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Differences in soil-water characteristics of monoculture oil-palm plantations, agroforestry oil-palm plantations and natural forest

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Abstract. This study aims to determine the soil water retention curves and infiltration rates for three different land use types located in Jambi province, Sumatra, Indonesia: natural forest, monoculture and agroforestry oil palm plantations (divided into new agroforestry (2,5 years) and old agroforestry (over 10 years)). Data on the infiltration rate of the soil for the different land use types was collected by using a double infiltrometer. A Horton curve was fitted to these measurements. The results on the soil water characteristics were compared between all land use types. This concluded that there is a significant difference in constant infiltration rate between the value of the natural forest and the new agroforestry and the value of the other land use types. The forest also has a significant smaller porosity. The results of the study concluded that plantations have a bad influence on the soil characteristics investigated, but in general agroforestry has a less bad impact than monoculture. However, this is highly dependent on the features of the locations investigated.

1. Introduction

Due to a growing population, more stress is put on the agriculture all over the world [1]. This causes the need for more agricultural land, and more productive agriculture. The first need can result into deforestation all over the world. While the second needs research into how more productive agriculture could be reached.

Some areas in the world where a lot of deforestation takes place due to agriculture are Borneo and Sumatra, both located in Indonesia [2]. The major cause for deforestation in Indonesia is agriculture with mainly oil palm plantations as driver [3]. The agricultural sector plays a vital role in the economy of Indonesia [4]. This makes sustainable agriculture even more important in these areas. It is important to have the agricultural production as high as possible and keep the ground suitable for agriculture for a long time period. Mostly deforested areas are transformed in monoculture plantations, which have a negative impact on the climate and ecosystem of an area. Therefore, more sustainable options should be found for this problem.

University Gadjah Mada (UGM) works together with the Kehati Foundation on a project called “Strategi Jangka Benah”. The aim of the project is to transform monoculture oil palm plantations in Jambi province, Sumatra, into agroforestry plantations which are expected to have a better influence on the climate and ecosystem. However, this has not been proven yet. Therefore, this research focusses on

soil water characteristic, namely water retention curves and infiltration rates. These are two of the important factors which can help provide more insight in the impact of the change of monocultural plantations to agroforestry plantations, but also the changes regarding to natural forest. The impact of these different land uses on the soil-water characteristics can then be linked to the growth of vegetation, as the two characteristics indicate the water availability for plants and the flow into the soil which can transport nutrients into the ground which are beneficial for plant growth.

In the research of Dislich et al. [5] and Tarigan et al. [6] there is only focussed on the difference in infiltration between monoculture oil palm plantation and the natural forest. This means knowledge on the agroforestry land use and the differences of this land use with the other two land use types, is still missing as well as the knowledge on water retention curves for these land use types. This study aims to investigate the differences in soil-water characteristics of monoculture oil-palm plantations, agroforestry oil-palm plantations and natural forest. The results of this study can be beneficial for agricultural decisions and specifically for the "Strategi Jangka Benah" project to transform more monoculture into agroforestry plantations, when the conclusion can be made that the agroforestry land use type has better soil water characteristics.

2. Method

First, data was gathered on mostly visual features of the different areas like soil colour, vegetation density, organic material at the surface layer and the bulk density. This was done to make a fair comparison between the different land use types and explain the differences between them. Most features were determined in the field. The bulk density of the soil however was determined in the lab after oven drying the samples for 24 hours at a temperature of 80°C by using equation 1 in which $M_{s\,(od)}$ is the mass of the oven dried soil (g) and V_s is the volume of the soil sample (cm^3).

$$D = \frac{M_{s\,(od)}}{V_s} \qquad \text{(Equation 1)}$$

Data on the water retention curves was collected by collecting 15 undisturbed samples in the field in cylindrical rings (with a height of 5,4 cm and a diameter of 4,9 cm). First the porosity of the soil was determined for one sample (see equation 2). For this one sample of each land use type was soaked in water for 48 hours. This determined the range in water content for the filter paper method. All samples were given a specific water content by adding water to the samples. The filter paper method was executed on the samples as described by Almeida et al. [7]. After 7 days an equilibrium has been set between the soil and the filter paper. By determining the weight of the wet filter paper, the water content of the filter paper was determined. By using equation 3 and 4 for the calibrated Whatman filter paper the suction corresponding with the water content was determined [8]. Both were plotted in a graph.

$$\varphi = \left(1 - \frac{\rho_s}{\rho_p}\right) = \frac{V_p}{V_t} \qquad \text{(Equation 2)}$$

$$For\ wc_{fp} > 45{,}26\% \qquad log_{10}\,Suction = 5{,}327 - 0{,}0779\,(wc_{fp}) \qquad \text{(Equation 3)}$$

$$For\ wc_{fp} \leq 45{,}26\% \qquad log_{10}\,Suction = 2{,}412 - 0{,}0135\,(wc_{fp}) \qquad \text{(Equation 4)}$$

In the field the data on the infiltration rates was gathered by using a double ring infiltrometer. At each land use type at least 6 measurements were done, which should be a sufficient number following to get representative results on the infiltration rates [9]. As the aim was to collect the infiltration rate of the soil, the organic matter at the surface layer was removed before placing the double ring infiltrometer. The decrease in water level was measured at constant time steps. This data was plotted into a graph and the Horton equation (see equation 5) [10] was fitted to the measured data. In equation 5 f_c is the final

constant infiltration capacity at saturation (cm/h), f_0 is the initial infiltration capacity (cm/h), k is soil specific decay constant depending on soil and vegetation (-) and t is the time (h)

$$f_p = f_c + (f_0 - f_c)e^{-kt} \quad \text{(Equation 5)}$$

Finally, the data collected on the soil water characteristics was compared (by an independent sample t-test) and explained by making use of the found features of the different locations. For further detail information about the equations used in this study, we suggest readers to refer the primary references.

3. Results and Discussion

3.1. Features of the land use types

First the features of the research locations were determined. In **Error! Reference source not found.** the locations of the research areas are shown.

shows a picture of land use types to illustrate the differences between the locations. Based on the research there was found that the vegetation density of the forest is the highest followed by the new agroforestry plot. The old agroforestry and monoculture both had a really low vegetation density. This corresponded with the thickness of the organic matter layer which was the largest for the natural forest. The bulk density was investigated in this part and this resulted in an average bulk density of 1,15 g/cm^3 for the natural forest and an average bulk density of around 1,56 g/cm^3 for the other land use types. This difference can be explained by the compaction of plantation plots, while preparing or working on the plots.

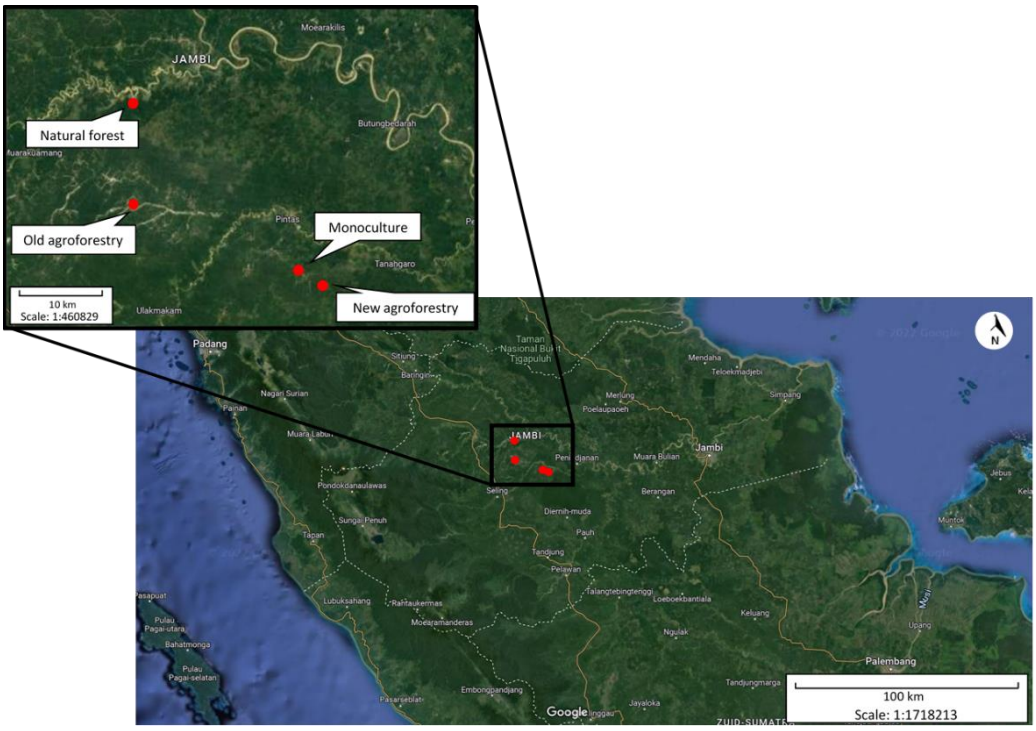

Figure 1. Research locations Sumatra, Indonesia (Source: Google Maps)

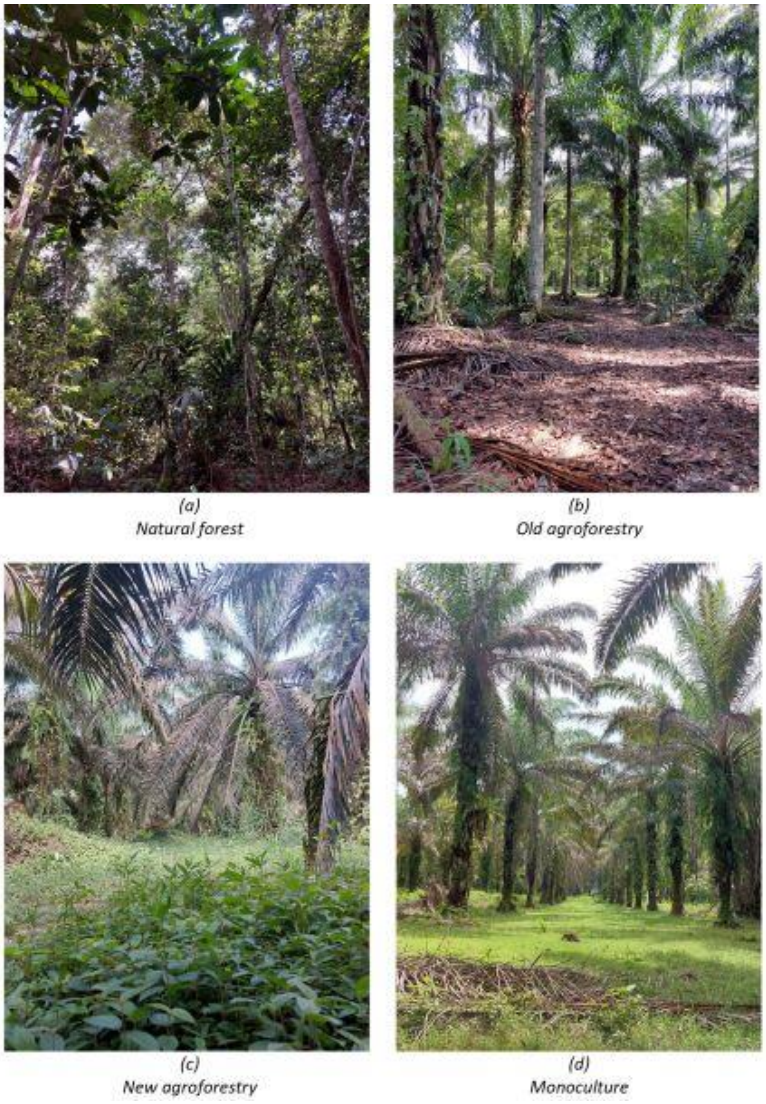

Figure 2. Different land use types of the study area

3.2. Water retention curves

The results from the filter paper method could unfortunately not be used. The results only showed the suction of the filter paper at two suction values (see figure 3), which is not representable for the actual water retention curve. This failure was most likely caused by the use of not certified filter paper, which was not known before using. Due to time limits the method could not be executed again. However, the porosity of the soils can be used. This gave that both agroforestry plots had the lowest porosity (porosity new agroforestry = 0,28, porosity old agroforestry = 0,29). The monoculture plot had a similar porosity of 0,31, while the forest had a way higher porosity of 0,44. This could be partly explained by the bulk density found.

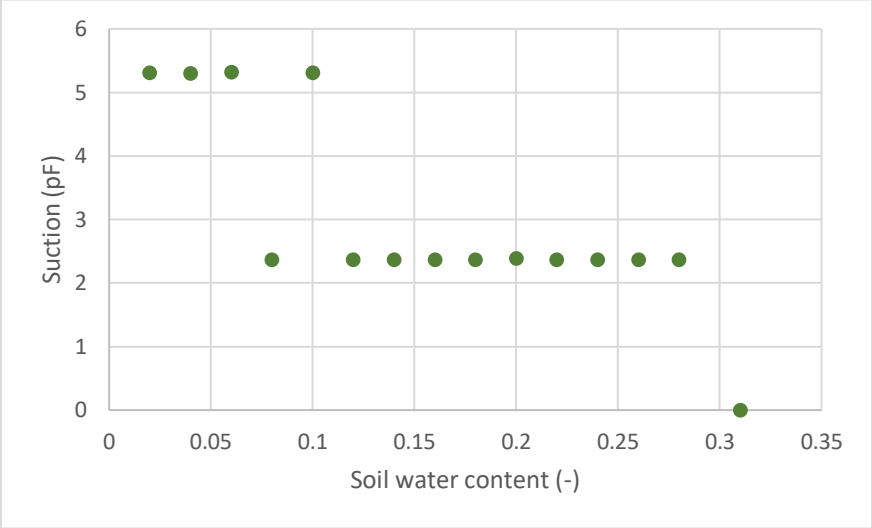

Figure 3. Soil water retention curve of the monoculture plantation

3.3. Infiltration rates

For the results on the infiltration rates, it was found that there was a lot of variability within all land us types, but this variability was hard to explain. The Horton equation fitted to the measurement points gave for most measurement locations a high correlation (0,77 or higher), four measurements had a correlation below this value, but still showed a correlation with a correlation value between 0,65 and 0,70. The range in parameter values from the Horton equation is given in table 1.

Table 1. Infiltration parameters

Land use type	f_0 min – max (cm/h)	f_c min – max (cm/h)	k (t^{-1})
Natural forest	3.27 – 131.90	0.90 – 39.60	0.99 – 19.13
Old agroforestry	0.30 – 4.77	0.06 – 1.50	1.37 – 5.38
New agroforestry	8.87 – 86.28	2.40 – 10.95	0.81 – 1.85
Natural forest	0.16 – 3.02	0.075 – 0.90	1.02 – 2.51

The values for the constant infiltration rate for all land use types are shown in figure 4. it turned out there is a significant difference between the values of the forest and new agroforestry and the values of the old agroforestry and monoculture, despite the big variability. Both the natural forest and new agroforestry has significantly higher constant infiltration rates compared to the other two land use types. The differences between the old agroforestry and monoculture are not significant. This is the same case for the new agroforestry and natural forest which differences in constant infiltration rate are also not significant. The decay factor gained from the Horton equation was also compared between land use types, this is shown in figure 5. For this there was only a significant difference found between the new agroforestry plot and the other three land use types. The decay factor for the agroforestry is lower, which means it takes longer for the soil to reach a constant infiltration rate.

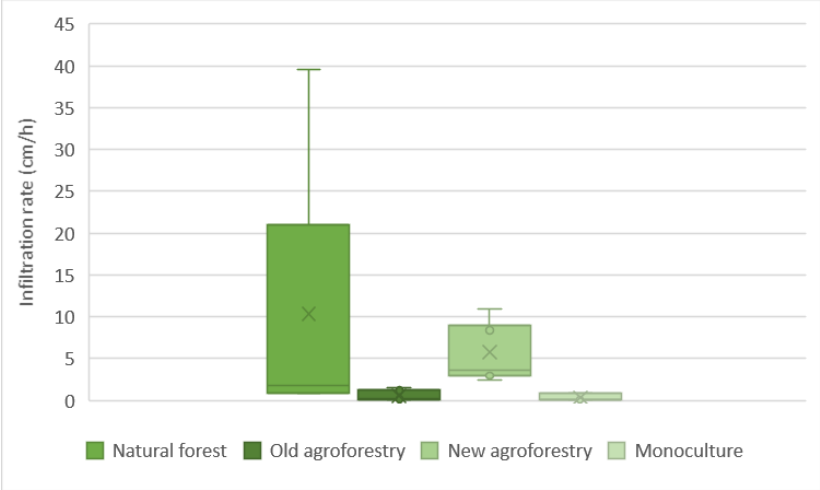

Figure 4. Constant infiltration rate different land use types

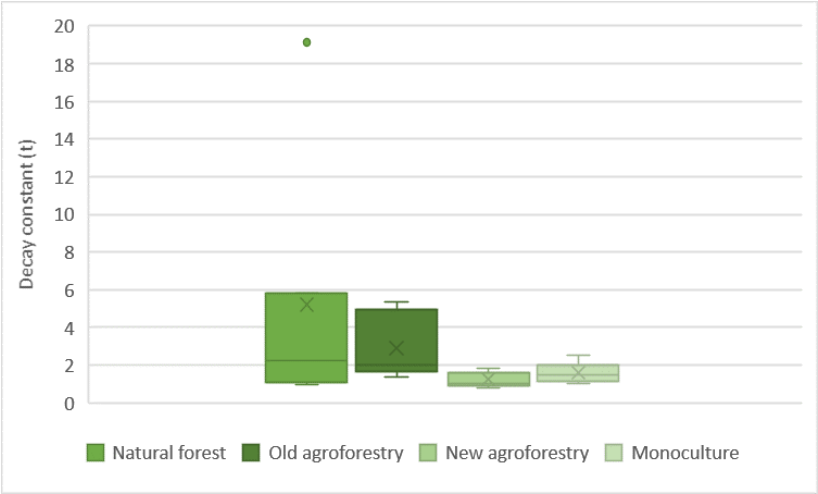

Figure 5. Decay constant Horton different land use types

3.4. Discussion

The methods chosen and choices made during the project could have influenced the outcomes of the research. One of the points up for discussion is the available data. There was almost no data available which made it hard to explain the results and differences between the land use types. Besides, the precision of the double infiltrometer and its set up could have given slight deviations in the actual infiltration rates, due to human factors as well by factors caused by the procedure.

4. Conclusion

Based on the research, generally the conclusion can be made that the natural forest has the most optimal soil water characteristics, namely the highest constant infiltration rate and the highest porosity, followed by agroforestry. Monoculture as a negative effect on the soil water characteristics investigated. This is in line with the research of Suprayogo [11] and Dislich [2]. However, the soil water characteristics are highly dependent on the features of the locations investigated which can indicate that the statement made above is not always the case, this can be seen in this research in the difference between the old agroforestry and new agroforestry. Finally, the results of this study can support the application of the

"Strategi Jangka Benah" project to transform monoculture oil palm into oil palm agroforestry inside the state forest since the oil palm agroforestry has resulted in better soil water characteristics.

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