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Cover Crops and Frond Piles for Improving Soil Water Infiltration in Oil Palm Plantations

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Abstract. Oil palm plantations may cause problems in the hydrological cycle due to a low soil water infiltration capacity. In this study, we (a) compared oil palm plantations with other land use types, and (b) within oil palm plantations, analyzed whether legume cover crops and the deposition of frond piles can change soil water infiltration. The study was conducted in the lowlands of Sumatra in mixed jungle rubber stands, and in monospecific rubber and oil palm plantations by using ring in filtrometers. Observed infiltration rates in jungle rubber and monospecific rubber stands (approximately 20 cm h^{-1}) were about 5 times higher than in oil palm plantations, underlining the problem. Within the oil palm cultivation system, a legume cover crop, as well as the deposition of palm fronds, significantly enhanced infiltration rates. We conclude that indeed low soil water infiltration is very low in conventional oil palm plantations. Management including the planting of cover crops and deposition of fronds may offer options for improving the situation.

Keywords: soil moisture, jungle rubber, rubber plantation, water scarcity, vegetation cover

1. Introduction
Hydrological cycle in oil palm plantations is considered to solve water problematic status in an oil palm plantation, especially where the infiltration rate after the land-use change from rubber or forest covers is lower, it would make sense to find out adaptive methods to improve water infiltration at oil palm plantation.

Water requirement of oil palms is equal to other trees cropping systems such as rubber, jungle rubber or even forest in a value of 1.5 - 3.0 mm day^{-1} [1, 2, 3]. However, oil palm in the monoculture system exposed more water requirements than oil palm in the agroforestry system [3]. Evapotranspiration value mature plantation exposed to 1216 ± 34 mm yr^{-1} and concurrently immature oil palm evapotranspiration value of 918 ± 46 mm yr^{-1} [4]. Similar research results also showed that evapotranspiration for the immature plant was 1000-1600 mm yr^{-1} and for the mature plant was 1200 - 1800 mm yr^{-1} [5]. A significant of the problem of water balance in the oil palm ecosystem is, that the rate of infiltration and its capability at oil palm plantation are very low under

3 cm h^{-1} [6]. Due to minimum water supply especially during the dry season, the water scarcity circumstances are under pressure since about 40% of precipitated water is absorbed by the canopy as interception water, and an amount of less than 1% reaches the soil through stemflow movement [7].

Water management is more critical on hilly and undulating soils to maintain soil moisture and minimize soil nutrient losses. Digging of silt-pits, additional terrace management, and supplementary foothill drains to trap water sediments from surface runoff require more energy and human labor especially at smallholder farmers. Stacking fronds across the slope to reduce the speed of water runoff downhill slopes and to conserve water through mulching and planting legume cover crops (LCC) will support replenishing soil organic matter stock and reducing the velocity of soil and water movement. The LCC commonly established in oil palm estates include *Mucuna bracteata*, *Pueraria javanica*, *Calopogonium mucunoides* and *Centrosema pubescens*. On the other hand, water management and soil conservation are not involuntarily practiced especially by smallholder farmers.

The purpose of the observation and experiment was to obtain the certainty about the level and capacity of frond pile row and legume cover crops and how to manage it to improve the infiltration rate under oil palm plantation. We evaluated the affectivity of LCC application for mulching at an oil palm plantation and the frond piles stacking on the improvement of water infiltration rate at the terrestrial landscape of smallholder plantation.

2. Methods

Field experiments and observations were arranged at smallholder plantation in Batanghari District, in Jambi, Indonesia in an area measurement of 4.0 ha for oil palm at coordinate S 01°47'12.6'' and E 103°16'14.1'' with altitude about 50m above sea level, 4.0 ha for rubber plantation at S 01°48'18.2'' and E 103°15'52.0'' with altitude 72m above sea level, and 3.0 ha jungle rubber plantation at S 01°47'07.3'' and E 103°16'36.9'' with altitude 72m above sea level. The distance between the three locations is less than 3 km away. For the observation purpose, the study sites were categorized in four slope levels i.e. plain (0-5%), slight (6-10%), moderate (11-21%) and heavy slope (24-33%). Sunlight transmission was about 20%. All of them were replicated four times. The location is classified as an undulated area. The distance between the plain area at the ridge position to the valley position was about 100 m. The observation was conducted during the dry season from April to October 2014. In the year of 2001-2016, averagely 2229 ± 308 mm (stdev.) of annual precipitation with an average temperature of 26.7 ± 0.2 °C were recorded by Indonesian Bureau of Meteorology, Climatology, and Geophysics (BMKG) - Airport Sultan Thaha, positioned approximately 35 km from the study location, 2017. Soil is terrestrial and classified as yellowish-red podzolic soil type in the group of acid soil ultisol. The oil palm age at the study area was 8-year old, rubber was 8 years old and a jungle rubber about 12 years old.

For identification of the affectivity of land use system to conserve water by the keeping of higher infiltration rate, a double ring infiltrometer was applied for 40 minutes of continuous measurement per each single infiltration point. The infiltration rate equation thereafter was formulated to calculate the average infiltration rate during and after a 4-hour time. During the measurement to reach the constant Ks-value as saturated hydraulic conductivity, a sum of water had succeeded in infiltrating into the soil with a higher infiltration rate in unsaturated water movement in the soil. The infiltrated water mainly from precipitation in unsaturated soil conditions, especially during 4-hour infiltration measurement time, is quite important to provide adequate soil moisture for the growing plant. The average infiltration rate was calculated as the mean value of the infiltration rate from 0-4 hours. After this 4-hour time, it shows the maximum value of the infiltration rate and also reached a status as a saturated hydraulic conductivity as Ks-value.

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Gravimetric soil moisture was analyzed on a wet basis at the depths of 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-60 cm, and 60-100 cm. The sampling points at oil palm plantation were located in 'weeding circles' (< 100 cm distance from the trunk), on 'active' path area (at 280 and 370 cm distance, respectively) and 'inactive' path area. 'Inactive' paths are the locations for the placement of pruned fronds in inter-rows (about 2 m wide); of every three inter-rows, one is prepared as 'inactive' path, and the remaining as 'active' paths, i.e. for maintenance and harvest activities. 'Weeding circles', around the trunks of the palms, show no ground vegetation due to frequent harvesting operations as well as a weed control application.

At each land use, measurement of infiltration was conducted. However, due to the relevance to the plantation culture, legume cover crop *Centrosema pubescens* (Benth.), *Mucuna bracteata* (DC.), and *Pueraria javanica* (Benth.) were planted at oil palm plantation as treatments. The infiltration rate at oil palm plantation was measured under the three legume cover crops, at ring area of oil palm trunk at the radius of 1m, at frond pile area and active path of plantation area. At rubber and jungle rubber plantation, the infiltration measurements were observed among the main trees.

3. Results and Discussion

The most intensive activity of oil palm culture is placed at a weeding circle area at a radius of 1m around of oil palm tree consisting of averagely 3 times herbicide spraying per year, preparation and collection of harvested fresh fruit bunch, including its pieces falling fruits and other maintenance activities as well. These activities support soil compaction and increase soil bulk density. The oil palm land use system increased bulk density characteristics [8]. This phenomenon is supposed to influence the infiltration capacity in the circle area. The average infiltration rate at the circle area exposed at 7.75 mm h^{-1} with Ks-value 2.33 mm h^{-1}, at active path area was 9.26 mm h^{-1} and 3.71 mm h^{-1} respectively. Impressive infiltration value was found under the frond pile area, where significant improved average infiltration rate at 27.00 mm h^{-1} and Ks-value at 10.8 mm h^{-1} compared to the weeding circle area and active path area. However, the frond pile area at the study location covered only 13% of the plantation area, and the weeding circle covered 5% of the plantation area. An increase of frond pile area for conservation purposes to 50% of plantation area would improve the average infiltration value of plantation area from averagely 11.49 mm h^{-1} to 18.05 mm h^{-1}, and increase the Ks-value from 4.56 cm h^{-1} to 7.19 cm h^{-1}.

Centrosema pubescens culture at oil palm increased the average infiltration rate at the value of 19.44 cm h^{-1} with Ks-value 5.05 cm h^{-1}. Better infiltration improvement was found under *Mucuna bracteata* with an average infiltration rate at the value of 35.64 cm h^{-1} with Ks-value 10.34 cm h^{-1} and *Pueraria javanica* with average infiltration rate at the value of 32.40 cm h^{-1} with Ks-value 9.72 cm h^{-1}. The infiltration improvement by legume cover crops *Mucuna bracteata* and *Pueraria javanica* reached equivalency affectivity with frond piling treatment. However, its performance could not be maintained easily, since the oil palm canopy reached covering rate to the soil surface at 80% level with sunlight transmission in the value of less than 20%. Due to insufficient sunlight transmission, the legume cover crop features were at sub-optimum performance with less than 80% of the canopy covering rate to the soil surface.

Rubber and jungle rubber had an equivalent value of average infiltration rate and Ks-value with the average value of both land-use systems 39.25 cm h^{-1} and 19.40 cm h^{-1}. The infiltration rate at rubber and jungle rubber plantation exposed in about 3-4 times higher than in oil palm plantation. The estimated average infiltration and Ks-value at oil palm, rubber, and jungle rubber plantation are presented in Table 1.

Table 1. Estimated average infiltration and Ks-value at oil palm plantation with and without legume cover crop planting compared to rubber and jungle rubber culture

Land Use	Position to oil palm trunk/ ground over	Average infiltration rate ($cm\ h^{-1}$)*	Ks-value ($cm\ h^{-1}$)*
Oil Palm	Active path area**	9.26a	3.71[a]
Oil Palm	Circle (trunk ring area)***	7.75a	2.33[a]
Oil Palm	Frond pile area (inactive path)****	27.00bc	10.8[b]
Oil Palm	*Centrosema pubescens******	19.44b	5.05[ab]
Oil Palm	*Mucuna bracteata* *****	35.64cd	10.34[b]
Oil Palm	*Pueraria javanica******	32.40cd	9.72[b]
Rubber	-	36.71cd	19.83[c]
Jungle rubber	-	41.80d	18.96[c]

*Values with different indexed letters within the same column are significantly different ($p<0.05$, Duncan's Multiple Range Test).
**Occupation 82% of the total plantation area
***Occupation 5% of the total plantation area
****Occupation 13% of the total plantation area
***** Active path area

More infiltrated water into the soil is the key to increase water availability for oil palm growing, especially for the most smallholder farmers, where the water irrigation system is found in very limited construction. Corporate farmers have more resources to control and to provide their water requirements system. Soil moisture was taken into consideration as an indicator of water availability. After examining the moisture status during the dry season observation in various soil depths, the soil at the active path and inactive path at 0-10 cm soil depth was better moisturized than soil at the weeding circle area. In this case, at frond pile position 2.0% more water was available than at active path and 3.2% more water was available than in the weeding circle area. In the soil depth of 10-60 cm, there was no difference in soil water content between the weeding circle position and the active path. Moreover, compared to the position at an active path, higher moisturized condition at the value ranging from 0.9-2.0% of soil water content at the soil depth of 0-60 cm the inactive path was noted. Soil water content under the weeding circle, active path, and the inactive path are presented in Figure 1.

Regarding water availability, more available water in the upper soil layer is the key role for sustainable oil palm production system, whereas at the related research area the oil palm coarse root and fine roots distribution are relevant to the water absorption for the plant. Both of root systems were found dominantly at the layer of 10-30 cm soil depth and much lower at soil surface at the depth of 0-10 cm [9].

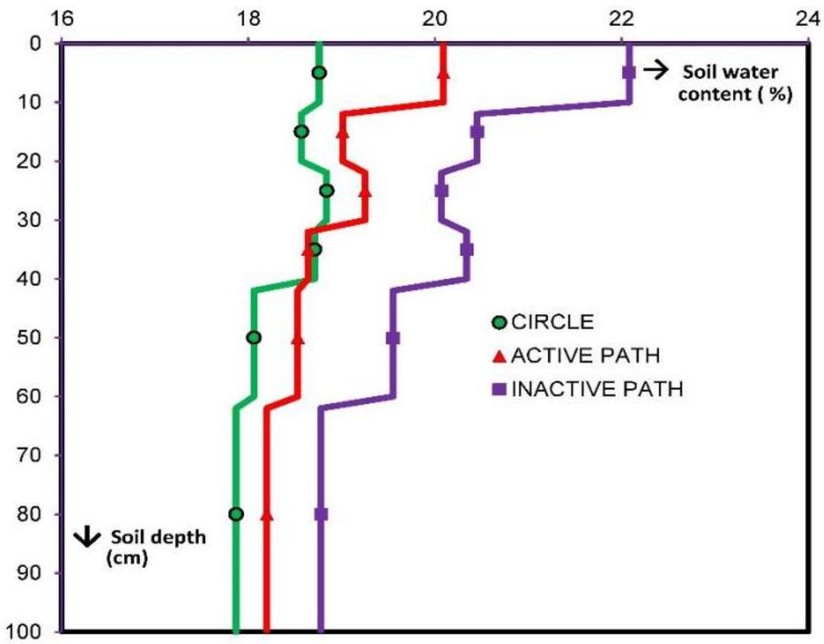

Figure 1. Soil water content in oil palm plantations under weeding circles, active and inactive paths at 0-100 cm soil depth

4. Conclusion and Recommendation

The average infiltration rate and saturated hydraulic conductivity K_S-value at circle area and active path area exposed lower than at the frond pile area, which at the frond pile area its values reached 27.00 cm h^{-1} and 10.8 cm h^{-1} respectively. An increase of frond pile area measurement for conservation purposes up to 50% of plantation area would improve the average infiltration value of plantation area from averagely 11.49 mm h^{-1} to 18.05 mm h^{-1}, and increase the K_S-value from 4.56 cm h^{-1} to 7.19 cm h^{-1}. Weeding circles were less moist than both active and inactive path areas, especially in the upper soil layer (0-30 cm). In deeper layers, there was no significant difference in soil water content under weeding circles and active path area, while under the inactive path area, soil water content was significantly higher at 0-60 cm soil depth.

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References

[1] Röll A, Niu F, Meijide A, Ahongshangbam J, Ehbrecht M., Guillaume T, Gunawan D, Hardanto A, Hendrayanto, Hertel D, Kotowska M, Kreft H, Kuzyakov Y, Leuschner C, Nomura M, Polle A, Rembold K, Sahner J, Seidel D, Zemp DC, Knohl A, Hölscher D 2019 Transpiration on the rebound in lowland Sumatra *Agricultural and Forest Meteorology* **274** 160-171

[2] Röll A, Niu F, Meijide A, Hardanto A, Hendrayanto, Knohl A, Hölscher D. 2015.Transpiration in an oil palm landscape: effects of palm age. *Biogeosciences*, **12** 5619-5633

[3] Ahongshangbam J, Khokthong W, Ellsäßer F, Hendrayanto, Hölscher D, Röll A 2019 Drone-based photogrammetry for predicting tree and oil palm water use *Ecohydrology* **e2115**

[4] Meijide A, Roell A, Fan, Y, Herbst M, Niu, F, Tiedemann, F, June T, Rauf A, Hoelscher D, Knohl A. 2017. Controls of water and energy fluxes in oil palm plantations: Environmental variables and oil palm age *Agricultural and Forest Meteorology* **239** 71-85
[5] Manoli G, Meijide A, Huth N, Knohl A, Kosugi Y, Burlando P, Ghazoul J, Fatichi S 2018 Ecohydrological changes after tropical forest conversion to oil palm *Environ. Res. Lett.* **13** 064035
[6] Merten J, Röll A, Guillaume T, Meijide A, Tarigan S, Agusta H, Dislich C, Dittrich C, Faust H, Gunawan D, Hein J, Hendrayanto, Knohl A, Kuzyakov K, Wiegand K, Hölscher D 2016 Water scarcity and oil palm expansion: social views and environmental processes *Ecology and Society* **21** (5):1-21
[7] Agusta H, Hendrayanto, Sudaryanto MT, Dewi AM, Hoelscher D. 2019. Infiltrated Water and Runoff at Four Gradient Slopes at Smallholder Oil Palm Plantation in Dry Season in Jambi, Indonesia *J. Jpn. Inst. Energy* **98** (5):101-105
[8] Guillaume T, Holtkamp AM, Damris M, Brümmer B, Kuzyakov Y 2016 Soil degradation in oil palm and rubber plantations under land resource *Agriculture, Ecosystems and Environment* **232** 110-118
[9] Pransiska Y, Triadiati T, Tjitrosoedirjo S, Hertel D, Kotowska MM 2016 Forest conversion impacts on the fine and coarse root system, and soil organic matter in tropical lowlands of Sumatera (Indonesia) *Forest Ecology and Management* **379** 288-298