the data obtained before the Analysis of Variance (ANOVA) and T-test were carried out. The ANOVA test was carried out to determine the effect of different land covers on the observed parameters with a confidence level of 95%. An advanced test was conducted with Duncan Multiple Range Test (DMRT) to determine differences between land cover types and if there is a significant effect of land cover types on the measured parameters. In addition, a correlation test was carried out to see the closeness of the relationship between parameters, and regression was carried out to determine the form of the relationship between parameters.

## RESULTS AND DISCUSSION

### General Condition of Study Site

Curah Tangkil Block of the Cempaka forest area has an area of about 92 hectares with Andisol soil order. Land cover in this region has different conditions. NTFP is land cover with the function of forest with tree species whose utilization is not from the wood but from the by-products of the tree such as sap, fruit, leaves, and seeds. The first plot of NTFP is located in a valley between hills. It is located close to a spring with an altitude of about 1,024 meters above sea level (asl). It has vegetation, including rukam plants, amazon nuts, gamal, and understorey in the form of grass. The second plot of NTFP is located directly above the first replication of NTFP with an altitude of around 1,037 meters above sea level (asl). It has coffee, duwet, eucalyptus vegetation, and an understorey of grass. The third plot of NTFP is located on Pring Benol Hill with an altitude of around 1,074 meters asl and has vegetation in the form of candlenuts, coffee, and avocado plants.

Meanwhile, TFP is land cover consisting of tree species used or harvested for wood. TFP's first plot is located on the slope of Bukit Curah Tangkil Hill, with an altitude of about 1,075 meters asl and has vegetation dominated by mahogany trees. Apart from mahogany trees, there are also jatropha and cloves. The second plot of TFP is located on the same hill directly above the first TFP with an altitude of around 1,096 meters asl and is still dominated by mahogany trees. Apart from mahogany plants, there are also clove and sengon plants. The third plot of TFP is located on a hill known as Putuk Elang Hill with an altitude of around 1,180 meters asl and has vegetation such as acacia and jatropha. The first plot of Pinus is located on the slopes of Curah Tangkil Hill with an altitude of around 1,128 meters asl and has vegetation dominated by pine trees. In addition, there are also mahogany and avocado plants. The second plot of Pinus is located on Pring Benol Hill with an altitude of 1,096 meters asl and has vegetation other than Pine, namely mahogany and sintok.

Furthermore, the last plot of Pinus is located on the same hill as the second replication with an altitude of around 1,128 meters asl and has vegetation other than Pine, such as white teak and saga trees. In Shrubs, cover crops are dominated by paitan plants and grasses. All the plots are located on the same hill, namely Tangkil Hill. The altitude of the first, second, and third plots are 1,077 meters asl, 1,097 meters asl, and 1,108 meters asl, respectively. The three plots were covered with bush, except for sporadic avocado plants in the second plot.

### Infiltration Rate

The results of infiltration rate measurements showed that differences in land cover significantly affected the infiltration rate ($p < 0.05$) (Figure 1). The highest infiltration rate occurred in Pinus land cover with an average value of 76.2 cm $hr^{-1}$. Meanwhile, the infiltration rate of NTFP, TFP, and Shrub land cover was not significantly different with the successive infiltration rate value of 48.1 cm $hr^{-1}$, 32.7 cm $hr^{-1}$, and 40.0 cm $hr^{-1}$. It is also found NTFP and Shrub were the landuse that have the fastest time to be saturated compared to Pine and TFP (Figure 2). The old age of the trees and the high density of Pinus land cover compared to other land covers are the determining factors for the high soil infiltration rate. In general, the presence of trees with an age range of 5-10 years or more can impact soil quality (Marbun, 2018). According to Shi et al. (2022), initial infiltration and stable infiltration rates are strongly influenced by land cover and soil surface biomass, including surface litter and humus layer thickness, as well as the amount of root tissue that effectively improves soil structure and infiltration rate.

The high amount of organic matter is suspected to increase soil pore space. Herdiansyah (2011) revealed that the high amount of organic matter supply in the soil elevated the number of soil pores, formed a crumb soil structure, and ended up with soil bulk density value depletion. Therefore, soil with low soil bulk density value is expected to have more pore space. The higher the pore space in the soil, the faster the infiltration rate. It is in line with Zhao et al. (2022), who found that soil bulk density,

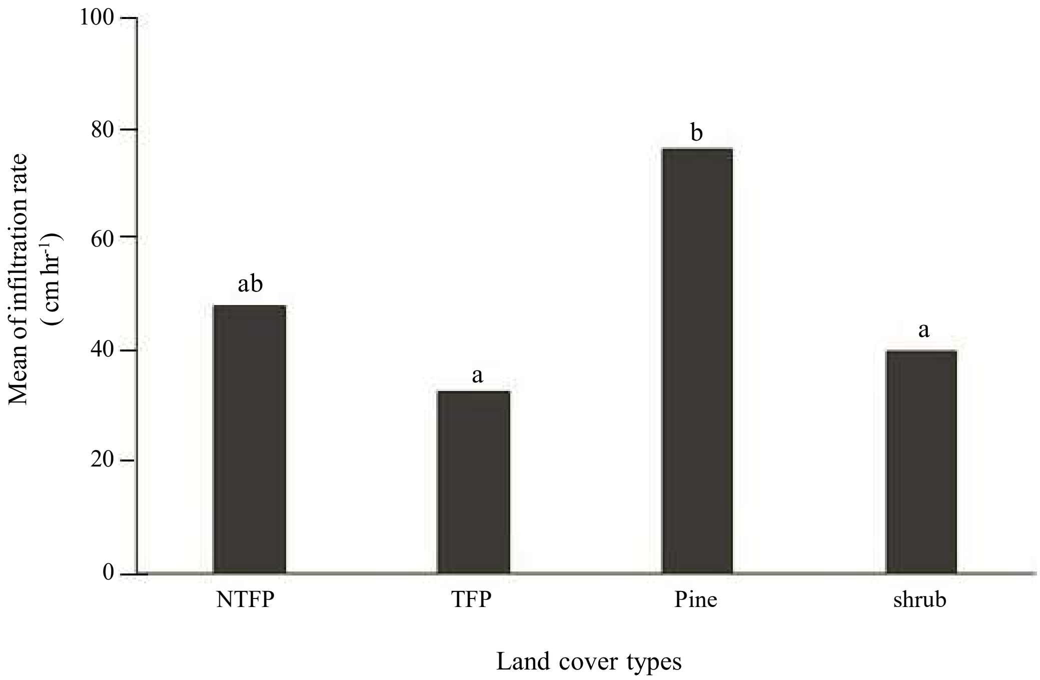


Figure 1. Infiltration rate in each land cover in the study area. NTFP: Non-Timber Forest Product; TFP : Timber Forest Product mean with different letter are significantly different.

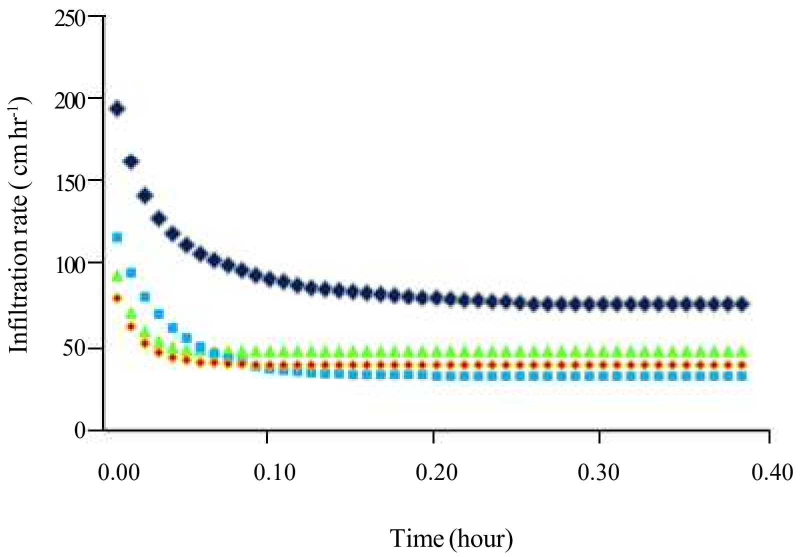


Figure 2. Infiltration rate curves in each land cover ((NTFP: Non-Timber Forest Product, TFP: Timber Forest Product). ▲: NTFP, ■: TFP, ◆: Pine, ●: shrub.

capillary porosity, and clay content were the main factors influencing water infiltration in the soil. The initial infiltration rate will have a high value and decrease with time due to the increasing amount of water that fills the soil pore, resulting in the depletion of the infiltration rate.

## Factors Affecting Infiltration Rate

Correlation tests reveal that soil bulk density, soil porosity, and water content on saturated and field capacities conditions affect infiltration rate (Table 1). At the same time, other soil parameters demonstrate a weak correlation. Other correlations between soil physical properties indicate a relationship between the percentage of sand with soil bulk density, soil particle density, soil bulk density, and soil bulk density with clay content.

Soil bulk density has a negative correlation with infiltration rate. The coefficient correlation value of soil bulk density and infiltration rate in the two soil depths are similar, i.e., -0.614 and -0.595, respectively, for 0-15 cm and 16-30 cm of soil depth. The relation between those parameters is represented by the regression equation $y = -127.84x + 135.47$ dan $y = -90.52x + 119.03$ for the two depths. X represents soil bulk density, and y represents infiltration rate, in which from the equation, it can be interpreted that each addition of 1 $g.cm^{-3}$ of bulk density can reduce the soil infiltration rate by 127.84 cm $hr^{-1}$ and 90.52 cm $hr^{-1}$, respectively (Figure 3).

Infiltration as a process of water entering from the soil surface is undoubtedly more significantly influenced by each traversed layer's soil characteristics. Soil bulk density in the two soil

Table 1. Correlation between observed parameters

| Correlation between Parameters | r values |
|---|---|
| BD (0-15 cm) vs Infiltration rate | -0.614* |
| BD (16-30 cm) vs Infiltration rate | -0.595* |
| Soil porosity (16-30 cm) vs Infiltration rate | 0.598* |
| Θ pF 0 (16-30 cm) vs Infiltration rate | -0.698* |
| Θ pF 2.5 (16-30 cm) vs Infiltration rate | -0.681* |
| PD (16-30 cm) vs BD (16-30 cm) | 0,621* |
| Soil porosity (16-30 cm) vs. BD (16-30 cm) | -0.989** |
| Clay content (16-30 cm) vs. PD (16-30 cm) | 0.726* |

Notes: * = p < 0,05; ** = p < 0,01; BD = Bulk Density; PD = Particle Density; pF (potential of Force); r = volumetric soil water content

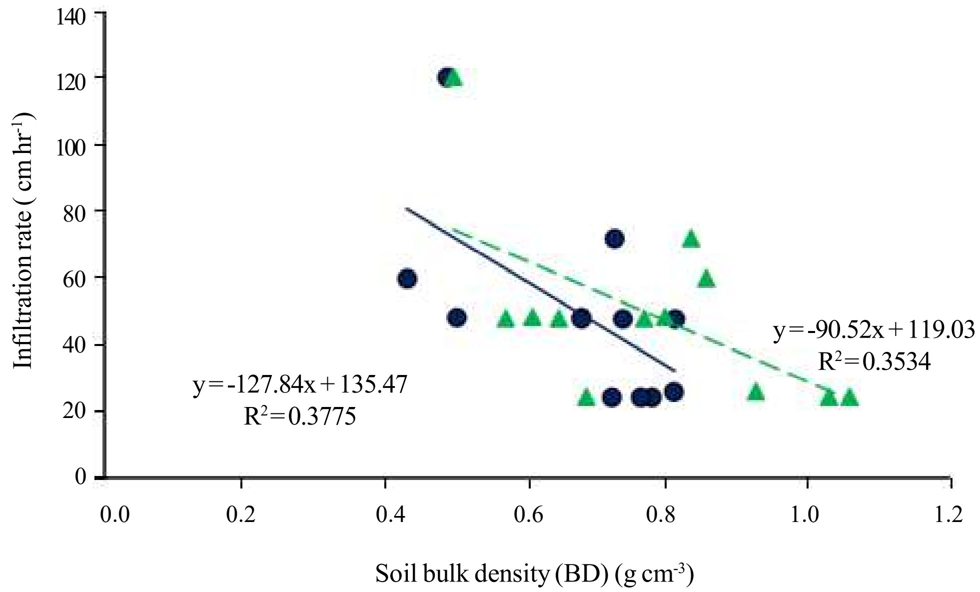


Figure 3. Relationship between soil bulk density and infiltration rate. ●: BD (0-15 cm), ▲: BD (16-30 cm), ——: Linear (BD (0-15 cm)), – – –: Linear (BD (16-30 cm)).

depths showed a nonsignificant difference in the mean value ($p < 0.05$). It causes a free lane for water to penetrate the whole soil layers. It is reinforced by the value of the determination coefficient between the average value of bulk density from the two depths and the infiltration rate, $R^2 = 0.50$, with the equation $y = -145x + 154,5$. It is all in line with Haynes et al. (2013), who found that increasing the soil bulk density value decreased soil infiltration rate. Bi et al. (2014) stated that soil bulk density significantly influences the initial infiltration rate in some periods of observations. The dropped water in the soil surface will be infiltrated through soil pore spaces, in which the increasing proportion of pore space decreases soil bulk density. The highest amount of pore space in the soil and the highest amount of water infiltrated into the soil end up with the fastest infiltration rate. A significant correlation ($r = 0.598$) between infiltration rate and soil porosity increasingly elucidates this condition, as soil porosity

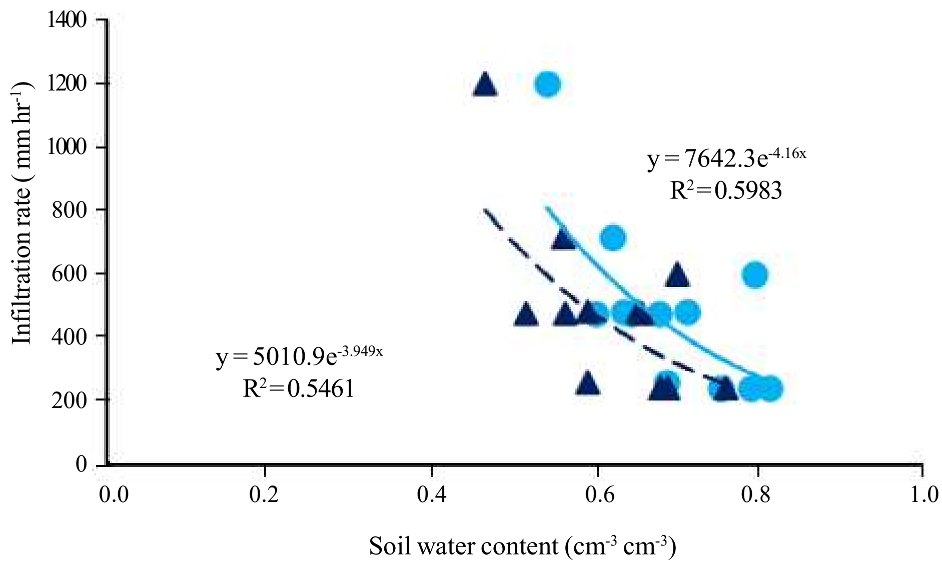


Figure 4. Relationship between soil water content at pF 0 and pF 2.5 and infiltration rate in 16-30 cm of soil depth. ●: pF 0, ▲: pF 2.5, ——: Expon (pF 0), – – –: Expon (pF 2.5).

is also related to soil bulk density. Haryati (2014) stated that soil with low soil bulk density value will quickly infiltrate the water into the soil. The lowest the soil bulk density, the fastest the infiltration rate due to the abundance of soil pore space.

The correlation between infiltration rate and other soil physical properties indicates that it is more related to the soil physical characteristics of the deeper layer. It is shown by the significant correlation between infiltration rate and soil porosity and soil water content of pF 0 and 2.5 from the second depth (16-30). The coefficient correlations between infiltration rate and water content at pF 0 and pF 2.5 in the two depths (0-15 cm and 16-30 cm) are 0.698 and 0.681, respectively. While the influence of the two parameters toward the infiltration rate is expressed in the equation $y = 7642{,}3e^{-4{,}16x}$ dan $y = 5010{,}9e^{-3{,}949x}$, respectively, for water content at pF 0 and pF 2.5 (Figure 4).

## Soil Physical Properties and Surface Biomass

### Soil texture

Soil particle observation in each plot was conducted by extracting the samples from four random locations in two soil depths. The result indicates that all land covers and depths have the same soil texture (silty loam). This is inline with Susilawati et al. (2017) who found that even the physical soil properties were different from varied land uses, however, the change of the land use did not alter the soil mineralogy characteristics. The similar soil texture in all land covers and depths occurred due to the same parent materials that composed the soil in the observation site (Figure 5). The domination of silt particles (> 50%) brings the characteristic of the soil in which it has enough capability to hold water due to the moderate particle size and insufficient macro pore. The silty soil texture also has a fast infiltration rate (Manfarizah et al., 2011).

However, even though both depths have similar soil texture classes, the soil fraction, particularly in the first depth (0-15 cm), has a significantly different proportion of sand content. The average sand content in Pinus was the highest amount and gave a significant difference value with TFP, which has the lowest percentage of sand (Figure 6). On the contrary, the proportion of sand, clay, and silt in 16-30 cm of depth indicates a non-significantly different value.

### Soil Bulk Density, Soil Particle Density, and Soil Porosity

The data from soil bulk density and particle density observations showed that land covers did not influence significantly ($p > 0.05$). Bulk density, as stated by Ahad et al. (2015), is a mass of solid phase divided by the total volume of the soil. This parameter is a fundamental soil property in which its value is influenced by soil texture, the density of sand, silt, clay, and organic matter, as well as the arrangement of soil particle packing. Soil bulk density that describes the soil density, is also highly influence the plant growth for instance the number of pods, number of roots, and the number of fresh root weight (Abosede et al., 2019). In this study, soil bulk density in 0-15 cm of depth range from 0.43 – 0.81 g $cm^{-3}$, while the second soil depth (16-30 cm) range from 0.49 – 1.06 g $cm^{-3}$. The whole soil bulk density values in the study site indicate a low value compared to the typical mineral soil's bulk density range from 1.0 g $cm^3$ – 2.0 g $cm^3$ (Blake et al., 1986). This condition is suspected because of the high amount of organic matter on the forest floor. It is in line with Enck et al. (2022), who found that

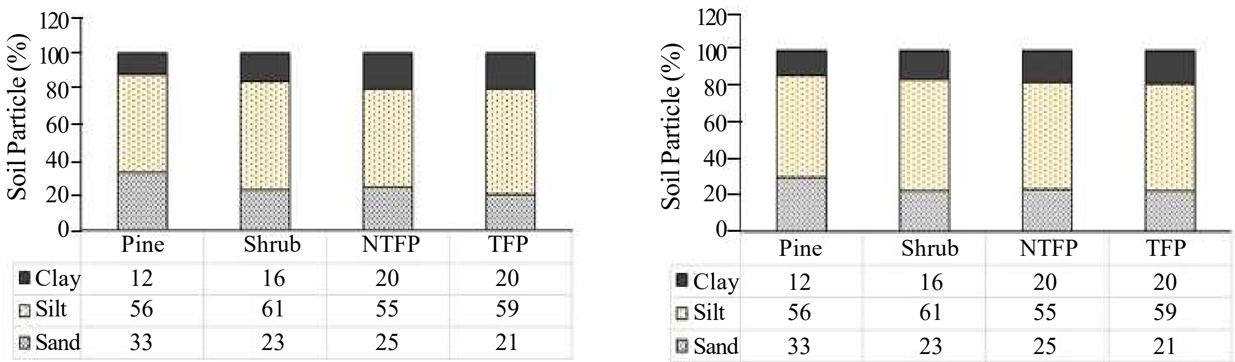


Figure 5. Soil particle percentage in each land cover in Cempaka Education Forest at (a) 0-15 cm; (b) 16-30 cm of depths.

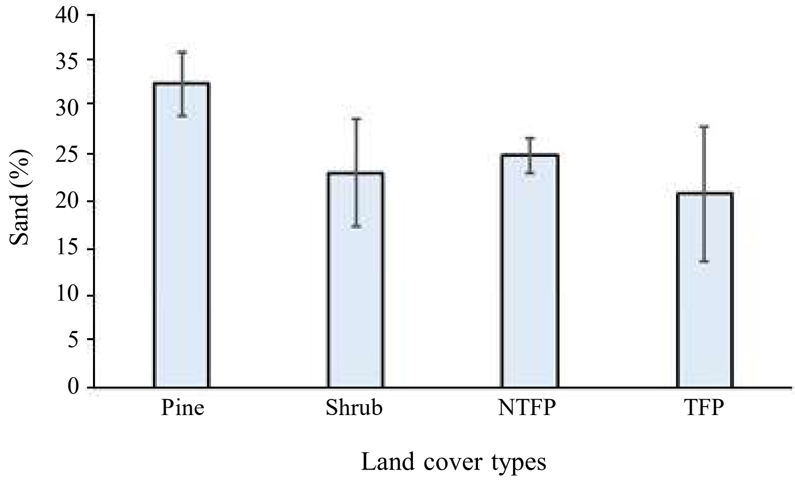


Figure 6. Sand particle percentage in each land cover at 0-15 cm of depth. NTFP: Non-Timber Forest Product; TFP: Timber Forest Product.

forest, particularly in the tropic zone, has a high amount of soil organic matter compared to other land uses. Silt content that dominated the soil was fathomed as another factor of the low value of soil bulk density in the study site. The silt content showed a significant difference value ($p < 0.05$) compared to sand particles. The low value of silt's particle density (Linsley et al*.,* 1982) can contribute to the low soil bulk density value due to its low dry mass value. The role of silt content on soil bulk density is further strengthened by Broch et al. (2017), who found that the existence of silt particles is more related to soil density, even compared to organic matter, and has more decisive influence compared to the sand particles on demoting soil density, which is shown from the high value of correlation and regression coefficient produced. Soil bulk density also indirectly influences infiltration from its role to facilitate the penetration of roots into the soil. The high soil density will cause root resistance to transpierce the soil matrics (Hamza et al*.,* 2005), and the stormwater in the soil surface will be difficult to enter the soil profile.

Meanwhile, soil particle density is influenced by parent material, organic matter, and soil minerals. Blake (2008) expected that soil particle density is a soil particle density in which the value is dependent on the mineral and humus proportion. Therefore, the soil particle density calculation compares the total mass of solid particles with volumes of solid, organic material, and other mineral particles. Based on the soil particle measurement in this study, land covers did not show a significant difference in influence ($p > 0.05$). Soil particle density in the first and second soil depth range from 1.73 – 2.11 g $cm^{-3}$ and 2.00 – 2.29 g $cm^{-3}$, respectively. Those soil particles' density is approximately similar to the typical value of particle density in mineral soil, which ranges from 2.0 – 2.5 g $cm^{-3}$ (Rosyidah et al*.,* 2013). Soil particle density in the 16-30 cm depth has a significant linear correlation with clay content. The highest amount of clay content is the highest value of soil particle density, with r = 0.726 and R2 = 0.527. It is in line with McBride et al. (2012), who said that soil particle density was found to vary in value because of the differences in clay content. Besides soil organic matter, clay content could also accurately predict soil particle density value (Schjonning et al*.,* 2017). Additionally, soil porosity, which is defined as the proportion of pore space between soil particles (commonly filled by water or air) and total soil volume (Surya, 2017), which is closely related to soil bulk density and particle density, did not show significant difference values because of the land cover different.

## Soil Water Content

The soil water content measured in this study is a potential soil water content. Potential soil water content stems from potential energy components resulting from water adsorption by solid surface, soil solution, air tension, and gravitational force (Campbell, 1987; Hillel, 1980). Potential water content in this study was only measured in saturated condition (pF 0) and field capacity condition (pF 2.5) to determine the total water that can be moved by gravitational force and the total water stored in all of the soil pores (Wibowo, 2010). The data showed that land cover significantly influenced ($p < 0.05$) the soil water at pF 0 and pF 2.5. In contrast, the total gravitational water did not significantly influence by the difference in land cover type (Table 2).

NTFP's soil showed the highest ability to adsoprs water compared to other land covers. The one in HKK, Pine, and Shrub indicated a similar character. The low soil water content at pF 0 at NTFP described the low capability to adsorp and hold water in soil pores in saturated conditions. It means the total volume of soil pores in NTFP soil is lower than in other land covers. It is in line with the soil porosity data, which shows that the lowest soil porosity value was in NTFP land cover, even the soil porosity did not influence by land cover. Soil water content at pF 2.5 showed a similar value with pF 0, in which NTFP's soil produced the lowest soil water content data compared to other land cover. The soil pore condition is an essential factor. Along with the soil depth, soil water content at pF 0 and pF 2.5 were getting escalated except for Pine and Shrub land covers.

**Litter and Understorey**

The data informs that land covers significantly influence the amount of litter and understorey ($p < 0.05$). The understorey ranged between 0.004 – 0.118 Mg ha$^{-1}$ from all the observed land covers (Figure 7). Destaranti et al. (2017) found that understorey is a primary vegetation type that grows under the forest stand and non-saplings with stem diameter < 5 cm.

The understorey can be comprised of grass and herbs. The different types of staple plants in a specific land cover can influence the structure and composition of the understorey. Vegetation with a broad canopy can generate microclimates such as air temperature and soil water content suitable for various understories (Kunarso et al., 2013). Pine forests with a dense canopy and high stand density will inhibit understorey growth. On the other side, grass, as a dominant plant in the shrub's land cover,

Table 2. ANOVA results between land cover and soil water content at pF 0, pF 2.5, and gravitational water.

| Land Cover | Soil Water Content at pF 0 (cm$^3$ cm$^{-3}$) | Soil Water Content at pF 2.5 (cm$^3$ cm$^{-3}$) | Gravitational Water (cm$^3$ cm$^{-3}$) |
|---|---|---|---|
| NTFP | 0.60$^a$ | 0.55$^a$ | 0.05 |
| TFP | 0.68$^b$ | 0.62$^b$ | 0.06 |
| Pine | 0.72$^b$ | 0.66$^b$ | 0.07 |
| Shrub | 0.72$^b$ | 0.64$^b$ | 0.11 |

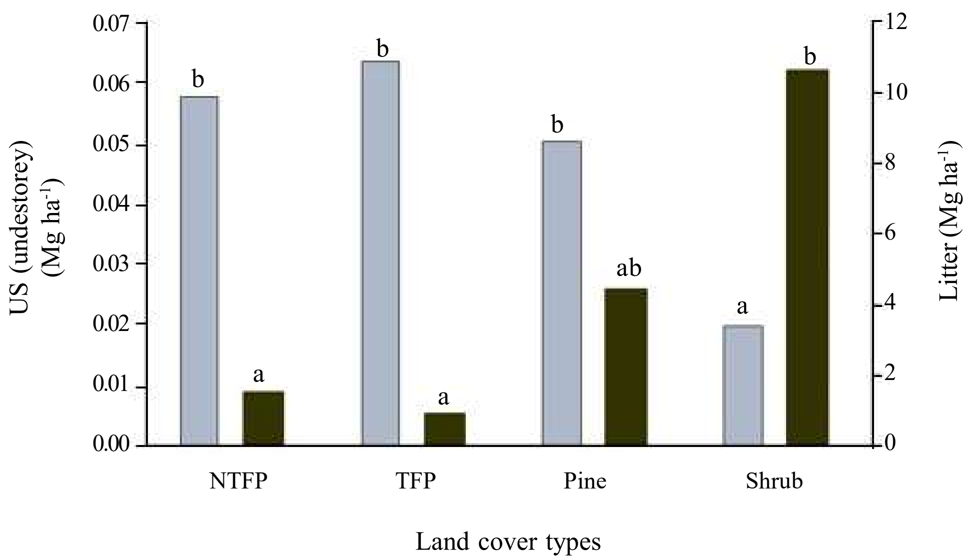


Figure 7. Understorey and litter biomass means different land cover types. ■: US (Mg ha$^{-1}$), □: Litter (Mg ha$^{-1}$). NTFP: Non-Timber Forest Product, TFP: Timber Forest Product different letter (a, b, ab) indicates the different of significance level.

is categorized as an understorey, which makes the amount of the understorey from this land cover highest compared to other land covers.

In contrast, litter in the shrub land cover showed the smallest quantity (3.39 Mg $ha^{-1}$) because of the small number of tree stands, as we know that trees will contribute to the litter (leaves and twigs). Litter in the three other land covers did not show a significant difference amount with the average value of 9.78 Mg $ha^{-1}$.

## CONCLUSIONS

Infiltration rates because of reforestation which resulted in NTFP and TFP, have yet to fully show an improvement compared to infiltration rates in the Pine that become a reference land cover (unburned). Since NTFP and TFP were Pine landcover before they burned, the initial soil properties were assumed to be the same as the recent Pine landcover in this study. The refinement process of soil physical properties (soil pore and bulk density) for four years after reforestation likely increases the infiltration rate. However, the uplift of infiltration rate on NTFP denotes a better enhancement and is statistically posed between Pine and Shrub. Meanwhile, other soil physical properties influenced by land covers were soil water content in various retention (pF 0 and 2.5). The refinement of infiltration rate and other soil physical characteristics expected can be continuously occurring align with the plant growth in each land cover.

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