Lund Institute of Technology

THE INFLUENCE OF LAND-USE CHANGE, ROOT ABUNDANCE AND MACROPORES ON SATURATED INFILTRATION RATE

A FIELD STUDY ON WESTERN JAVA, INDONESIA

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A Minor Field Study supervised by:
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Abstract

The aim of this study was to examine the infiltration rate of water and some parameters affecting it. Especially the land usage, the abundance of roots and macropores were investigated. A field study was carried out on western Java in Indonesia, on the slope of Mount Salak.

The study compared four different land uses; i.e. forest, shrub areas, tree plantation and cropland since there was a high occurrence of these land uses in the area and they seemed suitable for comparison. The infiltration rate was measured with a double ring infiltrometer in 39 sampling points with at least eight locations at each land use. At 16 of these sites a soil pit was also dug, four at each land use. Root samples and soil samples were taken at six depths down to 150 cm. At the locations with soil pits, experiments with blue dye tracer were also conducted and the traces of the blue dye in the soil were photographed. Fine roots were examined both for length and weight of the sample. The soil samples were analysed at a laboratory for initial water content, bulk density, total porosity, pF-values, texture and carbon content. The differences between the four land uses were examined. A comparison in saturated infiltration rate was also conducted between tree based land uses and land uses without trees. The correlations between saturated infiltration rate and parameters such as root weight, root length and amount of macropores were investigated. The photographs of the blue dye were qualitatively evaluated and discussed.

The infiltration rate showed differences when comparing shrub with forest and cropland, with shrub areas significantly lower than the other two. Plantation areas had the highest mean saturated infiltration rate 1260 mm/h. The lowest mean saturated infiltration rate was found in shrub areas where it was 580 mm/h. The comparison tree based land uses with land uses without trees showed a significant difference where the tree based land use had a higher saturated infiltration rate. Generally plantation had the highest root weights and cropland had the lowest, where as for root length cropland had generally quite high values and forest the lowest. For correlations with saturated infiltration rate, the root weight had the best significant R-value (0.66). Macropores showed a slight correlation with saturated infiltration rate. The examination of the blue dye tracer showed that the flow of infiltrating water is clearly preferential but no difference can be seen between the different land uses. There was no clear connection between the depth or spreading of the blue colour and the saturated infiltration rate.

The results of this study showed that saturated infiltration rate is affected by the land usage, especially whether it is tree based land use or land use without trees. The reasons for the differences are not completely clear. There is a connection to the fine root weight and possibly to the amount of macropores. The infiltrating water was clearly preferential as it was following root paths and macropores. These results together show the importance of keeping land covered with vegetation, preferably with trees, in order to maintain the lands capacity to handle heavy rainfall.

Keywords: saturated infiltration rate, land use change, double ring infiltrometer, roots, blue dye tracer, soil properties, Indonesia, west Java

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1 Introduction

Changes in infiltration rate due to human activity are of interest in many places of the world when lower infiltration capacity can result in more frequent overland flow. Overland flow can cause problems with more erosion and an increased surface runoff. A faster runoff can give more frequent floods.[1] Erosion can lead to for example soil degradation, in terms of nutrient content, and high amounts of sediment transported downstream, resulting in poorer water quality in the recipient[2]. There are several factors that determine the infiltration rate. One is land use practice, which can either enhance or slow down infiltration rate depending on whether the land use practice creates soil compaction or not[3]. Porous zones created by decayed roots and also living roots have been found to affect steady state infiltration[4]. Further, coarse soils, well-vegetated land, low soil moisture, and burrowing insects and animals in topsoil layers are said to be elements that increase infiltration rate[5].

Java, Indonesia, is a part of the world where the population density is very high and the pressure to intensify land-use is increasing. The landscape is of great importance to man, but its biophysical properties are sensitive to change. There is a need to find a sustainable use of the land, a balance that will be of benefit for the ecosystem and local livelihoods. Indonesia has had great problems with floods, in year 2002 over 5000 people were injured or affected and over 100 000 displaced by this type of natural disaster[6]. Western Java and especially the Jakarta region have severe problems of this kind almost every rainy season. Jakarta was for example in early 2002 struck by a flood, which flooded more than 20% of the city[7]. It was reported to be the worst flood in Jakarta for decades.

The purpose of this study was to examine infiltration rate of water, and to investigate what factors are affecting this process. The key factor that was focused on was land usage, how different ways of using the soil can affect infiltration rate. Other factors that were investigated were the role of roots and macropores when addressing infiltration rate and also the pathway for water entering the soil. Closely connected to this is also the role of trees for infiltration, which was also examined. A field study was carried out on western Java, Indonesia. Infiltration rate was measured in field experiments and several soil properties were measured in order to try to find connections.

This study was carried out as a Minor Field Study, financed by the Swedish Agency for International Development Cooperation, SIDA. The work was done under supervision from Department of Water Resources Engineering at Lund Institute of Technology, Sweden. The idea for the project was proposed by Center Of International Forestry Research (CIFOR) in Bogor, Indonesia. This is a research institution working to conserve forest and improve the means of living for people in the tropics[8]. The project was done with supervision and help from one of their three research programs, namely Environmental Services and Sustainable Use of Forests Programs. The study is a part of an ongoing project called Ecosystem Functions and Services in Forested Catchments where the goal is to "*sustain and enhance*

[1] Ward and Robinson, 2000
[2] Roose, 1996
[3] Fetter, 2001
[4] Noguchi et al, 1997
[5] Fetter, 2001
[6] Asian Disaster Relief Centre, n.d.
[7] International Federation of Red Cross and Red Crescent Societies, 2002
[8] Centre for International Forestry Research, 2003

forest ecosystem and catchment functions to increase their resilience and their ability to provide environmental services and products"[9]. Other partners involved were students and staff from the Bogor Agricultural University (IPB) and students from the Swedish Agricultural University (SLU).

1.1 Hypotheses

To find out what factors could influence the saturated infiltration rate at the selected site on Java and to see if different land usage would influence biophysical properties the following hypothesises were created and tested:

- Saturated infiltration rate is significantly affected by land use (given similar climate, topography and soil).
- Saturated infiltration rate under tree based land use and natural forests are higher than for land without trees (given similar climate, topography and soil).
- Root abundance is significantly different between land uses (given similar climate, topography and soil).
- Saturated infiltration rate increases with an increase in root weight and root length in the soil.
- The presence of nearby situated trees affects the saturated infiltration rate.
- The more macropores in the soil the higher the saturated infiltration rate.
- The abundance of roots and macropores in soil will affect the pathway for soil water infiltration.

2 Site description

2.1 Location

The location for the fieldwork was set to be south of Bogor, in the Cibojong microcatchment (outlined in red in the northwest corner on the map in Figure 2) situated within the Cicatih watershed in western Java. The study area ranged in altitude from 813 to 1525 meter above sea level (masl) and covered an area of approximately 406 hectares. This area was chosen for several reasons. It contained several different land uses that were of interest. It was relatively easy to access by car. The surrounding areas are highly populated and the pressure on the land was intense, making it an interesting area to study. It was also an area well known for producing bottled drinking water. The forests and plantations in the area were owned by Perhutani. This is a state owned enterprise, which possesses forest and nature reserves, totally covering 19% of the land on Java[10]. CIFOR and IPB had at an earlier stage conducted a meeting with stakeholders to insure that it would be possible to conduct fieldwork on the land. Also other related projects had and was being done at the time by IPB students in collaboration with CIFOR in nearby areas, making it a well-known area to CIFOR personnel.

[9] pers.comm. Ulrik Ilstedt 2005-11-07
[10] Whitten et al., 2000

2.2 Climate

The area is situated on the slopes of Mount Salak (2210 m), which is an active volcano. In this part of Java, up in the highlands, the average rainfall is about 5000 mm per year[11]. The climate at the time was hot and humid with mean temperatures ranging between 15 and 22 °C according to nearby Pakuwon weather station. During the time when the fieldwork was conducted, July-August 2005, it was dry season in the region; meaning rain was still falling but not as often at during the rainy season.

2.3 Soil type

Within the Cibojong microcatchment there were four different soil types as can be seen in Figure 2. To rule out soil type as a factor affecting the infiltration rate it was decided to limit the study area further so that it would only contain one soil type. The final area chosen can be seen in Figure 3, shown as the darker brown area. The soil type here is Brown Yellow Latosol. A Latosol is a soil that is rich in iron, alumina, or silica and formed in tropical woodlands under very humid climate with relatively high temperature[12]. The soil is of volcanic origin and could therefore have non-massive particles meaning that internal porosity could occur in the soil particles[13].

2.4 Land uses

Within the selected area the following land-uses could be found; forest, shrub, plantation, cropland, rice-fields, garden, grass and settlement. Our field study focused on four of these land uses namely forest, shrub, plantation and cropland. These were chosen because they covered a majority of the study area and seemed to be suitable contrasting areas to compare with each other. A more detailed description of each specific study site is provided in Appendix A.

2.4.1 Forest

The forest areas were found mostly in the northern parts of our study area. Generally they were quite dense in terms of vegetation with a high diversity of trees, bushes and lianas (Figure 1). Some areas were very steep and not always accessible. At a first glance the forest seemed quite untouched and quiet but as work preceded it became clear that regular human activity occurred in the areas. A widespread network of narrow trails existed, where small-scale loggers transported logs and other forest products down to the villages.

Figure 1. Forest area.

[11] Whitten et al., 2000
[12] Soil Science Society of America, 1997
[13] pers.comm. Conny Svensson 2005-12-01

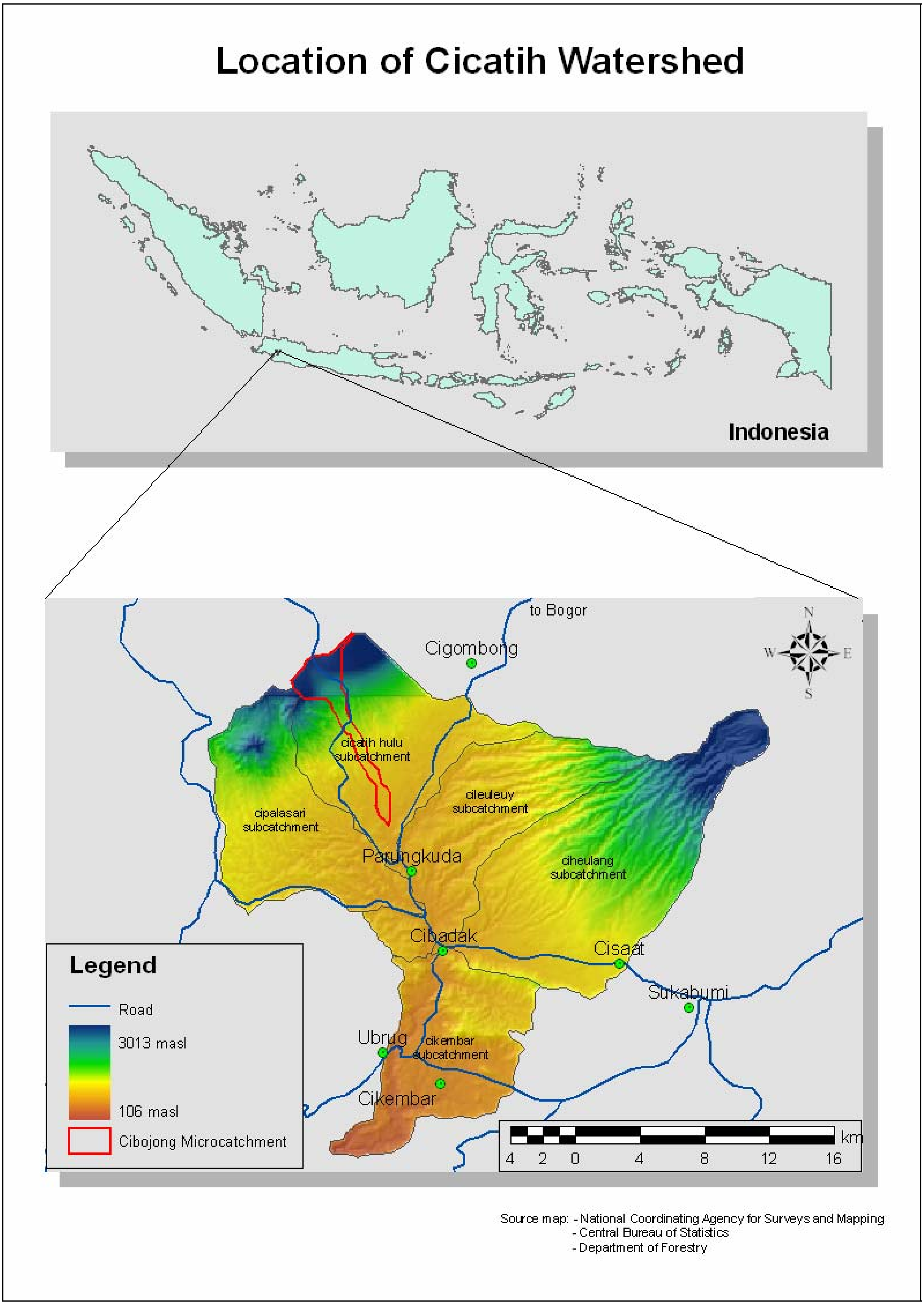

Figure 2. Location map of the Cicatih Watershed

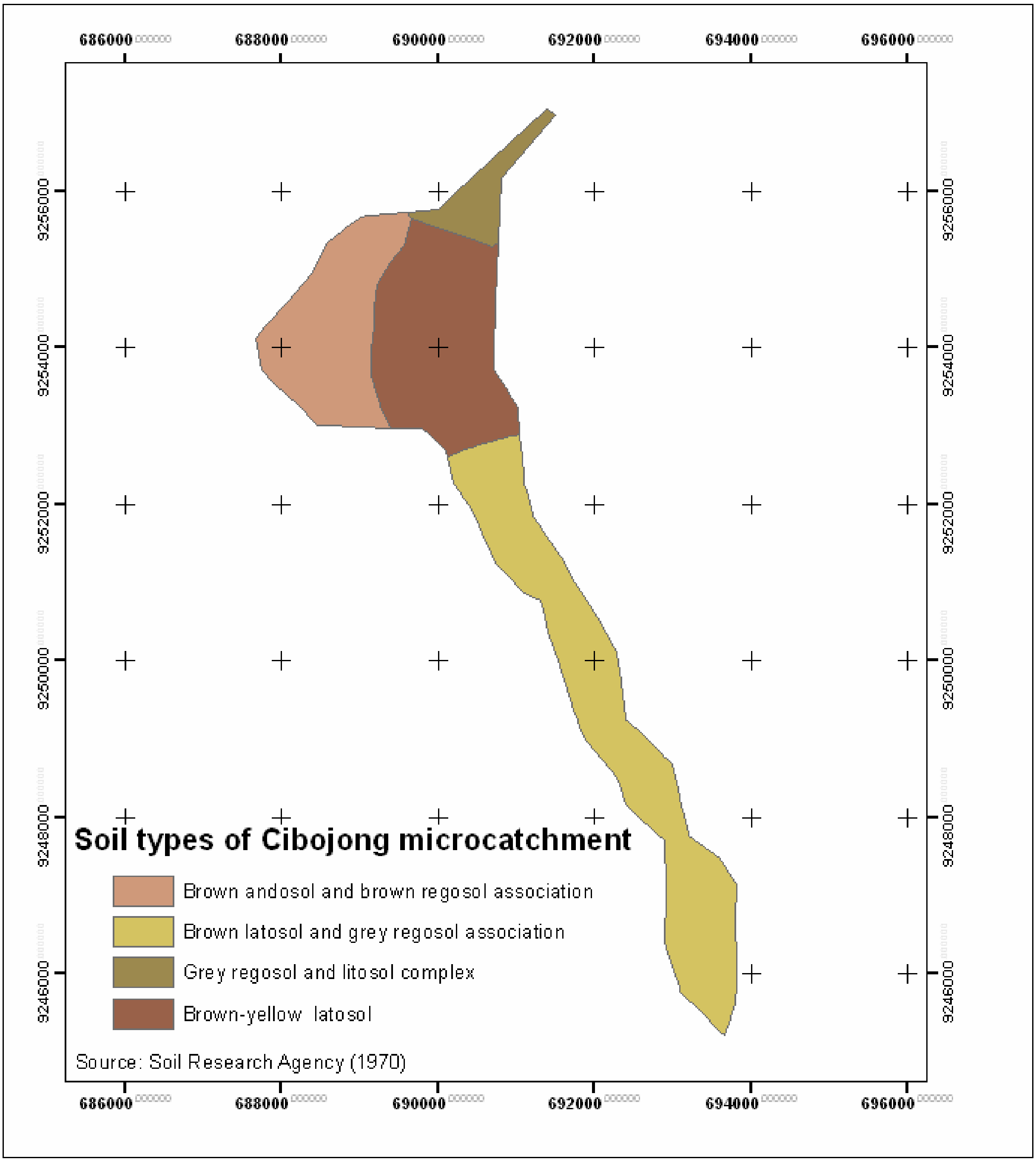

Figure 3. Soil type map of Cibojong microcatchment.

2.4.2 Shrub

The shrub areas consisted of less large vegetation. There were generally no or very few trees. Most of the areas were covered with grass and lower bushes, sometimes very dense and hard to access (Figure 4). Plants in these areas were sometimes harvested by local people indicating human activity.

Figure 4. Shrub area.

2.4.3 Plantation

The tree plantation areas that were examined contained to a greater part the tree *Agathis* (Figure 5). This tree is grown for its timber. In all places there were grass and bushes growing close to the ground. Trails were quite common in these areas. The plantations varied in age from approximately three to thirty years old according to local people.

Figure 5. Plantation area.

2.4.4 Cropland

The different cropland areas were not as homogenous as the areas described above. They varied in type of crop grown and design of the fields. Some were plain flat fields and some consisted of smaller elevated plots where the crops were planted. On steep places fields were shaped as terraces. Examples of crops that were grown are corn, onions, asparagus, cassava, banana, taro, tea bushes, jackfruit, and chilli. An example of cropland is shown in Figure 6. It was quite common to mix different crops in the same field. Agriculture was small scale, mostly run without machines. Water buffalos were used to plough fields in some cases but most work seemed to be done by hand. In some cases fields were not in use at the time of examination, meaning that nothing was currently cultivated in the soil. Some type of vegetation usually grew anyway, such as grass and weeds.

Figure 6. Cropland area.

3 Methodology

3.1 General outline for field study

In this experiment four different land uses were examined in the chosen area of study. They were forest (1), shrub areas (2), tree plantation (3) and cropland (4). Forest and plantation sites were further classified as tree-based land uses, whereas shrub and cropland sites were classified as land uses with no trees. For each land use at least 8 sample points were randomly chosen with the help of a grid-lined map (Appendix B) and local guides. Totally 39 sample points were examined in the study. The intention was to spread out the sampling points on all 600×600 m^2 squares on the map, but practical reasons made it not feasible to reach some of the areas. It was impossible to follow the map alone since some areas were not reachable due to very dense vegetation and/or steep slopes. In other cases some locations could not be examined because there was no water source close enough, which was needed for infiltration measurements. In the land uses with smaller areas, i.e. cropland and shrub, it occurred that sampling points got quite close to each other, due to lack of suitable sampling areas. At all sample points the saturated infiltration rate was measured using the double ring infiltrometer method. This method is described more in detail in section 3.2. At 16 of the sampling points water coloured with Brilliant Blue dye (5 g/l) was applied to the soil surface. A pit was then dug and the dye pattern was photographed. This is further discussed in section 3.3. The soil pits were dug 1.5 metres deep. Soil samples and root samples were taken at six different depths as will be further described below in separate sections.

At all sites photos were taken to clearly describe the surroundings. Presence of nearby trees was measured in two ways. First, the number of trees within a radius of 10 meters was counted, second the distance to the nearest tree was measured. Altitude, coordinates, litter, undergrowth and distance to water were also recorded for the sample point.

3.2 Infiltration rate

When rainfall reaches land surface it can enter into the soil through the soil surface. This is known as *infiltration.* The maximum rate at which water can enter through soil is known as *infiltration capacity.* This parameter is affected by many factors such as soil type and moisture content. At first when water enters soil there are capillary forces dragging the water downwards and the infiltration capacity is at its highest (f_0). With time soil moisture content increases and small soil particles swell. This causes the infiltration capacity to decrease until reaching a steady state, the saturated infiltration rate (f_c). If the rate of rainfall is higher than infiltration capacity, then some precipitation will remain on surface ground and not infiltrate. This can lead to overland flow, sometimes termed Horton overland flow. [14]


Figure 7. Double ring infiltrometer setup

In this study saturated infiltration rate was measured on site with the double ring infiltrometer method[15]. The materials used were two regular rice cookers with different diameters where the bottoms had been cut off (Figure 7). The inner ring diameter was 30 cm. Two sizes of outer rings were used with diameter 40 cm and 45 cm. The infiltrometer rings were pushed into the soil to appropriate depth (depth where leakage did not occur). The outer ring was filled with water and a relatively constant water level was held, in order to create a "buffer" outside the smaller ring and thereby stopping water to spread horizontally. In the inner ring water was added continuously and with the help of a ruler attached to the inner ring and a stopwatch the infiltration time was measured. The time for the water level to sink between an upper and a lower mark on the ruler was measured. The distance between the marks was usually 2 cm but at locations with slow infiltration a shorter distance was sometimes used. The stopwatch was running continuously and the times were recorded when the water level was at the upper respectively lower mark. This procedure was followed in order to get time series of the infiltration. The measuring went on until a steady state was noticed or until maximum two hours had passed. To avoid erosion of the soil inside the rings when water was poured in, a banana leaf or a piece of cloth was put on the soil surface. In certain areas the ground was too steep to allow a proper measurement. In these cases soil was dug out creating a small terrace on the slope where the infiltration rings were pushed down.

3.3 Blue dye tracer

To find out if roots and macropores play a role in determining the pathway for soil water blue-dyed water was added to the soil. After the infiltration measurement was done and the last water had gone into the soil, 3.5 litres of coloured water with the concentration of 5 g/l Brilliant Blue was added into the inner ring. This volume of water resembled a rainfall of approximately of 50 mm. The volume was chosen after reviewing and comparing with appropriate literature[16,17,18]. About one hour after the blue colour had infiltrated, the rings were removed and cross sections of the soil were dug out and photographed. The photos were taken at a distance of 70 cm at all times. For each land use four replicas were made (total 16

[14] Fetter, 2001
[15] Bouwer, 1986
[16] Noguchi et al, 1997
[17] van Noordwijk et al, 1991
[18] Booltink, 1991

analysed sites). Maximum depth was recorded. A qualitative analysis was made by looking at, and comparing photos of different land uses. Maximum coloured depth was compared to the infiltration rate. Possible differences in maximum coloured depth between land uses were statistically tested with Student's t-test (one variable, $\alpha = 0.05$).

3.4 Root analysis

Figure 8. The soil rings

The abundance of fine roots, roots with a diameter < 2 mm including visible root hairs, was measured as both root weight and root length. Soil pits were dug down to 1.5 metres depth. Root samples were taken with metal soil rings that were 4 cm high and 7.6 cm in diameter (Figure 8). Samples were taken by pushing down the soil rings in just uncovered soil at depths 0-10 cm, 10-20 cm, 20-30 cm, 50-55 cm 90-95 cm and at 150 cm and collected in plastic bags. Later the roots were separated from the soil by washing with water in fine sieves, the roots were first dried in the sun and later in an oven between 5-18 hours at temperature 105°C. Directly after drying the roots were weighed. The total length of the roots for each sample was also measured, using millimetre paper. Some samples contained a lot of fine roots and in these cases only a fraction of the roots were measured to save time. The measured fractions were then re-weighed again. At the cross section presence of bigger root endings sticking out of the soil were counted down to depth 150 cm.

3.5 Physical properties of the soil

To investigate a possible correlation between saturated infiltration rate and macropores soil samples were collected and analysed in a laboratory. The samples were collected at the same depth and with the same kind of rings as mentioned above for the root analysis. The soil in the sample should be undisturbed soil therefore the samples were taken with fresh, just uncovered soil. The soil rings were sent to the laboratory Balai Penelitian Tanah in Bogor, Indonesia, for analysis within a week of soil sampling. Up to this time the soil rings were stored in sealed plastic bags. Other soil parameters were also analysed to get a clearer picture of the soil condition and to see if other factors than macropores might affect the infiltration rate. The samples were analysed for water content, bulk density, total porosity, pF-values (pF 1, pF 2, pF 2.54 and pF 4.2), available water, organic matter and texture. The pF-values describe the soil's capacity to retain water at different pressure heads. The methods used in the lab can be seen in Table 1. Amount of macropores were calculated by taking the total porosity minus the pF 1-values, which is said to resemble pores with a size > 0.3 mm in diameter[19]. The amount of pores smaller than 0.03 mm in diameter was calculated by taking pF 2 minus pF 2.54 values. Field capacity was investigated. It is defined as the water content in a soil that initially is saturated with water, but has been naturally drained, for example due to a lowering of the groundwater level. Further it is the highest water content a soil can hold against gravity. In order to calculate field capacity it is also defined as the soil's water content at pF 2, which resembles a vacuum equal to a water column of 100 cm height.[20]

[19] Grip, et al, 1994
[20] Grip et al., 1994

Table 1. Analysed parameters and the used methods.

Analysis	Method	Parameters obtained
Water content	Brabender or Archimedes	Water content Bulk density Total Porosity
Water Retention	Water Retention [21,22]	pF-curves Pore size distribution Available water capacity
Texture	Hydrometer[23]	Texture, 3 fractions USDA standard
C-Organic	Colorimetric[24]	Organic carbon

3.6 Data analysis

The infiltration data was fitted to the Horton equation (Equation 1), an empirical relationship between time and infiltration rate[25]:

$$f_p = f_c + (f_0 - f_c)\, e^{-kt} \qquad \text{(Equation 1)}$$

where

f_P = infiltration capacity at time t (L/T)
f_c = equilibrium infiltration capacity (L/T)
f_0 = initial infiltration capacity (L/T)
k = constant showing rate of decreased infiltration capacity (1/T)
t = time since start of infiltration (T)

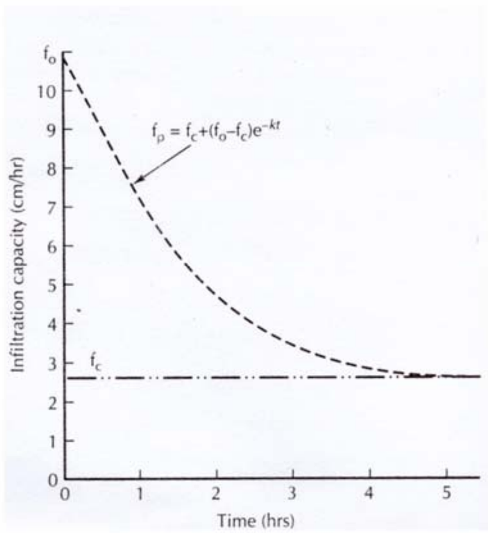

Figure 9. Infiltration capacity curve according to Horton (Fetter, 2001)

[21] Richards and Fireman, 1943
[22] Richards, 1947
[23] Boyoucus, 1962
[24] Graham, 1948
[25] Fetter, 2001

The infiltration capacity curve is illustrated above in Figure 9. There are other infiltration models that can be used to help predict infiltration, however the Horton model has shown to be appropriate in this case[26]. The fitting of the measured data was done in order to validate that the measured data seemed reasonable. From the fitting, initial infiltration (f_0) and k were derived. An optimisation of the model parameters was made in the computer program Microsoft Excel and the function *equation solver* was used. The best match was found by minimizing the root mean square error, RMSE, which is the root value of the mean square error or differences between the model and the measured values. The conditions used were that the calculated initial infiltration had to be higher than all the measured values and that the saturated infiltration of the model was the mean value of the last measurements. With the help of f_0, f_c, and k it was possible to plot general infiltration capacity curves for each land use to get an overview of how they differed.

To clarify differences between the land-uses the data was grouped according to land-use and compared two and two with the statistical method Student's t-test in Microsoft Excel (one-sided, $\alpha = 0.05$), to get statistically significant differences. The Student's t-test is used when testing if the means of two samples are statistically different from each other. When using Microsoft Excel a probability value (P-value) is presented that describes the probability that the two samples are derived from the same population. A P-value below 0.05 means that with a 95% significance the two samples are different from each other. One requirement for using this statistical method is that the values have to follow a normal distribution.

To examine the occurrence of possible relationships the software MATLAB was used to see how the different parameters were correlated with saturated infiltration rate. The function *corrcoef* was used, which gave all the correlation coefficients between the parameters. The coefficient is the R-value obtained when examining the relationship between two parameters. In this study values from a total of 15 measuring points were used to correlate infiltration. Originally 16 soil pits were dug where both infiltration measurements were done and soil samples taken, but one site was excluded due to divergent values (caused by an underlying rock in the soil). R-values were tested for significance in order to verify that correlations were not a coincidence. With the 13 degrees of freedom (n-2) R-values should exceed a value of 0.441 for 10% significance, 0.514 for 5% significance and 0.641 for 1% significance[27,28]. The best correlations were then analysed to see whether there was a combined relationship correlated to saturated infiltration rate. The results are presented as an equation that combines the factors that together can explain variations in saturated infiltration rate. In theory this equation should be able to provide a value of the saturated infiltration rate when contributing factors are known.

[26] Shukla et al 2003
[27] Crow et al., 1960
[28] Neag School of Education - University of Connecticut, n.d.

4 Results

4.1 Saturated infiltration rate for different land uses

4.1.1 Validation of measured infiltration data

The measured values for infiltration rates seemed to follow a normal distribution. There were some outlying values but this type of distribution fitted the best (Appendix C). There was generally fairly good matches between the infiltration measurements and the infiltration rates with the Horton equation, an example is shown in Figure 10. This shows that the measured data seems to be in accordance with the theory. The results of the analysis, initial infiltration, saturated infiltration and K-values for all sites can be found in Appendix D.

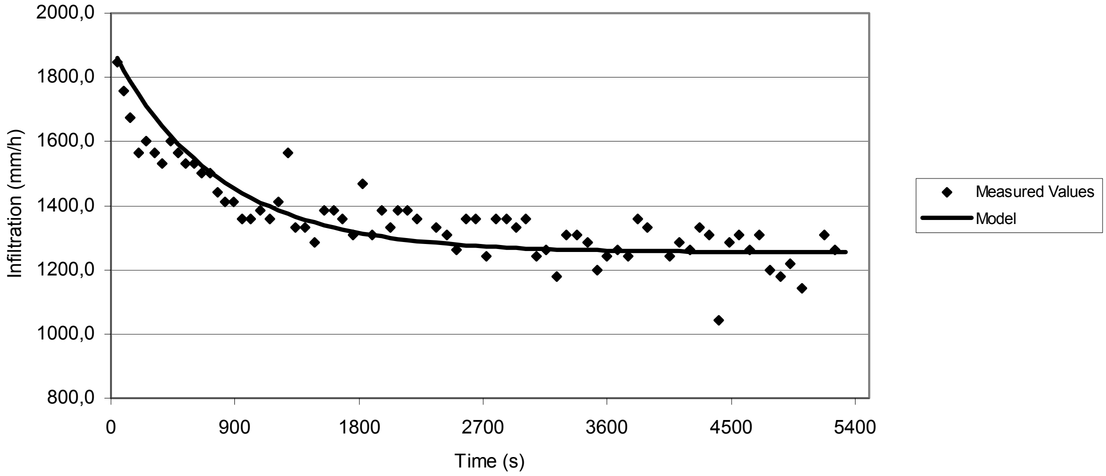

Figure 10. Infiltration as a function of time for soil pit 1K, an example showing how the Horton equation was adapted to measurements. f_0 =1894 mm/h f_c = 1254.4 mm/h k = 0.001308 s^{-1} RMSE = 99.3 mm/h and R^2 = 0.62

4.1.2 Infiltration data

The results generally showed very high infiltration rates with strong variations. The highest mean saturated infiltration rate was 1261 mm/h, found in plantation areas (Table 2). The lowest mean saturated infiltration rate was found in shrub areas, where it was 579 mm/h. In terms of individual measurements the highest was 3165 mm/h, found in forest and the lowest was 75 mm/h, found in cropland. Three values of saturated infiltration rate were removed, they seemed to be outlaying values. These values were taken in forest and in cropland. In two cases a big rock was found under the measure spot and in the third case water was leaking out horizontally.

Table 2. Measured saturated infiltration rates (mm/h), mean values (mm/h), standard deviation (mm/h) and 95% confidence interval for different land uses

Land use	Forest	Shrub	Plantation	Cropland
	489	457	1300	277
	1564	1130	717	920
	3059	230	700	594
	608	1241	2531	75
	588	274	1727	561
	826	618	1910	96
	3165	895	791	2167
	273	290	415	474
	1015	77		
	1254			
	249			
Mean inf. =	1190	579	1261	652
95% c.i.	± 609	± 274	± 511	± 468
Std dev	1030	420	737	675

When comparing land uses there was a significant difference in mean infiltration rate between forest and shrub (P = 0.047) confirming that infiltration rate in forest areas was higher than in shrub areas (Table 3). Plantation also had significantly higher mean values than shrub (P = 0.021). This shows that infiltration rate was significantly affected by land use when comparing forest with shrub and shrub with plantation. A diagram plotting time against mean infiltration rate where the curves were done using the different mean values for initial and saturated infiltration rate and K-value is shown in Figure 11. This was done using the Horton model to give a clearer picture of the differences in mean infiltration rate between land uses.

Table 3. P-values for comparisons of infiltration rate between different land-uses

Comparison	P-value
Plantation-Shrub	0,021
Forest-Shrub	0,047
Plantation-Cropland	0,053
Forest-Cropland	0,093
Cropland-Shrub	0,398
Plantation-Forest	0,431

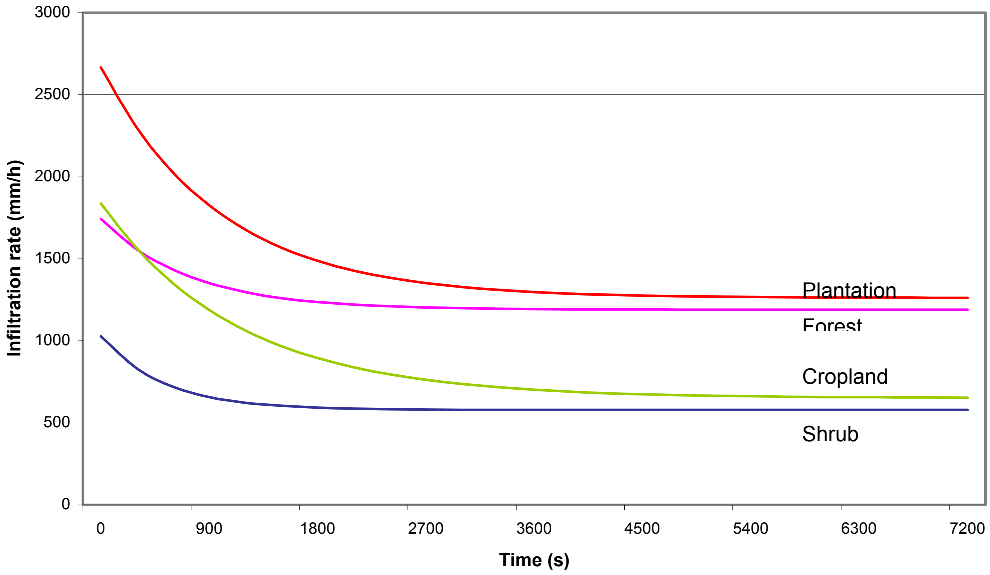

Figure 11. Infiltration rate plotted against time using mean values for initial and saturated infiltration rate and K-value showing the difference in infiltration for the four different land uses.

4.2 Saturated infiltration rate for tree-based land use and land without trees

The mean value for saturated infiltration rate in tree-based land was 1220 mm/h and for land without trees the mean was 613 mm/h (Table 4). A significant difference in saturated infiltration rate was found between the two areas (P = 0.0092) clearly showing that the saturated infiltration rate in tree-based land was higher than in land with no trees.

Table 4. Mean saturated infiltration rate (mm/h) for two land types (“trees” and “no trees”), standard deviation, 95% confidence interval and P-value from TTEST.

Land use	Trees	No trees
Mean inf. rate	1220	613
Std dev	896	537
95% c.i.	± 403	± 255
P-value	0.0092	

4.3 Root abundance for different land uses

Fine root abundance was measured both as root weight and root length. These two units gave quite different results as can be seen in Figure 12 and 13. The results are separately described below. Amount of larger root endings was correlated with saturated infiltration rate. The R-value was 0.024 and therefore no correlation could be pointed out.

4.3.1 Fine root weight

For the topsoil (0-30 cm) plantation was the land use with the highest mean root weight (Figure 12). At the same depths cropland showed the lowest mean root weights. The overall highest mean weight was 2.7 kg/m^3, found in plantation depth 0-10 cm (Appendix E). The overall lowest mean root weight was 0.06 kg/m^3, found in shrub depth 150 cm. For depths 10-20 cm and 20-30 cm shrub was significantly higher in fine root weight than cropland (P = 0.003) and (P = 0.029). At depth 10-20 cm plantation was also significantly higher in root weight compared to cropland (P = 0.041). It is worth noting that at a depth of 150 cm fine roots can be found. At this depth the total mean weight varied between 0.06 and 0.29 kg/m^3 (Appendix E).

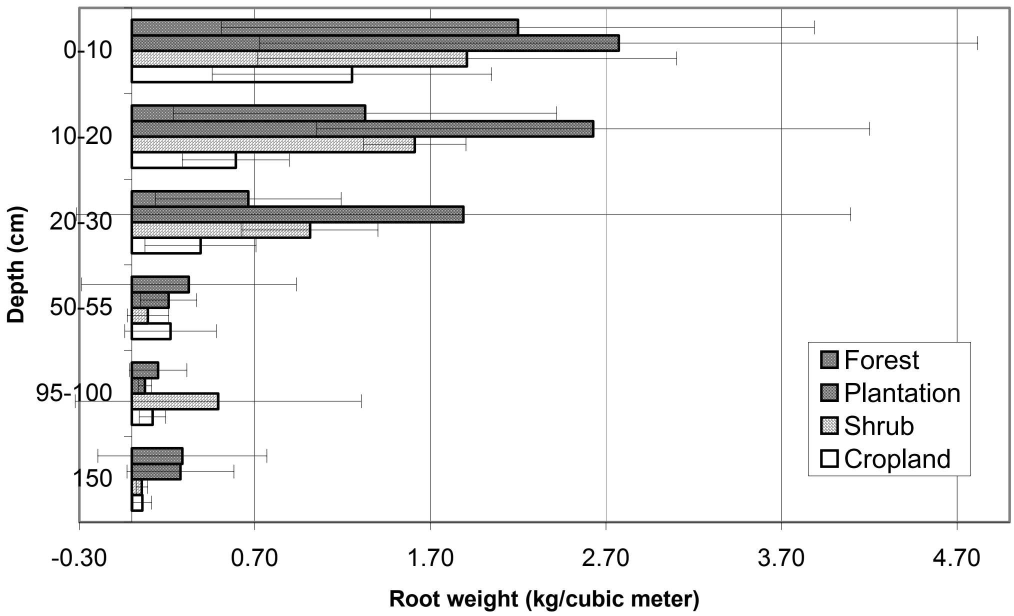

Figure 12. Fine root weight (kg/m^3) at different soil depths of four land uses; forest, plantation, shrub, and cropland (bars indicate 95% confidence interval).

4.3.2 Root length

There was a great variation in fine root length for all land uses. However when looking at mean values at different soil depths forest was the land use that contained the shortest lengths (Figure 13). The highest mean value for root length was 76000 m/m^3 found in cropland depth 0-10 cm. As could be expected the fine root length decreases with depth. No significant differences in root length were found at any depths when comparing land uses with each other.

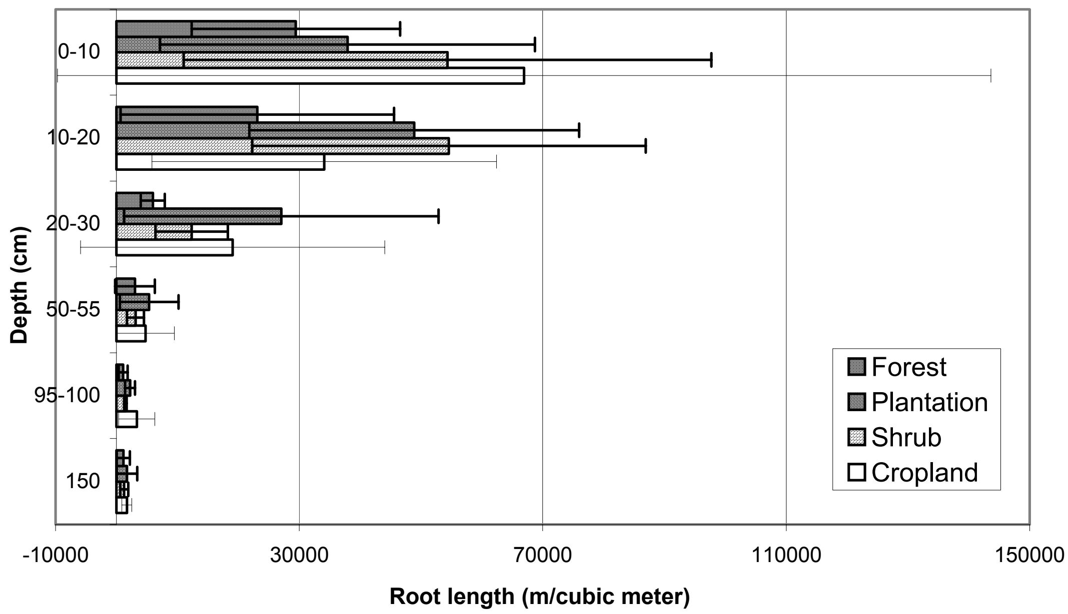

Figure 13. Fine root length (m/m^3) at different soil depths of four land uses; forest, plantation, shrub, and cropland (bars indicate 95% confidence interval)

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4.4 Correlating saturated infiltration rate with fine root weight

The data for the root weight was correlated with the infiltration data and the depths above 30 cm can be seen in Figure 14. A positive correlation was found for these depths indicated by the regression lines in Figure 14. The R-value at depth 10-20 cm was 0.67 and significant (1%). The R-value at depth 20-30 cm was 0.54 and significant (5%). The R-value 0.67 was the highest correlation values obtained among all the gathered data, indicating that the root weight was the best correlated parameter with the infiltration rate. The linear regressions all have a similar slope. For the lower depths the correlation values were lower and therefore less interesting. This correlation shows that saturated infiltration rate increases with an increase in fine root weight.

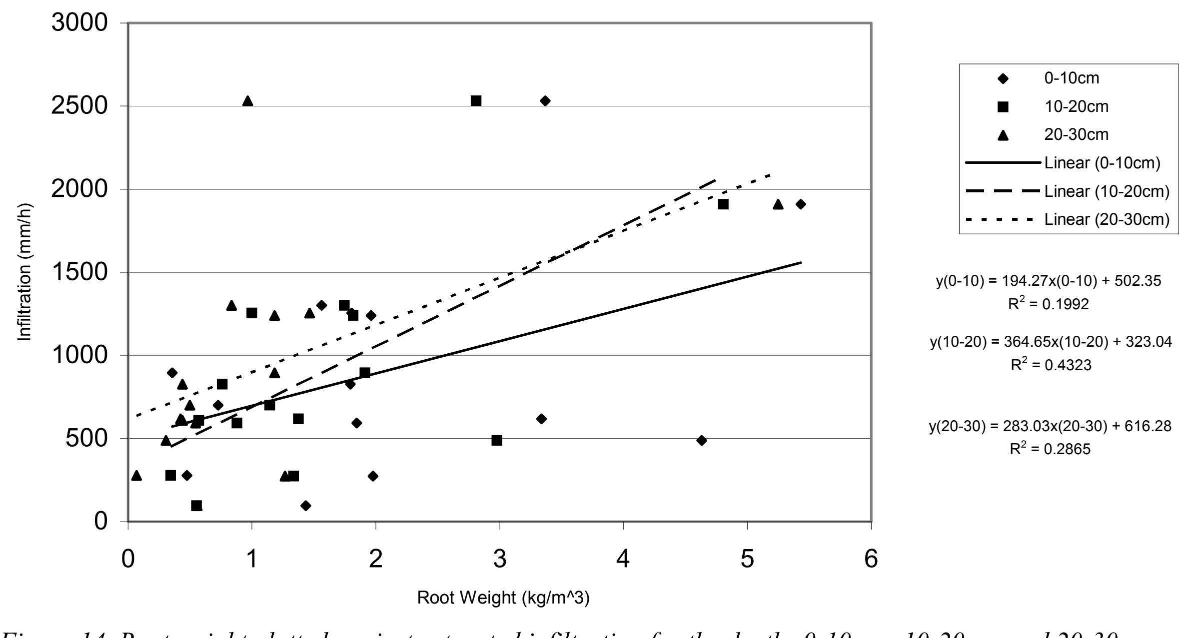

Figure 14. Root weight plotted against saturated infiltration for the depths 0-10 cm, 10-20 cm and 20-30 cm

4.5 Correlating saturated infiltration rate with fine root length

In Figure 15 a plot of root length and saturated infiltration rate for the depth down to 30 cm is shown. It is obvious that the root length for the uppermost layer (0-10 cm) was not very well correlated with the infiltration measurement, since it was the only negative relationship. The depths 10-20 cm, 20-30 cm and also 50-55 cm were better correlated with a positive slope and higher R-values. Figure 16 shows the plot for 50-55 cm. Comparing Figure 15 and 16, it seems like the slopes were getting steeper with the depth.

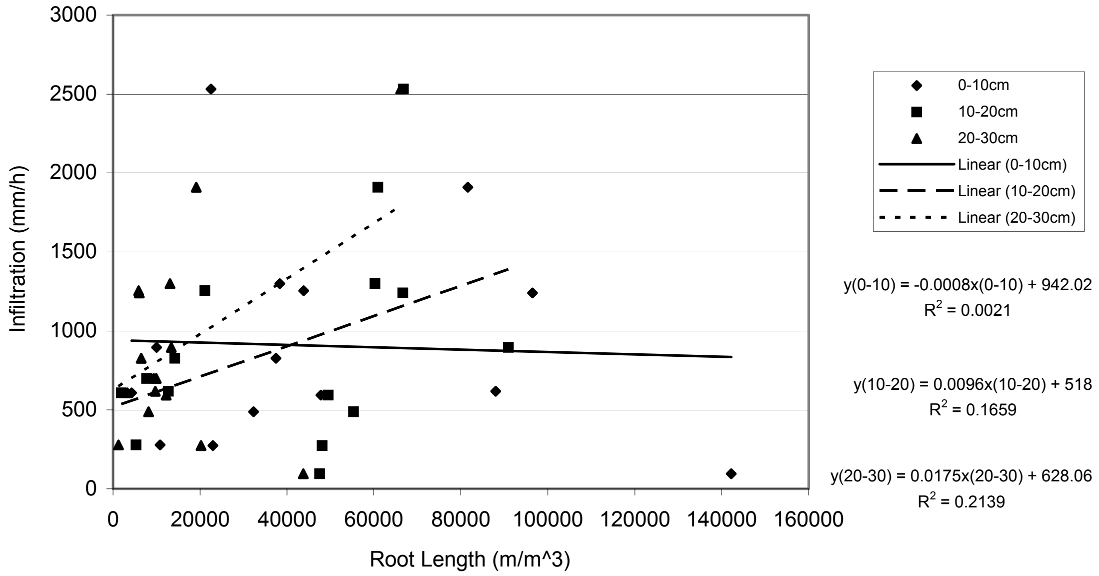

Figure 15. The root length against saturated infiltration for the depth 0-10 cm, 10-20 cm and 20-30 cm.

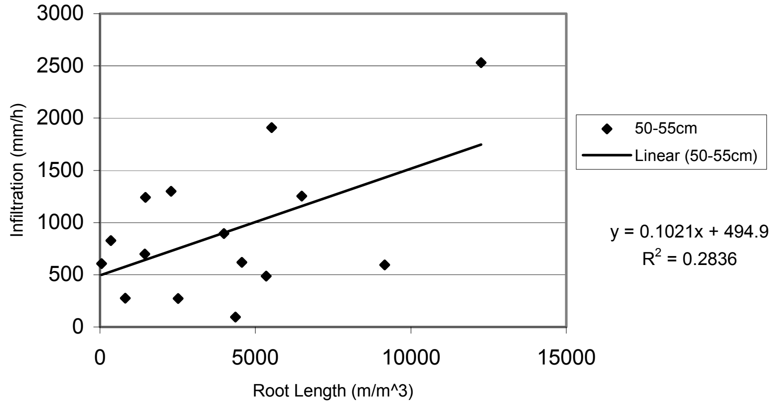

Figure 16. The root length against saturated infiltration for the depth 50-55 cm.

4.6 Connection between presence of nearby trees and saturated infiltration rate

No relationships could be found when correlating saturated infiltration rate with the tree data (distance to nearest tree, number of trees within a radius of 10 meters, perimeter of nearest tree). The best R-value found was -0.27 and that was for the relationship between the distance to the nearest tree and the saturated infiltration rate (Appendix F). For the number of trees within the 10 m radius-circle around the infiltration spot, there was a slightly negative relationship and the R-value was -0.044.

4.7 Correlation between macropores and saturated infiltration

Table 5 shows the correlation coefficients for saturated infiltration rate and the amount of macropores. The correlations coefficients are shown in Figure 17; the highest value was 0.37, which is not significant.

The Student's t-test showed that shrub and plantation generally had higher mean values for amount of macropores, around 35%, than forest and cropland, which was around 23% (Appendix E). There was no significant difference between shrub and plantation areas at any depth. Between forest and cropland there was no significant difference at any depths either. Comparing the higher values from either shrub or plantation with the lower values from either forest or cropland a significant difference does occur at some depths and doesn't at some.

Table 5. Correlation coefficients for saturated infiltration, F_c with pore size.

Depth	0-10 cm	10-20 cm	20-30 cm	50-55 cm	95-100 cm	150 cm
Pore>0.3	0.15	0.37	0.33	0.14	0.049	-0.26

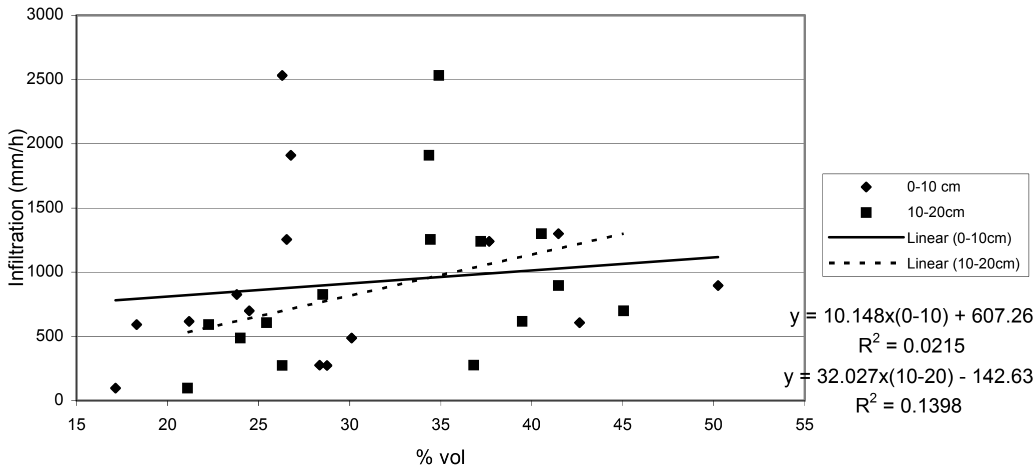

Figure 17. Amount of big pores plotted against saturated infiltration rate for the depths 0-10 cm and 10-20 cm.

4.8 Qualitative analysis of blue dye tracer

Figure 16. Example of preferential flow in soil, Photo shows soil from cropland (site 4C).

Results are shown as photographs, one per soil pit, total 15 photos (one of the replicas for cropland was taken away due to outlying values) (Appendix G). Results clearly showed that preferential flow occurred, meaning that the blue coloured water followed distinct pathways in the soil. One example is shown in Figure 18. The pathways seemed to follow roots, macropores and possible cracks. Photos from soil pit 2G, 3A and 4C shows roots sticking out particularly from the blue coloured areas (Appendix G). Another observation supporting the idea of preferential flow was the fact that in some soil pits patches of un-coloured soil was found just below the soil surface. Further down in the soil the coloured patches and pathways re-appear. It was not uncommon that the blue colour was spread out horizontally below the depth to where the soil ring had been pushed down. This was observed in soil pits 1K, 2F, 2G, 3A, 3C, 3D and, 4A (Appendix G). Maximum depth of the coloured soil was compared to saturated infiltration rate to see if there could be a correlation. No pattern was found between the two parameters (Table 6).

Table 6. Maximum depth of coloured soil And saturated infiltration rate for 15 soil pits.

Land use/ Soil pit	Maximum coloured depth (cm)	Saturated infiltration rate (mm/h)
Forest / 1A	54	489
Forest / 1D	36	608
Forest / 1F	30	1254
Forest / 1K	42	826
Shrub/ 2D	34	1241
Shrub/ 2E	35	274
Shrub/ 2F	57	618
Shrub/ 2G	24	895
Plantation/ 3A	40	1300
Plantation/ 3C	30	700
Plantation/ 3D	53	2531
Plantation/ 3F	32	1910
Cropland/ 4A	34	277
Cropland/ 4C	48	594
Cropland/ 4F	31	96

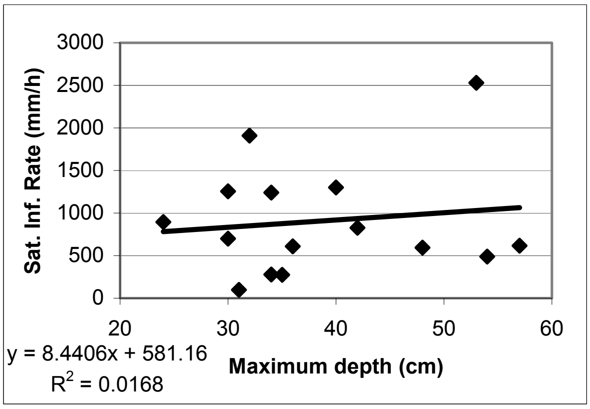

Figure 19. Correlation between saturated infiltration rate and maximum coloured depth.

In Figure 19 maximum coloured depth is plotted against saturated infiltration rate. There was a very week positive correlation between the two parameters with an R-value of 0.13. No significant differences were found between any of the land uses when comparing in Student's t-test.

4.9 Additional measured soil parameters

Other soil parameters were also analysed to give a broader picture of the soil condition in the study area. This was done to get a better understanding of the results that were analysed for the stated hypothesis, and to make sure that these factors did not affect the results. In Appendix E mean values for all the different investigated parameters are shown, divided after land-use. This appendix also contains the result of the t-test, the probability value, when making comparisons for all the parameters to find significant differences between land-uses. Below is a brief description of the results.

4.9.1 Initial water content

Forest had the highest initial water content in the topsoil (0-30 cm) compared to all other land uses. The difference was significant in the comparisons with all three land uses (0-30 cm). The three other land uses seemed to be quite similar in comparison to each other. The mean initial water content for forest varied between 60% and 66% at different depths. For shrub it varied between 51% and 65%, for plantation 46% - 55% and for cropland 43% - 54%. Differences in initial water content should not affect the saturated infiltration rate. Variances in this factor could be explained by factors, such as recent rainfall etc.

4.9.2 Bulk Density

Bulk density values were quite similar in all land uses, ranging between 0.4 and 0.7 g/cm^3 (mean values). The only difference found was that cropland had higher values for the two most upper layers (0-20 cm). The t-test showed low probability values, two significantly different (under 0.05) and the four other under 0.1, when comparing cropland with the other land uses for these depths. The slightly higher bulk density in cropland might be one explanation to the lower infiltration rate in this land use.

4.9.3 Field Capacity (pF 2)

Forest had the highest mean values for the field capacity ranging between 46 and 52% vol. Significant differences could be found when comparing forest with shrub and plantation for depths 10-20 cm, 20-30 cm and 50-55 cm. Mean values for shrub areas ranged between 30 and 43% vol. for the different depths, for plantation areas it ranged between 35 and 44% vol. and for cropland it ranged between 39 and 47% vol. Comparing these results with the results for the macropores a similarity can be found, where the areas with big pores, shrub and plantation, generally have low values for the field capacity and similar for the areas with less big pores seems to have higher field capacity. This is fully logical when the big pores are fast draining, which would give lower values for field capacity.

4.9.4 Pore Size < 0.03 mm

For the small size pores cropland areas generally showed the highest mean values, ranging between 4.7 and 5.3% vol. The other land uses generally had values between 4 and 5% vol. and only one value was over 5% (5.2%). There were some significant differences when doing comparisons with different land uses, but no clear pattern could be found. This result could contribute to the slow infiltration rates in cropland areas.

4.9.5 Sand content

The sand content in all land uses was quite the same. With the exception of one land use comparison at one depth (shrub-cropland, depth 150 cm) there was no significant difference in sand content between the land uses. The highest mean value was found in shrub, it was 42% (depth 50-55 cm). The lowest value was found in forest with a sand content of 13% (depth 0-10 cm).

4.9.6 Silt content

The silt content seemed to be quite the same for all land uses. No significant difference was found at all between land uses. The highest mean silt content was 71% (depth 150 cm) and the lowest was 45% (depth 50-55 cm), both these values were found in shrub areas.

4.9.7 Clay content

There were more differences in clay content between the land uses compared to the previous two texture parameters. Both forest and shrub showed significantly higher clay content than cropland in three of the six depths intervals. The highest mean value was 25% (depth 0-10 cm), found in forest. The lowest mean value was 5% (depth 150 cm), this was found in cropland. High clay content usually contributes to low infiltration rates, which is the opposite of this case. The low clay content for cropland does not explain the low infiltration values found for these areas.

4.9.8 Carbon content

Cropland had significantly lower carbon content than all the other land uses when looking at the upper 10 cm of the soil. The same relation was valid when comparing shrub and plantation to cropland down to 55 cm depth. The highest mean values at different depths were all found in shrub, they varied between 5% and 13%. The lowest mean value was found in cropland and it was 1% (depth 150 cm).

4.10 Correlations with saturated infiltration rate

The correlation coefficients, R-values, correlating all different parameters with the saturated infiltration rate are shown in Table 7. The highest R-value present was the value for the correlation between root weight for the depth 10-20 cm and the saturated infiltration. This value was approximately 0.66. This value was the only coefficient that shows 1% significance. It was almost only root weight that was correlated to the saturated infiltration for the upper depths. The root length can also be correlated to the infiltration but it was less clear than the weight. There was also a high correlation value for initial water content at depth 95-100 cm. At 150 cm there was also high correlation for bulk density and porosity. For the lower depths there is a greater suspicion that the high correlation factors present were coincidental. Variation among one single parameter, that has a negative correlation for one depth and a high positive value for the next, is also suspicious.

Table 7. Correlation coefficients for correlations between saturated infiltration rate and different parameters. Values with 10% significance in green (>0.441), 5% significance red (>0.514), 1% significance blue (>0.614).

DEPTH	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
Root length (m/m^3)	-0.0455	0.4073	0.4625	0.5325	0.0641	0.1494
Root weight (kg/m^3)	0.4463	0.6575	0.5353	0.3241	0.1203	0.1714
Initial Water (% vol)	-0.1984	-0.0496	-0.1317	-0.4031	-0.4328	-0.2057
Bulk Dens (g/cm^3)	0.0221	-0.1530	-0.1030	0.2465	0.3078	0.6121
Tot Porosity (% vol)	-0.0221	0.1530	0.1030	-0.2465	-0.3078	-0.6121
Sand (% vol)	-0.0745	-0.0743	-0.1137	-0.3234	-0.2689	-0.0559
Silt (% vol)	0.1897	0.0624	0.1100	0.3856	0.1630	-0.1837
Clay (% vol)	-0.0933	0.0376	0.0487	-0.1382	0.3524	0.4445
Carbon (% vol)	0.1910	0.1164	0.0563	0.0490	-0.2062	-0.1444

The parameters with the best correlation coefficients were the root data, both weight and length had good values, second best was the value for macropores. The best R-value was 0.66 for root weight, depth 10-20, and for macropores 0.37 for the same depth. Combining these two parameters in one equation that states saturated infiltration rate as a function of root weight and macropores (Equation 2), resulted in an equation that gives a fairly good estimation of saturated infiltration rate, with a significant R-value of 0.712. The two parameters did not correlate with each other (R-value = 0.16). Figure 20 showed the real values plotted against the modelled values, resulting from the equation.

$$f_{c\ mod} = 1496 * RW_{10\text{-}20} + 19.1 * MP_{10\text{-}20} \qquad \text{(Equation 2)}$$

where:

$f_{c\ mod}$ = modelled saturated infiltration rate (mm/h)

$RW_{10\text{-}20}$ = fine root weight (kg/m^3)

$MP_{10\text{-}20}$ = amount macropores (% vol)

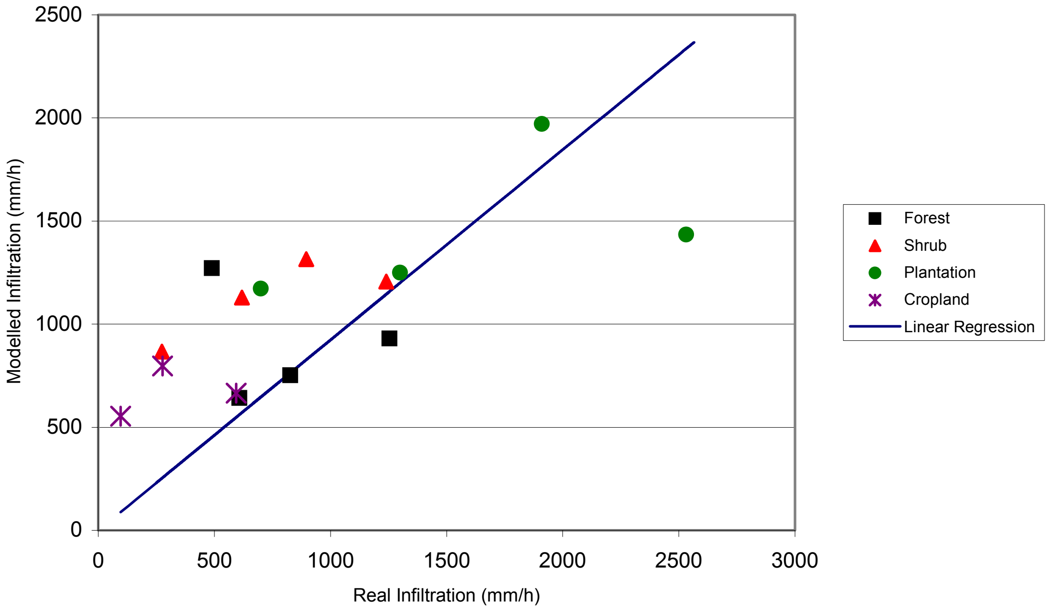

Figure 20. Modelled saturated infiltration rate values plotted against the measured values.

5 Discussion

5.1 Sources of errors

Values of saturated infiltration rate were quite high and were probably overestimated due to the choice of method. According to Bouwer[29] the diameter of an infiltration ring should not be less than one meter to get good estimations of infiltration capacity, due to the lateral divergence of the flow. A divergence of the flow would give an overestimation of the saturated infiltration. The photographs of the blue dye also showed lateral flow in some cases. Due to practical reasons it was not possible to measure infiltration with rings of this size. It would require an amount of water that was impossible to provide out in the field. Bouwer also states that even though the method is imprecise it can be used for comparative purposes if handled carefully. In this study it is the comparison that is the main focus, therefore the ring infiltrometer is still an appropriate method. The actual infiltration values should though be looked upon with this discussion in mind.

It can also be questioned whether the infiltration measurements were conducted during a sufficiently long period of time. Especially in the beginning of the field study this question is valid, due to lack of experience. It should be stated though that the error percentage caused by the procedure should be quite small since the fitting of the measured data with Horton's equation (Equation 1) was quite good.

If the soil samples remained undisturbed up upon arrival to the laboratory is not sure. Handling and transporting soil rings may have affected bulk density and pore size distribution. Best possible care was however taken.

Measuring root length was not always an easy task. The thinnest roots were sometimes very similar in appearance to other organic material, which made it difficult to separate them from

[29] Bouwer, 1986

each other. This might have contributed to an overestimation of root length. When separating fine roots from the soil very small roots might have been lost in the water, causing an underestimation of root abundance. For root samples containing a lot of roots, only a fraction of the sample were measured due to practical reasons. This procedure adds some uncertainties to the root length. Approximations of the root abundance should however be sufficient when comparing and correlating.

5.2 Discussion of results

The infiltration measurements showed that the infiltration rate differed between the four land uses (Figure 11). The saturated infiltration rate for shrub areas was significantly lower than both plantation and forest. The other comparisons however showed no significant differences. More differences between the land uses might have been found if doing a bigger study, where the large variation found might be explained by additional variables. When comparing land uses with trees and without trees a significant difference could be found in saturated infiltration rate, where the tree based land uses had the higher mean. This is in accordance with an earlier study by Mapa[30], where reforested land areas showed significantly higher saturated infiltration rate than cultivated areas and grassland in Sri Lanka. A study by Van Noordwijk[31] in Southern Nigeria and Southern Sumatra, Indonesia, also showed higher infiltration rates for secondary forest than for recently cleared land. Similarly Abeli[32] showed in a study conducted in Tanzania, that water infiltration rate significantly decreased in areas that were recently cleared and currently grazed compared to natural forest.

Measuring of root abundance caused some problems when deciding what unit to use for this parameter. The two examined parameters, root weight and length, showed quite different results, see Figure 12 and 13. When measuring root weight generally plantation was the land use with the highest mean root weight and cropland had the lowest mean root weights. For the root length forest had the shortest mean length for all depths, whereas cropland had among the highest values. In other words the cropland results were very different from each other. With one parameter (root length) it seems like cropland had the highest abundance of roots whereas the other parameter (root weight) indicates that cropland had a smaller abundance of roots compared to the other land uses. This would indicate that the roots in cropland were thinner and lighter compared to other areas. Earlier studies have shown that root abundance, in terms of weight, generally is much lower for cropland than for rain forest[33]. The variation was strong for both weight and length measurements. The weight showed only significant differences between shrub and cropland for two depths and between plantation and cropland for one depth. No significant difference was found among the root length data.

A positive correlation was found between saturated infiltration rate and fine root weight, meaning that the infiltration rate increases with an increase in fine root weight. The R-values, the correlation coefficients, showed two significant correlations, for the depths 10-20 cm and 20-30 cm. The depth 10-20 cm showed the strongest correlation found in this study. The other depths also showed fairly good correlations, but not significant. One could suspect that the correlation should decrease with depth. A reason for not getting a good correlation at 0-10 cm could be that the root sample was disturbed, possibly by the litter layer. This indicates a

[30] Mapa, 1995
[31] Van Noordwijk et al., 1991
[32] Abeli, 1999
[33] Young, 1997

relationship between the two parameters that should be further studied. In this study only four replicas per land use were made. More replicas might give a stronger correlation.

A slight positive correlation was found between saturated infiltration rate and fine root length, the best one at depth 50-55 cm. It was not as strong as for root weight. The comparison of root length for different land uses showed that forest had the shortest length. The infiltration data however showed that saturated infiltration rate in forest was the second highest out of the four land uses. This goes against a possible positive correlation between the root length and saturated infiltration rate. The found correlation here might instead be a result of a possible correlation with root length and root weight. The relationship for root weight is then also displayed for root length. It became clear that root weight was a more suitable parameter to measure for the purposes of this study since it showed a higher correlation to saturated infiltration rate.

When looking at presence of nearby trees, the number of trees surrounding each sampling point within a radius of ten meters showed no correlation with saturated infiltration rate. Distance to the nearest tree also gave a very weak correlation, which in reality probably means that there is no relationship. These results do not agree with earlier findings in this study, where it was shown that tree-based land uses (natural forest and tree plantations) had a significantly higher saturated infiltration rate than land uses with no trees (shrub areas and cropland areas). This result is unfortunate because if there would indeed exist such a relationship it would be possible to easily get an estimate of how the infiltration rate would differ.

A positive correlation was found between amounts of macropores and saturated infiltration rate, however the R-values were not significant for any depth. The best depth was 10-20 cm, where the R-value was 0.37. The analysis of blue dye traces showed that the infiltrating water clearly had a preferential flow, it followed pores and root channels. This suggests that there should be a connection between macropores and saturated infiltration rate. Other studies have found a clear positive connection between the saturated infiltration rate and the amount of macropores under natural conditions[34]. The pictures showed however some cases with horizontal flow (e.g. site 3C seen in Appendix G), this might indicate a systematic error in the measuring method. According to the theoretical method the flow should be mainly vertical[35]. Using infiltration rings with bigger diameter could minimize this error. The horizontal flow might also occur due to an underlying layer with lower hydraulic conductivity or cracks and pores in horizontal directions. There was no connection between maximum depth of the blue dye and the saturated infiltration rate. Land uses did not differ from each other either. These results correspond to the observed preferential flow. If there was a uniform flow the connections between the maximum depth and the saturated infiltration rate might have been clear, whereas with a preferential flow the water has so many other ways to take and one cross section is not representative for the whole situation. To get a better picture of the real situation more cross sections should have been made for each soil pit. The pictures should also be analysed by looking at the area of the blue dye, which together could give a picture of the 3D spreading.

Investigations of the other soil parameters showed that cropland data had clearly protruding values. It often showed differences to the other land uses, possible explained by lack of vegetation for this land use. Bulk density values for cropland were slightly higher in the two

[34] Leonard et al., 2004
[35] Bouwer,1986

upper most layers (0-20 cm). High bulk density values should cause a decrease in infiltration rate, which could explain the somewhat lower infiltration values for cropland. The high-density values could be explained by compaction by human activities or possible by the formation of a hard crust on the top layer caused by for example heavy rains, as described by Mapa[36]. In Mapa's study the cultivated areas and the grassland also had significantly higher bulk density than the reforested area. The small pores showed outstanding values for cropland, where it had the highest amount of pores with the size under 0.03mm. This result is somewhat contradicted by the fact that cropland has got the lowest amount of clay. Large amounts of small pores are usually connected with large amounts of clay, but this case was showing the opposite. The high occurrence of small pores could possibly be explained by the formation of a crust. The low amount of clay could be an indication that heavier erosion has occurred in cropland than in other compared land uses but it could also be just a coincident. Low values of carbon for cropland could be due to the fact that the cultivation process supplies the soil with more oxygen and thereby the organic carbon is oxidized to a higher extent[37]. This effect is usually enhanced by a raise in temperature due to the removal of the forest cover[38]. It could also be explained by the fact that existing plants are cultivated and therefore harvested/taken away. Dead plants are not left to decay in the soil as usually happens in natural forest for example. In shrub areas the highest values of organic carbon were found. Why this land use shows higher values than forest and plantation is a question still unanswered. It might be a coincidence since the differences were not significant.

When looking at the parameters best correlated to saturated infiltration rate it is clear that the fine root weight and the amount of macropores showed the best results. The significant infiltration equation (Equation 2) that was made based on these two parameters should be further investigated with a bigger study to verify the accuracy of the relationship and the constants. It should be kept in mind that this study is rather small. There is a great variation in the measured parameters as can be expected in nature. To get more secure and reliable results, more sample points and replicas would be necessary. This study however gives indications of differences between land uses and also of the relationships governing infiltration rate.

Even though the root weight was the parameter which was best correlated to infiltration measurements; there are still factors that might also explain the found differences between the land uses. One example that has been proposed to influence the saturated infiltration rate is the slope[39], where the infiltration rate should have a close positive relationship to the slope. It was suggested that steep slopes hampered the formation of a crust, allowing water to infiltrate more easily than on more gentle slopes. Since the study area was situated on the hills of Mount Salak some sites were quite steep. There might be other factors that can, together with the found equation (Equation 2), help explain the variation in the infiltration rate or the other examined parameters.

What will be the consequences of the obtained results? The decrease in infiltration rate, when converting to land uses without trees, is in percentage quite drastic, but the average saturated infiltration rates for the four examined land uses are still very high. The shrub areas, with the lowest infiltration rates had a mean infiltration of almost 600 mm/h. It is extremely rare to have rainfall intensities exceeding this rate. The measurements showed however a big variation in saturated infiltration rate. The problems start when the rainfall intensities exceeds

[36] Mapa, 1995
[37] Polglase, 2001
[38] Allen, 1985
[39] Janeau, 2003

the infiltration capacity, this is when the hortonian overland flow occurs. A look at the measurements of saturated infiltration rate can give an indication if these events occur but lack of proper rainfall data makes it difficult to say more in detail how often it happens. For example a rain with the intensity 300 mm/h is not an unrealistic rainfall event for a short duration in an area with this kind of rainfall regime and with an annual mean precipitation of 5000 mm. Data from Kuala Lumpur, Malaysia shows intensities of around 5 mm/min (300 mm/h) for short durations (less than 5 min), for an area with an annual mean of 2300 mm[40]. In Appendix D it can be seen that 9 of the 36 measurements have a saturated infiltration capacity lower than 300 mm/h, it corresponds to 25% of the points. When investigating the values it is clear that two of these occurred in tree based land uses, corresponding to 11% of the measurements for tree based land uses. The other seven occur in the land uses without trees, corresponding to 41% of those measurements. If looking at a rain intensity of 150 mm/h, there are three measurements below this intensity, all occurred at land uses without trees. It relates to about 18% of the measurements for land uses without trees, where overland flow would happen. If the measurements are representative for the whole area, it means that the frequency of overland flow will increase quite drastic when changing from a tree based land use to a land use without trees. It should be noted that the infiltration values probably are overestimations as mentioned in section 5.1. To make a proper discussion of this kind one must have more infiltration data, investigate whether it is representative for the whole catchment, have good data on precipitation and do a proper statistical investigation. The example above however gives a suggestion of the consequences of land use change.

The overland flow can give problems with downstream flooding and degradation of the soil due to erosion. Many areas on Western Java already have serious problems with flooding during rainy seasons. In an area such as this where the population pressure is immense, many people are dependent on what the land can produce, one must be very careful when converting land for production purposes. Different kinds of agroforestry have long been practised in Indonesia, a system where crop production is combined with forestry plantations[41]. If the results of this study were to be correct it seems like a land use of this kind would be appropriate in many aspects. Crops would be provided to people and the ecosystem functions would be preserved. However this land use has not been included in this study and the reasoning is not based on any specific data. According to Whitten et al. agroforestry systems are not suitable for all crops and therefore it might not be applicable for all situations. It would be very interesting to follow up with a study on this type of land use.

[40] bin Mohamed Desa, 1997
[41] Whitten et al., 1996

6 Conclusion

- The saturated infiltration rate decreased when changing land use from tree based land to land with no trees
- Many parameters determine the saturated infiltration rate. In this study some of them were analysed. The parameters best correlated were fine root weight and amount of macropores, showing a positive correlation.
- Roots and macropores contribute strongly to a preferential flow of the soil water.
- The occurrence of overland flow becomes more frequent when a change has been made from tree based land use to land uses with no trees.

These results together shows the importance of keeping land covered with vegetation, preferably with trees, in order to maintain the lands capacity to handle heavy rainfall. This would in the long run be beneficial, preserving ecosystem functions and assuring a livelihood for people in these areas.

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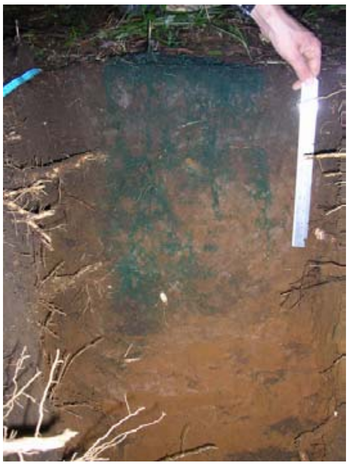
8 Appendices

8.1 Appendix A: Information about different sampling points.

1. Forest

1A (with soil pit)
Date: 2005-07-22
Altitude: 1125m
Coordinates: 6,74759 south, 106,712552 east
Vegetation: Few very large trees, Several of medium height. Undergrowth made up of ferns, relatively large. Litter ~0,005m.
Infiltration: Small amount of oil in the water. After 2nd measure soil went dry for a couple of minutes.
Blue tracer: Infiltration time 1,10 h. No visible spreading horizontally.



1B
Date: 2005-07-26
Altitude: -
Coordinates: 9254802 north, 689499 east
Vegetation: Dense forest, lots of lianas, fairly close to shrub area, 150 m to water. Litter layer ~3 cm, contains lots of fine/small roots.
Infiltration: Incredibly fast, a lot of fine roots, rings fairly flat.

1C
Date: 2005-07-27
Altitude: -
Coordinates: 9253946 north, 689584 east
Vegetation: Dense big trees, ferns the size of trees. Dense undergrowth. Litter layer ~3 cm mostly un-decomposed.
Infiltration: Used only one ring since the infiltration was so fast!

1D (with soil pit)
Date: 2005-07-27
Altitude: -
Coordinates: 06 44 540 south, 106 42 975 east
Vegetation: Dense forest, very steep, close to river (ca 40 m). Undergrowth some banana trees, ferns and a lot of small vegetation. Litter layer consisting of leaves but in general quite little, ~ 0,5cm.
Infiltration: Area too steep, the ground was dug out to flatten the rings.
Blue tracer: Depth: 0,35 m blue stained.

1E
Date: 2005-08-02
Altitude: 1259 m
Coordinates: 9254930 north, 689411 east
Vegetation: Mainly fern trees, a few very large trees. Undergrowth mostly ferns and bushes. Litter layer 1-2 cm, mainly old fern leaves.
Infiltration: Heavy rain occurred Used umbrella to cover the infiltration rings.

1F (with soil pit)
Date: 2005-08-04
Altitude: 1056 m
Coordinates: 9254248 north, 690086 east
Vegetation: Fern trees, ferns. Litter layer ~3 cm, large leaves and decomposing sticks.
Infiltration: Made indentation to be able to arrange infiltration cylinders.
Blue tracer: Approximately 45 min infiltration. Deepest 40 cm
Other comments: Steep slope

1G
Date: 2005-08-04
Altitude: -
Coordinates: 9253532 north, 689518 east
Vegetation: Border between shrubby banana plantation and forest. Very thick vegetation, lots of young/smaller trees. Undergrowth thick and plenty, many small trees. Litter layer ~4cm.
Infiltration: Very fast

1H
Date: 2005-08-11
Altitude: 1169 m
Coordinates: 9254666 north, 690243 east
Vegetation: Forest area just beside a small stream, 15 m to water. Undergrowth quite dense with banana trees, bushes etc. Litter layer ~ 1cm with lot of surface roots.
Infiltration: Very slow, probably due to a big underground stone
Blue tracer: Blue Colour appear 2-3 dm down slope on the ground, soil pit not dug due to appearance of big stone, which probably limited the infiltration.
Other comments: Values excluded due to the stone.

1I
Date: 2005-08-23
Altitude: -
Coordinates: 9254802 north, 689499 east
Vegetation: see 1B
Infiltration: Very big difference to 1B, which was taken 5m from this location!
A big rain occurred the day before
Other comments:
Retake of 1B. Distance to water: 150 m

1J

Date: 2005-08-23
Altitude: -
Coordinates: 9253822 north, 689281 east
Vegetation: One very large tree (5.90m perimeter!) 3m from rings. Undergrowth ferns and bushes. Litter layer ~ 3 cm. Many dead leaves and sticks.
Other comments: Very close to 1A.
Distance to water: 150 m.

1K (with soil pit)

Date: 2005-08-24
Altitude: 954 m
Coordinates: 9253758 north, 690187 east
Vegetation: A mixture between high trees and dense under vegetation. On a slope to a small river. Undergrowth dense ferns and bushes. Litter layer ~6cm very large dead leaves.
Blue tracer: A lot of roots & stones. Possible to see that blue colour had followed root channels. Blue colour appear 64 cm under ground, 1m away outside the inner ring.
Other comments: A big stone at level 1.5m. For soil samples level 0-10 – 95-100 taken on the opposite side of the pit as the infiltration. Not the usual! Level 150 cm taken at the usual side up slope the pit.
Distance to water: 40 m.

1L

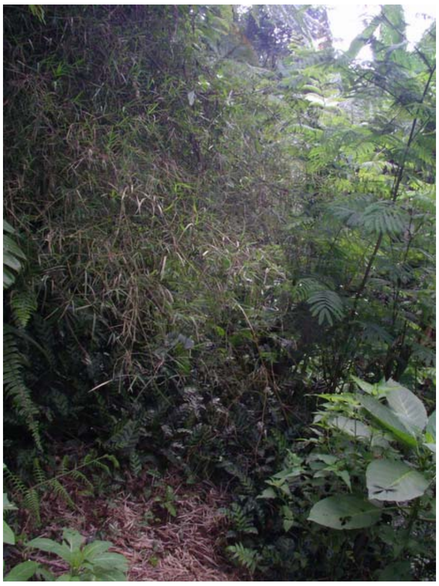
Date: 2005-08-24
Altitude: 1155 m
Coordinates: 9254674 north, 690253 east
Vegetation: Steep forest, besides trees also banana trees. Undergrowth thick leafy, around 0.5-1m high Many surface roots. Litter layer ~ 1cm, mostly dead decomposed leaves.
Infiltration: Very stony ground, ground was levelled due to steepness, a big rain occurred two days before.
Other comments: Distance to water: 30 m. Very close to 1H.

2. SHRUB

2A

Date: 2005-07-26
Altitude: -
Coordinates: 9254622 north, 689447 east
Vegetation: Trees few, far apart. Shrub and grass, 20-30 cm, covering the ground.
Litter layer ~3 cm,
a lot of old grass,
few leaves,
hard to get a good measure.

2B
Date: 2005-07-27
Altitude: -
Coordinates: 9254408 north, 689640 east
Vegetation: Undergrowth mostly bamboo and small plants (20 cm).
Litter layer; quite dense litter, fine pieces (sticks), ~ 4 cm.
Infiltration: Very fast, area quite steep and close to waterfall.



2C
Date: 2005-08-02
Altitude: -
Coordinates: 9253652 north, 689442 east
Vegetation: No trees. Somewhat close to forest area. Undergrowth shrubby, small banana plantation close to the point. Not so much litter but plenty of high grass.

2D (with soil pit)
Date: 2005-08-02
Altitude: -
Coordinates: 9253610 north, 689409 east
Vegetation: No trees. Undergrowth thick and plenty. Litter layer ~10cm, lot of half decomposed stems and old roots and debris.

2E (with soil pit)
Date:
2005-08-10
Altitude: 945m
Coordinates:
9253074 north,
690508 east
Vegetation:
No trees.
Grass and
bushes.
Litter layer
~2cm, dead
grass.

Blue tracer: Blue tracer found 51 cm outside the inner ring, plastic bag found 7 cm underground from the outer rim of the inner ring and out.

2F (with soil pit)
Date: 2005-08-11
Altitude: 1145 m
Coordinates:
9254532 north,
690339 east
Vegetation:
No trees.
Ferns and herbs.
Litter layer
branches and
some leaves.
Blue tracer: Blue
colour 30 cm
outside inner ring and 75 cm down.

2G (with soil pit)
Date: 2005-08-12
Altitude: 963 m
Coordinates:
9252880 north,
690380 east
Vegetation:
No trees.
Undergrowth
ca 2 m high
bushes. Litter
layer 2-3 cm
deep.

2H

Date: 2005-08-12

Altitude: 917 m

Coordinates: 9253170 north, 690569 east

Vegetation: No trees. Shrub area, steep, close to area with banana trees. Small bushes. A lot of old grass and stems as litter layer (2-3 cm).

Infiltration: Quite slow, made indentation to be able to arrange infiltration cylinders, possible soil compaction.

Other comments: Distance to water: 75m

2I

Date: 2005-08-23

Altitude: 1226 m

Coordinates: 9254614 north, 689388 east

Vegetation: Small Agathis trees along a path, approximately 2-3yrs old (Martin's guess). Path 10m from the infiltration site. Thick dense undergrowth, bushes, grasses. Big fern close by. A lot of litter (~4cm)! Dead branches, grass, ferns & different kind of leaves.

Infiltration: Very slow, third try for this infiltration (two different places tried before, the other places no infiltration, possible disturbed.) A huge rain the day before, maybe soil was saturated with water.

Other comments: Distance to water: 100m

3. PLANTATION

3A (with soil pit)
Date: 2005-07-28
Altitude: -
Coordinates: 9253708 north, 689572 east
Vegetation: A few large trees but smaller trees and shrubs dominate the area. Agathis and some other trees planted, Ecotone. Litter layer leaves and sticks.

Blue tracer: Clear preferential flow, mainly by the roots. Max depth 41cm middle, 50cm edge.

3B
Date: 2005-08-05
Altitude: 939 m
Coordinates: 9253624 north, 690781 east
Vegetation: Agathis plantation. Undergrowth; bushes and grass. Litter ~1cm.

3C (with soil pit)

Date: 2005-08-05
Altitude: 968 m
Coordinates: 9253774 north, 690668 east
Vegetation: Agathis Plantation Trees about 3m apart, a few other trees: banana. Agathis planted 8 years ago. Undergrowth large ferns, various bushes, quite dense. Litter layer (a few cm) was removed.
Blue tracer: Deepest part 80 cm underground from +18 cm, it was following a root/macropore along the whole pit.
Other comments: Distance to water: 300-400 m. Worms present.

3D (with soil pit)

Date: 2005-08-09
Altitude: 929 m
Coordinates: 9253524 north, 690826 east
Vegetation: Agathis plantation about 3-5 yrs old, there were also some pine trees and bamboos in the area. Bushes and high grasses. Litter layer (~2cm) consisted of dead leaves and grass.
Infiltration:
Went dry a couple of times.
Blue tracer: Clear patches, not connected with the top part. The blue colour reached 20 cm outside the inner ring at the side.
Blue tracer 65 cm at deepest.
Other comments:
Distance to water: 100 m.
Many roots, especially in the top layer. Worms present, many large stones.

3E
Date: 2005-08-09
Altitude: 924 m
Coordinates:
9253380 north,
690600 east
Vegetation: Plantation with only Agathis about 30 years old. Ferns and shrubby thick vegetation, some trails into the area too. Litter layer mostly dead Agathis leaves (~2cm).
Other comments:
Distance to water: 400-500m.

3F (with soil pit)
Date: 2005-08-10
Altitude: 908 m
Coordinates:
9253274 north,
690482 east
Vegetation: Large Agathis trees, about 30 years old.
Dense undergrowth; bushes and grasses.
Litter layer (~3cm) dead Agathis leaves, sticks.
Blue tracer: Deepest 40 cm
Other comments:
Big roots present, one with diameter 6 cm (depth: 20-30 cm), one with perimeter 11 cm (depth: 110-120 cm).

3G
Date: 2005-08-10
Altitude: 968 m
Coordinates:
9253108 north,
690168 east
Vegetation: Agathis trees, ferns and bushes. Litter layer (~3cm) dead Agathis leaves and sticks.

3H
Date: 2005-08-12
Altitude: 1978 m
Coordinates:
9253522 north,
689805 east
Vegetation: Agathis plantation about 30 years old. Area close to a camping ground. Quite little undergrowth, bushes 1-2 cm litter, dead leaves and branches.

4. CROPLAND

4A (with soil pit)
Date: 2005-08-18
Altitude: 1111 m
Coordinates:
9253644 north,
689505 east
Vegetation: Field surrounded by banana trees, area has been used 2-3 years. <1 month ago area was weeded and is now prepared to be cultivated, old maize field.
Other comments:
Distance to water: 40m.

4B
Date: 2005-08-19
Altitude: 1076 m
Coordinates:
9253496 north,
689596 east
Vegetation: One tree in the middle of cropland. It has been cultivated for 5 years with banana trees and cassava right now only. The area has been burnt. A few large Agathis trees are far apart from each other. Litter layer ~1cm looks like dead grass.
Other comments: Distance to water: 150 m

4C
Date: 2005-08-19
Altitude: 875 m
Coordinates:
9253226 north,
690525 east
Vegetation: A combination of young cassava plants, taro, banana trees, tea bushes and trees for furniture. Very small Agathis trees and two jack fruit trees. 3 years of cultivation of crops. Not much undergrowth, very few weeds, looks like the area is cleared often. Litter consists of small sticks and dried grass irregularly spread out (0-0,5 cm).
Infiltration: Many stones, one very large at 75 cm depth, not directly under but next to the infiltration spot.

4D (two infiltrations; A and B)

Date: 2005-08-19
Altitude: 949 m
Coordinates:
9253484 north,
690852 east
Vegetation: Old farm land >25 years of cultivation.
Used to grow Asparagus and chilli
Trial A was taken above the dug soil heap where the asparagus grow,
B in between where the farmers walk!
2-3 m in between.
Litter < 1cm, small dead branches.

Infiltration: A: Water appear on both sides of the heap, 1-2 dm outside the ring. **B**: very slow
Other comments: Distance to water: 75 m
Values from **A** excluded due to horizontal leakage.

4E

Date: 2005-08-20
Altitude: 1033m
Coordinates:
9254034 north,
690471 east
Vegetation: Onions (Bawang Kucai) neatly planted in rows carefully weeded. Small terraces lined by banana trees or Agathis trees. Cultivated for 3 years, onions about 1.5 months.
Other comments:
Distance to water: 100m

4F (two infiltrations; A (with soil pit) and B)
Date: 2005-08-20
Altitude: 950 m
Coordinates:
9253540 north,
690943 east

Vegetation: A line of trees on the side of the field. Chilli and maize field, used for 2 yrs, before Agathis plantation. No crops at the moment.
A: The land is weeded but not prepared for planting, i.e. hard soil.
B: The land is prepared for planting. Distance A - B about 5m B closer to the trees.
Infiltration: A: Soil seems very compact and quite hard. Difficult to get inf. Rings into the soil.
B: land prepared for planting, loose soil
Other comments: Distance to water: 125m.
At 0.5 m ants discovered, above plenty of ant-canals

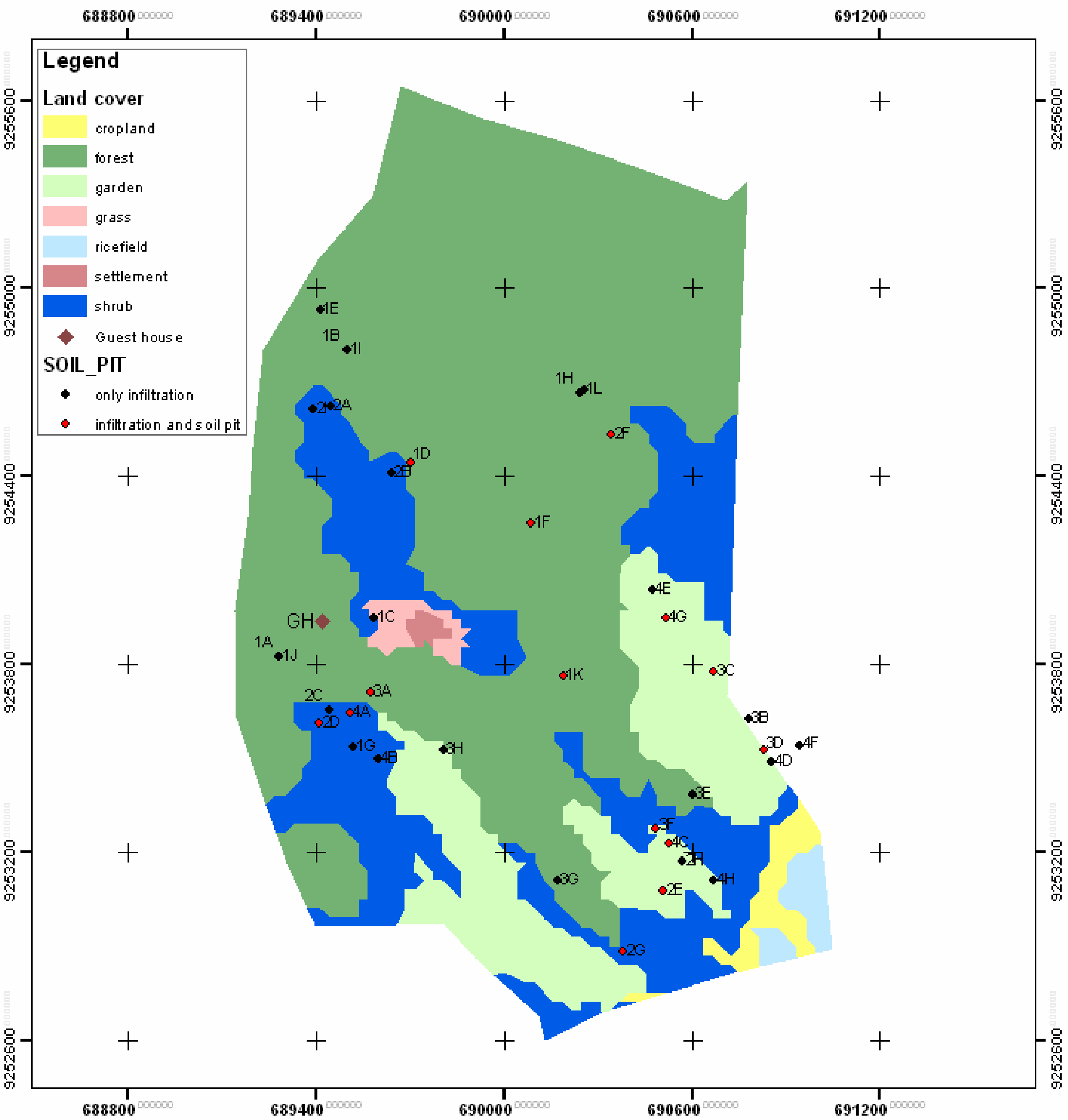
4G
Date: 2005-08-20
Altitude: 1008 m
Coordinates:
9253944 north,
690514 east

Vegetation:
The area is covered with cassava plants, banana trees, small jack fruit trees and small Agathis, few Albizia trees. It's not very well kept, the ground is covered in grass and bushes. The area as a whole is quite large. Cultivated for 3 yrs. Dense grasses and herbs, bushes. Dead grass, the odd banana leaf (dead).
Blue tracer: Blue dye 56++ cm sideways from the edge of the inner ring.
Other comments: Big rock found under inf. ring.

4H

Date: 2005-08-23
Altitude: 824 m
Coordinates:
9253106 north,
690669 east
Vegetation:
Narrow terraces with different crops in between padi fields. "Gur" terraces consists of small chilli bushes (9months old) (and low weeds). The other crops grown nearby are taro, banana, a red bean (kacang merah) sawi, selada. The terraces are 10-15 yrs old. Soils are tilled. Undergrowth a few small weeds.
Other comments:
Distance to water: 1m. There are plenty of small streams/man made channels with water.

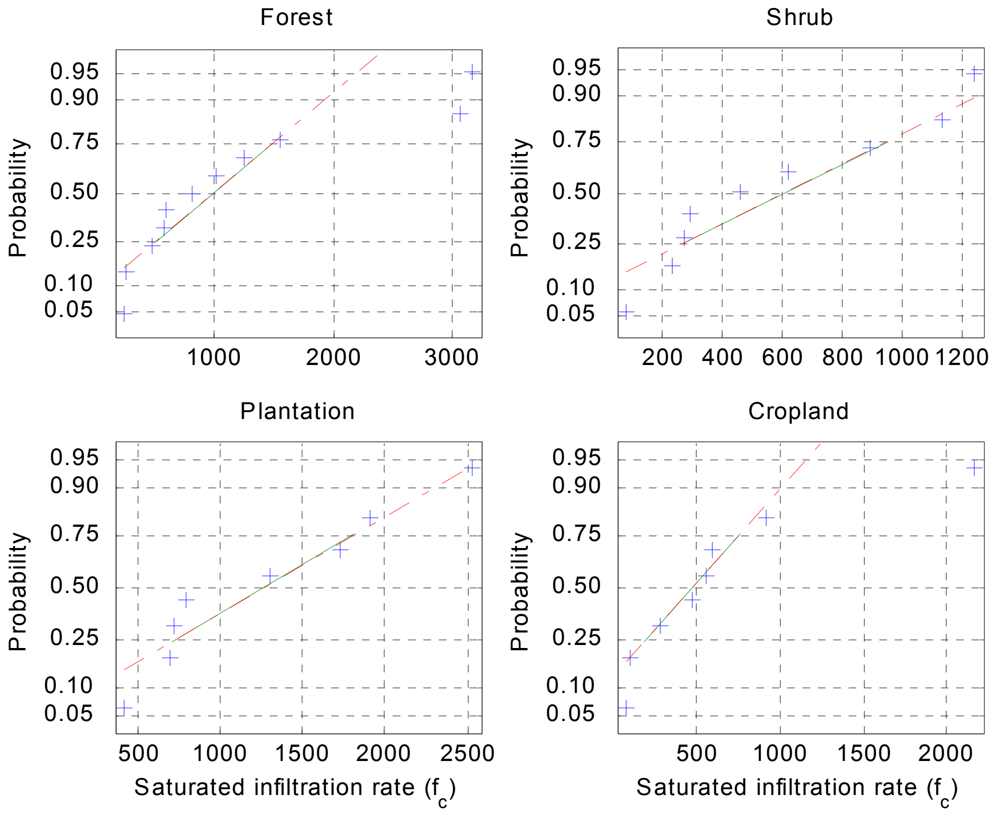
8.2 Appendix B: Map over study site and list of sample points



Forest		Shrub		Plantation		Cropland	
1A	infiltration and soil pit	2A	only infiltration	3A	infiltration and soil pit	4A	infiltration and soil pit
1B	only infiltration	2B	only infiltration	3B	only infiltration	4B	only infiltration
1C	only infiltration	2C	only infiltration	3C	infiltration and soil pit	4C	infiltration and soil pit
1D	infiltration and soil pit	2D	infiltration and soil pit	3D	infiltration and soil pit	4D	only infiltration
1E	only infiltration	2E	infiltration and soil pit	3E	only infiltration	4E	only infiltration
1F	infiltration and soil pit	2F	infiltration and soil pit	3F	infiltration and soil pit	4F	infiltration and soil pit
1G	only infiltration	2G	infiltration and soil pit	3G	only infiltration	4G	infiltration and soil pit
1H	only infiltration	2H	only infiltration	3H	only infiltration	4H	only infiltration
1I	only infiltration (retake of 1B)	2I	only infiltration (retake of 2A)				
1J	only infiltration (retake of 1A)						
1K	infiltration and soil pit						
1L	only infiltration (retake of 1H)						

8.3 Appendix C: Normal probability plot for the four different land uses

The normal probability plot shows graphically how the data fits to a normal distribution. If the measured values are laying on a straight line there is a great probability that the values come from a normal distribution.



8.3 Appendix D: Initial infiltration rate, Saturated Infiltration rate and k-value

1 – Forest   3 - Plantation
2 – Shrub   4 - Cropland

Forest	F0	fc	k
1A	-	489	-
1B	-	1564	-
1C	-	3059	-
1D	-	608	-
1E	1440	588	0.00296
1F	1335	826	0.00182
1G	5143	3165	0.00178
(1H)	(105)	(73)	(0.00040)
1I	444	273	0.00056
1J	1636	1015	0.00084
1K	1895	1254	0.00131
1L	319	249	0.00033
Mean value	1745	1190	0.00137
STD DEV	1611	1030	0.00091

Plantation	F0	fc	k
3A	-	1300	-
3B	4398	717	0.00131
3C	1106	700	0.00067
3D	3600	2531	0.00090
3E	3695	1727	0.00176
3F	3130	1910	0.00117
3G	1895	791	0.00049
3H	837	415	0.00079
Mean	2666	1261	0.00101
STD DEV	1386	737	0.00043

Plantation	F0	fc	k
2A	-	457	-
2B	-	1130	-
2C	384	229	0.00080
2D	2769	1241	0.00195
2E	316	274	0.00104
2F	1309	618	0.00091
2G	1143	895	0.00406
2H	1180	290	0.00376
2I	95	76	0.00099
Mean	1028	579	0.00193
STD DEV	907	420	0.00141

Cropland	F0	fc	k
4A	661	277	0.00154
4B	3191	920	0.00119
4C	1714	594	0.00047
(4D – A)	(4539)	(2203)	(0.00207)
4D – B	113	75	0.00026
4E	2542	561	0.00063
4F – A	590	96	0.00071
4F – B	4500	2167	0.00163
(4G)	(400)	(88)	(0.00812)
4H	1385	474	0.00062
Mean	1837	652	0.00088
STD DEV	1491	675	0.00051

Sample 1H, 4G and 4D were excluded from the calculations in this study due to divergent values caused by visible factors (big underlying rocks hindering infiltration and/or visible horizontal leakage). Some values of f_0 and k are not presented (marked -). Theses values were not possible to obtain due to a different way of measuring infiltration time in the field.

8.4 Appendix E: Mean values of different parameters and the result of TTEST

TTEST AND MEAN VALUES (DIFFERENT LAND USES) OF ALL MEASURED
P-values below 0.05 in red

1=FOREST
2=SHRUB
3=PLANTATION
4=CROPLAND

	Number of trees	Distance to tree	Perimeter tree
mean 1	9.5	2.0	81.5
std dev 1	6.4	0.8	51.5
95% c.i.1	6.2	0.7	50.5
mean 2	0.0	13.0	0.0
std dev 2	0.0	-	0.0
95% c.i.2	-	-	-
mean 3	16.0	1.7	76.6
std dev 3	4.4	0.2	81.9
95% c.i.3	4.3	0.2	80.3
mean 4	4.7	5.6	70.3
std dev 4	5.0	3.4	50.5
95% c.i.4	5.7	3.8	57.2
Ttest 1-2	0.141	-	0.025
Ttest 1-3	0.179	0.261	0.462
Ttest 1-4	0.234	0.184	0.411
Ttest 2-3	0.012	-	0.079
Ttest 2-4	0.125	-	0.150
Ttest 3-4	0.022	0.176	0.457

Root length (m/m^3)	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
mean 1	29464	23141	5969	3061	1086	1145
std dev 1	17470	22898	2003	3335	765	1095
95% c.i.1	17120	22439	1963	3269	749	1074
mean 2	54385	54614	12350	3133	1457	1275
std dev 2	44218	32982	6050	1407	221	666
95% c.i.2	43333	32322	5929	1379	217	652
mean 3	37956	48926	27089	5380	2251	1744
std dev 3	31420	27642	26343	4914	830	1711
95% c.i.3	30791	27089	25816	4816	813	1677
mean 4	66966	34114	19074	4777	3337	1727
std dev 4	67747	24999	22079	4188	2627	721
95% c.i.4	76661	28288	24984	4739	2972	816
Ttest 1-2	0.177	0.087	0.061	0.485	0.246	0.424
Ttest 1-3	0.329	0.101	0.104	0.234	0.058	0.291
Ttest 1-4	0.220	0.291	0.206	0.296	0.137	0.218
Ttest 2-3	0.285	0.400	0.174	0.218	0.075	0.319
Ttest 2-4	0.398	0.196	0.327	0.286	0.170	0.221
Ttest 3-4	0.273	0.247	0.340	0.434	0.276	0.493

Root weight (kg/m^3)	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
mean 1	2.20	1.33	0.66	0.32	0.15	0.29
std dev 1	1.72	1.11	0.54	0.62	0.17	0.49
95% c.i.1	1.69	1.09	0.53	0.61	0.16	0.48
mean 2	1.91	1.61	1.01	0.09	0.49	0.06
std dev 2	1.22	0.30	0.40	0.12	0.83	0.03
95% c.i.2	1.19	0.29	0.39	0.12	0.82	0.03
mean 3	2.77	2.63	1.89	0.21	0.07	0.28
std dev 3	2.09	1.61	2.25	0.16	0.04	0.31
95% c.i.3	2.05	1.58	2.21	0.16	0.04	0.30
mean 4	1.25	0.59	0.39	0.22	0.12	0.06
std dev 4	0.70	0.27	0.28	0.23	0.07	0.05
95% c.i.4	0.80	0.30	0.32	0.26	0.08	0.05
Ttest 1-2	0.397	0.326	0.168	0.257	0.238	0.208
Ttest 1-3	0.343	0.119	0.180	0.371	0.260	0.486
Ttest 1-4	0.187	0.141	0.215	0.386	0.390	0.212
Ttest 2-3	0.254	0.149	0.249	0.147	0.195	0.125
Ttest 2-4	0.206	0.003	0.029	0.224	0.218	0.462
Ttest 3-4	0.124	0.041	0.138	0.475	0.195	0.128

Pore>0.3 (% vol)	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
mean 1	30.8	28.1	18.5	22.9	18	20.4
std dev 1	8.3	4.6	7	4.2	8.3	7.7
95% c.i.1	8.1	4.5	6.9	4.2	8.1	7.6
mean 2	34.5	36.1	45.2	45.9	27.9	32.5
std dev 2	12.5	6.8	15.6	14.3	19.6	11.8
95% c.i.2	12.2	6.6	15.2	14	19.2	11.6
mean 3	29.8	38.7	38	36.4	26.7	24.7
std dev 3	7.9	5.1	8.6	9.3	14.2	21.9
95% c.i.3	7.7	5	8.4	9.1	13.9	21.5
mean 4	21.3	26.7	31.8	17	16.8	22.1
std dev 4	6.2	8.8	14.5	7.7	13.5	5.9
95% c.i.4	7	9.9	16.4	8.8	15.3	6.7
Ttest 1-2	0.321	0.052	0.017	0.022	0.201	0.073
Ttest 1-3	0.433	0.011	0.007	0.028	0.168	0.367
Ttest 1-4	0.072	0.411	0.125	0.16	0.451	0.378
Ttest 2-3	0.276	0.281	0.227	0.157	0.463	0.28
Ttest 2-4	0.066	0.102	0.149	0.01	0.207	0.097
Ttest 3-4	0.086	0.062	0.28	0.015	0.196	0.418

PS 0.3-0.03 (% vol)	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
mean 1	6.3	6.4	6.8	7.7	7.4	7.5
std dev 1	1.1	0.8	0.9	1.7	2	1.5
95% c.i.1	1.1	0.8	0.9	1.6	1.9	1.5
mean 2	6.3	6.1	4.6	4.2	4.8	6.2
std dev 2	2.9	1.5	2.6	1.2	2.7	1.5
95% c.i.2	2.8	1.5	2.6	1.2	2.6	1.5
mean 3	7.4	5.3	4.9	7	7	7.6
std dev 3	1.6	1.6	1.5	3.6	2.8	3.6
95% c.i.3	1.6	1.6	1.5	3.5	2.8	3.5
mean 4	9.7	9.8	7.6	10.9	11.6	10
std dev 4	1.2	1.4	2.2	0.8	1.9	1.9
95% c.i.4	1.4	1.5	2.5	1	2.1	2.1
Ttest 1-2	0.495	0.372	0.095	0.008	0.09	0.138
Ttest 1-3	0.157	0.142	0.041	0.371	0.42	0.467
Ttest 1-4	0.008	0.016	0.288	0.012	0.02	0.068
Ttest 2-3	0.273	0.252	0.423	0.112	0.152	0.249
Ttest 2-4	0.048	0.011	0.078	0	0.006	0.025
Ttest 3-4	0.039	0.006	0.075	0.058	0.026	0.159

Pore<0.03 (%vol)	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
mean 1	4.8	4.5	5.2	4.9	4.6	4.9
std dev 1	0.6	0.5	0.7	0.5	0.4	0.6
95% c.i.1	0.6	0.5	0.7	0.5	0.3	0.6
mean 2	4.5	4.7	4.6	4.1	4.5	4.3
std dev 2	0.5	0.6	0.3	0.2	0.2	0.2
95% c.i.2	0.5	0.6	0.3	0.2	0.2	0.2
mean 3	4.4	4	4.3	4.4	4.5	4.5
std dev 3	0.6	0.6	0.4	0.5	0.7	0.7
95% c.i.3	0.6	0.5	0.4	0.5	0.7	0.7
mean 4	5.3	5.3	4.7	5.3	5.1	5
std dev 4	0.2	0.4	0.7	0.7	0.6	0.7
95% c.i.4	0.3	0.5	0.8	0.8	0.7	0.8
Ttest 1-2	0.246	0.291	0.124	0.015	0.283	0.077
Ttest 1-3	0.247	0.131	0.052	0.085	0.405	0.275
Ttest 1-4	0.086	0.036	0.222	0.223	0.159	0.363
Ttest 2-3	0.463	0.077	0.151	0.172	0.468	0.26
Ttest 2-4	0.018	0.108	0.422	0.042	0.114	0.097
Ttest 3-4	0.035	0.01	0.217	0.065	0.148	0.207

Init Water (% vol)	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
mean 1	63.7	65.1	66.0	62.3	59.7	59.9
std dev 1	9.2	6.2	5.2	17.4	12.5	9.4
95% c.i.1	9.0	6.1	5.1	17.1	12.2	9.2
mean 2	51.4	55.0	57.4	57.8	63.0	64.6
std dev 2	8.4	6.8	5.7	4.4	5.4	10.4
95% c.i.2	8.3	6.7	5.6	4.4	5.3	10.1
mean 3	45.6	47.4	51.5	49.7	55.3	48.2
std dev 3	12.1	5.0	10.1	9.9	8.9	5.9
95% c.i.3	11.8	4.9	9.9	9.7	8.7	5.8
mean 4	44.0	46.1	42.9	47.5	53.7	46.3
std dev 4	10.7	7.8	5.1	8.4	8.6	3.4
95% c.i.4	12.1	8.9	5.8	9.5	9.8	3.9
Ttest 1-2	0.048	0.035	0.033	0.324	0.322	0.264
Ttest 1-3	0.029	0.002	0.028	0.134	0.295	0.044
Ttest 1-4	0.031	0.014	0.001	0.102	0.246	0.028
Ttest 2-3	0.234	0.064	0.179	0.104	0.098	0.021
Ttest 2-4	0.189	0.095	0.009	0.077	0.097	0.016
Ttest 3-4	0.427	0.408	0.102	0.380	0.413	0.305

Bulk Dens (% vol)	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
mean 1	0.439	0.494	0.576	0.609	0.695	0.635
std dev 1	0.087	0.092	0.165	0.191	0.113	0.114
95% c.i.1	0.085	0.090	0.162	0.187	0.111	0.112
mean 2	0.469	0.478	0.472	0.526	0.633	0.600
std dev 2	0.107	0.120	0.146	0.214	0.245	0.159
95% c.i.2	0.105	0.117	0.143	0.210	0.240	0.156
mean 3	0.499	0.476	0.507	0.564	0.631	0.688
std dev 3	0.127	0.086	0.047	0.139	0.143	0.209
95% c.i.3	0.124	0.084	0.046	0.136	0.141	0.205
mean 4	0.628	0.595	0.578	0.662	0.675	0.604
std dev 4	0.098	0.054	0.094	0.045	0.213	0.089
95% c.i.4	0.111	0.061	0.106	0.051	0.241	0.101
Ttest 1-2	0.337	0.419	0.1913	0.2923	0.3353	0.3676
Ttest 1-3	0.235	0.391	0.2368	0.3601	0.2583	0.3380
Ttest 1-4	0.028	0.065	0.4904	0.3099	0.4467	0.3512
Ttest 2-3	0.368	0.490	0.3370	0.3879	0.4958	0.2649
Ttest 2-4	0.051	0.076	0.1474	0.1473	0.4098	0.4849
Ttest 3-4	0.094	0.038	0.1601	0.1300	0.3893	0.2537

Total Pore (% vol)	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
mean 1	83.4	81.4	78.3	77.0	73.8	76.0
std dev 1	3.3	3.5	6.2	7.2	4.3	4.3
95% c.i.1	3.2	3.4	6.1	7.0	4.2	4.2
mean 2	82.3	82.0	82.2	80.2	76.1	77.4
std dev 2	4.0	4.5	5.5	8.1	9.2	6.0
95% c.i.2	4.0	4.4	5.4	7.9	9.1	5.9
mean 3	81.2	82.0	80.9	78.7	76.2	74.0
std dev 3	4.8	3.2	1.8	5.2	5.4	7.9
95% c.i.3	4.7	3.2	1.7	5.1	5.3	7.7
mean 4	76.3	77.5	78.2	75.0	74.5	77.2
std dev 4	3.7	2.0	3.5	1.7	8.0	3.4
95% c.i.4	4.2	2.3	4.0	1.9	9.1	3.8
Ttest 1-2	0.337	0.419	0.191	0.292	0.335	0.368
Ttest 1-3	0.235	0.391	0.237	0.360	0.258	0.338
Ttest 1-4	0.028	0.065	0.490	0.310	0.447	0.351
Ttest 2-3	0.368	0.490	0.337	0.388	0.496	0.265
Ttest 2-4	0.051	0.076	0.147	0.147	0.410	0.485
Ttest 3-4	0.094	0.038	0.160	0.130	0.389	0.254

AW(%) (% vol)	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
mean 1	20.9	22.5	25.4	21.4	22.0	22.7
std dev 1	3.4	2.3	3.6	10.2	4.0	6.0
95% c.i.1	3.4	2.2	3.5	10.0	3.9	5.8
mean 2	16.7	15.6	10.4	6.9	14.4	12.7
std dev 2	9.6	5.1	2.9	3.8	9.8	6.7
95% c.i.2	9.4	5.0	2.9	3.7	9.6	6.6
mean 3	20.5	16.5	16.0	14.2	19.3	15.0
std dev 3	6.8	1.5	8.8	5.7	5.5	3.2
95% c.i.3	6.6	1.5	8.6	5.6	5.4	3.1
mean 4	23.0	20.1	18.0	23.1	23.0	23.3
std dev 4	1.7	3.9	5.2	9.8	3.6	3.7
95% c.i.4	1.9	4.4	5.9	11.1	4.0	4.2
Ttest 1-2	0.228	0.033	0.000	0.030	0.113	0.034
Ttest 1-3	0.456	0.003	0.060	0.139	0.232	0.038
Ttest 1-4	0.180	0.199	0.058	0.415	0.368	0.445
Ttest 2-3	0.273	0.374	0.149	0.041	0.213	0.283
Ttest 2-4	0.143	0.124	0.055	0.045	0.090	0.024
Ttest 3-4	0.265	0.126	0.361	0.127	0.165	0.019

Sand (% vol)	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
mean 1	13.3	19.5	24.3	32.3	35.3	39.4
std dev 1	6.7	12.7	18.5	22.3	22.1	27.6
95% c.i.1	6.6	12.4	18.1	21.9	21.7	27.1
mean 2	19.6	23.3	23.5	42.1	31.5	15.2
std dev 2	4.1	2.6	7.6	12.1	23.1	5.2
95% c.i.2	4.0	2.6	7.4	11.9	22.7	5.1
mean 3	22.0	27.3	30.3	31.5	29.6	27.7
std dev 3	9.1	10.1	12.2	12.6	14.3	20.8
95% c.i.3	9.0	9.9	12.0	12.3	14.0	20.4
mean 4	20.4	27.0	40.6	37.4	38.3	33.0
std dev 4	3.8	7.3	17.8	13.8	24.7	4.6
95% c.i.4	4.3	8.3	20.2	15.6	28.0	5.2
Ttest 1-2	0.084	0.302	0.468	0.240	0.411	0.089
Ttest 1-3	0.090	0.187	0.306	0.474	0.342	0.264
Ttest 1-4	0.071	0.189	0.149	0.363	0.437	0.341
Ttest 2-3	0.329	0.242	0.193	0.135	0.448	0.160
Ttest 2-4	0.406	0.240	0.116	0.333	0.364	0.003
Ttest 3-4	0.382	0.477	0.224	0.293	0.312	0.325

Silt (% vol)	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
mean 1	62.0	66.8	62.2	54.4	53.9	48.9
std dev 1	6.1	10.7	18.1	15.7	15.9	26.2
95% c.i.1	6.0	10.4	17.7	15.4	15.6	25.7
mean 2	61.5	60.7	58.4	45.0	57.2	70.6
std dev 2	6.6	4.4	5.7	16.9	20.4	13.5
95% c.i.2	6.5	4.3	5.6	16.6	20.0	13.2
mean 3	64.6	60.6	58.7	59.0	57.2	56.0
std dev 3	5.8	8.4	9.8	10.2	16.3	20.1
95% c.i.3	5.7	8.2	9.6	10.0	15.9	19.7
mean 4	70.1	66.7	49.2	51.8	52.9	61.8
std dev 4	4.8	10.3	19.0	17.8	27.1	6.0
95% c.i.4	5.4	11.7	21.4	20.1	30.7	6.8
Ttest 1-2	0.459	0.178	0.354	0.222	0.403	0.104
Ttest 1-3	0.280	0.199	0.373	0.323	0.389	0.341
Ttest 1-4	0.054	0.495	0.203	0.424	0.480	0.202
Ttest 2-3	0.254	0.487	0.478	0.108	0.499	0.140
Ttest 2-4	0.051	0.215	0.246	0.317	0.416	0.152
Ttest 3-4	0.115	0.226	0.244	0.288	0.411	0.309

Clay	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
(% vol)						
mean 1	24.7	13.9	13.4	13.6	11.0	11.3
std dev 1	3.6	2.8	4.2	7.2	8.3	3.6
95% c.i.1	3.6	2.7	4.1	7.1	8.1	3.5
mean 2	18.8	15.8	18.1	13.1	11.1	14.5
std dev 2	6.5	5.3	4.0	5.2	5.3	16.7
95% c.i.2	6.4	5.2	3.9	5.1	5.2	16.3
mean 3	13.4	12.1	11.3	9.7	13.1	15.8
std dev 3	5.6	3.4	3.7	3.8	7.9	9.0
95% c.i.3	5.5	3.4	3.6	3.7	7.8	8.8
mean 4	9.7	6.6	10.2	10.8	8.9	5.0
std dev 4	1.2	3.7	1.7	4.1	3.1	1.7
95% c.i.4	1.3	4.1	1.9	4.6	3.5	2.0
Ttest 1-2	0.090	0.274	0.079	0.457	0.486	0.367
Ttest 1-3	0.009	0.224	0.237	0.193	0.359	0.205
Ttest 1-4	0.001	0.025	0.120	0.268	0.338	0.016
Ttest 2-3	0.126	0.144	0.023	0.166	0.347	0.448
Ttest 2-4	0.032	0.021	0.011	0.264	0.260	0.169
Ttest 3-4	0.141	0.054	0.319	0.372	0.194	0.046

Carbon	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
(% vol)						
mean 1	10.6	8.4	6.4	3.8	2.1	2.4
std dev 1	4.2	5.4	5.1	4.4	1.9	2.8
95% c.i.1	4.1	5.3	5.0	4.3	1.9	2.8
mean 2	12.7	11.6	8.9	8.8	5.0	4.7
std dev 2	1.5	1.5	3.6	3.9	4.0	4.0
95% c.i.2	1.5	1.5	3.5	3.8	3.9	3.9
mean 3	10.8	9.3	8.7	8.5	3.0	1.5
std dev 3	2.3	0.9	0.9	2.0	1.8	0.8
95% c.i.3	2.3	0.9	0.9	2.0	1.7	0.8
mean 4	4.8	4.9	4.5	3.2	2.5	1.2
std dev 4	1.0	0.4	0.8	2.2	3.4	1.6
95% c.i.4	1.2	0.4	1.0	2.5	3.8	1.8
Ttest 1-2	0.198	0.161	0.235	0.069	0.131	0.203
Ttest 1-3	0.463	0.380	0.220	0.059	0.266	0.288
Ttest 1-4	0.033	0.141	0.257	0.410	0.444	0.252
Ttest 2-3	0.116	0.022	0.472	0.446	0.206	0.109
Ttest 2-4	0.000	0.001	0.045	0.031	0.203	0.096
Ttest 3-4	0.004	0.000	0.001	0.015	0.409	0.388

Pf2.54	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
(% vol)						
mean 1	41.7	42.3	47.818	41.525	43.826	43.339
std dev 1	5.2	5.8	4.009	7.439	5.723	7.309
95% c.i.1	5.1	5.7	3.928	7.290	5.608	7.163
mean 2	37.1	35.0	27.813	25.945	38.858	34.423
std dev 2	9.5	2.2	7.765	5.557	11.687	6.524
95% c.i.2	9.3	2.2	7.609	5.446	11.453	6.393
mean 3	39.6	34.0	33.723	30.932	37.883	37.174
std dev 3	5.9	1.4	10.132	4.495	8.242	10.684
95% c.i.3	5.8	1.4	9.930	4.405	8.077	10.470
mean 4	40.0	35.7	34.010	41.798	41.078	40.098
std dev 4	3.1	5.8	9.311	7.338	4.732	3.050
95% c.i.4	3.5	6.6	10.536	8.304	5.354	3.452
Ttest 1-2	0.219	0.041	0.004	0.009	0.242	0.060
Ttest 1-3	0.310	0.030	0.031	0.030	0.143	0.191
Ttest 1-4	0.315	0.103	0.055	0.482	0.259	0.233
Ttest 2-3	0.335	0.230	0.196	0.107	0.448	0.339
Ttest 2-4	0.296	0.430	0.202	0.020	0.374	0.097
Ttest 3-4	0.453	0.329	0.485	0.052	0.274	0.317

pF2	0-10cm	10-20cm	20-30cm	50-55cm	95-100cm	150cm
(% vol)						
mean 1	46.4	46.8	52.979	46.456	48.427	48.163
std dev 1	5.4	6.0	4.216	7.869	5.674	7.356
95% c.i.1	5.3	5.8	4.132	7.711	5.561	7.209
mean 2	41.6	39.7	32.398	30.050	43.348	38.679
std dev 2	9.2	2.6	7.722	5.394	11.593	6.608
95% c.i.2	9.0	2.6	7.567	5.286	11.360	6.476
mean 3	44.1	38.0	38.022	35.328	42.402	41.723
std dev 3	6.5	1.6	9.914	4.059	8.624	11.184
95% c.i.3	6.4	1.6	9.715	3.978	8.451	10.960
mean 4	45.3	41.0	38.721	47.121	46.175	45.121
std dev 4	3.4	6.2	9.974	8.038	5.328	3.638
95% c.i.4	3.8	7.1	11.287	9.095	6.030	4.117
Ttest 1-2	0.202	0.046	0.003	0.008	0.236	0.052
Ttest 1-3	0.300	0.027	0.025	0.030	0.147	0.189
Ttest 1-4	0.377	0.139	0.059	0.459	0.308	0.254
Ttest 2-3	0.336	0.157	0.204	0.086	0.450	0.330
Ttest 2-4	0.247	0.381	0.209	0.022	0.343	0.082
Ttest 3-4	0.379	0.245	0.465	0.055	0.254	0.301

8.5 Appendix F: Tree and infiltration data for all land uses

Inf rate – Saturated infiltration rate, f_c (mm/h)
No trees – Number of trees in a circle with 10m radius around the infiltration site
Dist 2 Tree – Distances to the nearest tree (m)
Perimeter tree – The perimeter of the tree (cm)
** n.v. = no value*

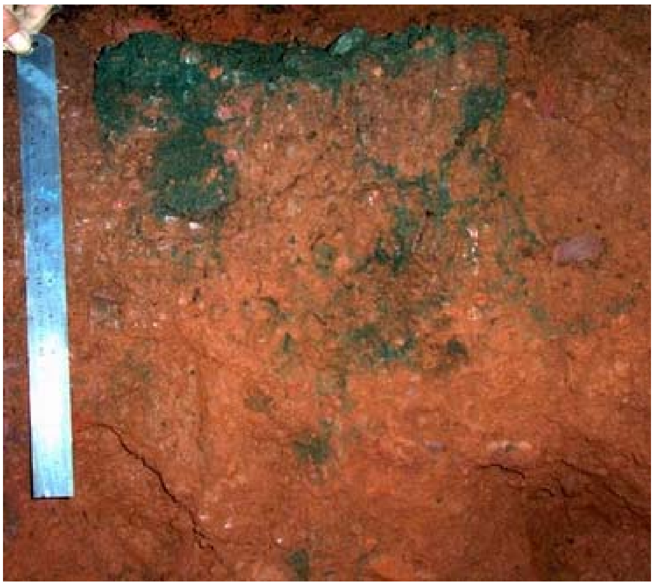
		Inf rate	No Trees	Dist 2 Tree	Perim Tree
Forest	1A	489	n.v.*	1.2	19
	1B	1564	9	0.9	61
	1C	3059	n.v.	2.3	135
	1D	608	n.v.	2.2	66
	1E	588	11	0.8	30
	1F	826	14	1.6	101
	1G	3165	4	1.4	19
	(1H	73	6	1.3	46)
	1I	273	9	1.0	55
	1J	1015	n.v.	1.1	34
	1K	1254	5	3.0	140
	1L	249	5	2.5	66
Shrub	2A	457	0	20.0	42
	2B	1130	n.v.	1.6	40
	2C	230	0	50.0	n.v.
	2D	1241	0	13.0	n.v.
	2E	274	0	n.v.	n.v.
	2F	618	0	n.v.	n.v.
	2G	895	0	n.v.	n.v.
	2H	290	0	40.0	n.v.
	2I	77	6	4.0	31
Plantation	3A	1300	n.v.	2.0	52
	3B	717	47	0.8	46
	3C	700	19	1.7	19
	3D	2531	18	1.6	38
	3E	1727	8	4.5	289
	3F	1910	11	1.6	198
	3G	791	7	2.0	80
	3H	415	9	1.2	80
Cropland	4A	277	0	n.v.	n.v.
	4B	924	1	1.5	140
	4C	594	10	3.2	35
	(4D - A	2203	4	5.0	n.v.)
	4D - B	75	4	5.0	n.v.
	4E	561	0	n.v.	n.v.
	4F -A	96	4	8.0	106
	4F - B	2167	4	8.0	106
	(4G	88	0	20.0	54)
	4H	474	1	10	43

Correlation "Infiltration rate - Number of trees"	R-value =	-0,044
Correlation "Infiltration rate - Distance to nearest tree"	R-value =	-0,272
Correlation "Infiltration rate - Perimeter tree"	R-value =	-0,066

8.6 Appendix G: Blue dye tracer results

A. Blue dye tracer experiment in <u>forest</u>, cross sections.

1A



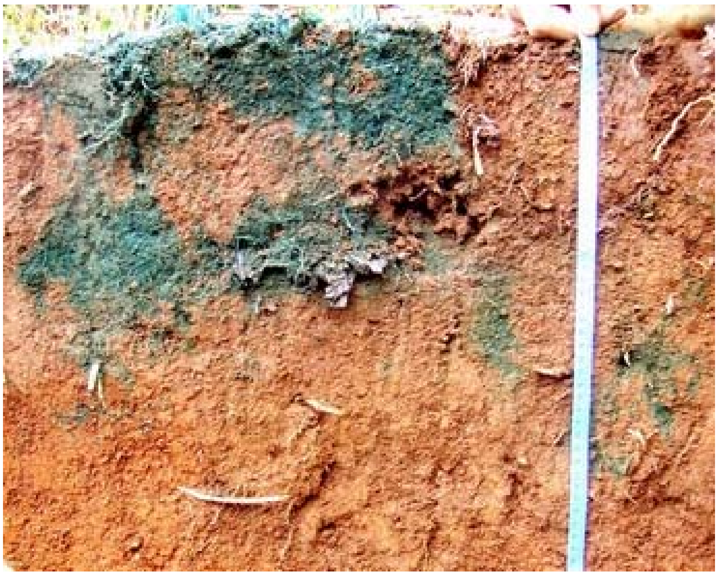
1D

1F

1K

B. Blue dye tracer experiment in <u>shrub</u>, cross sections.

2D



2E

2F

2G

C. Blue dye tracer experiment in plantation, cross sections.

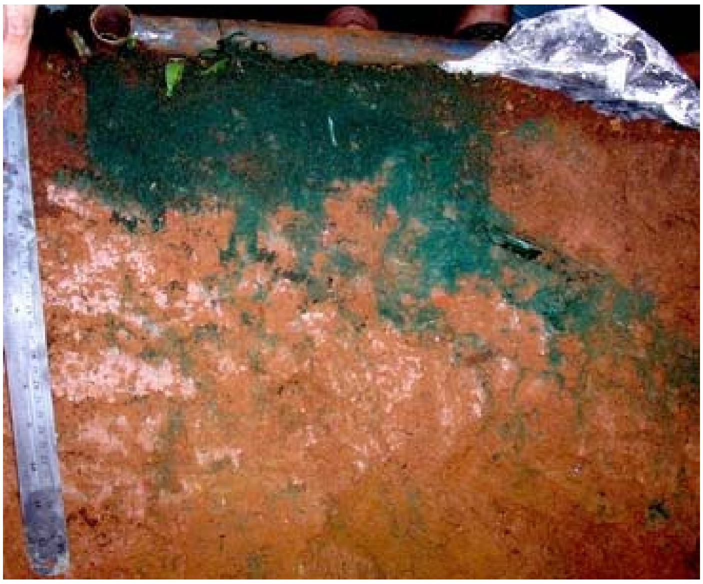
3A

3C

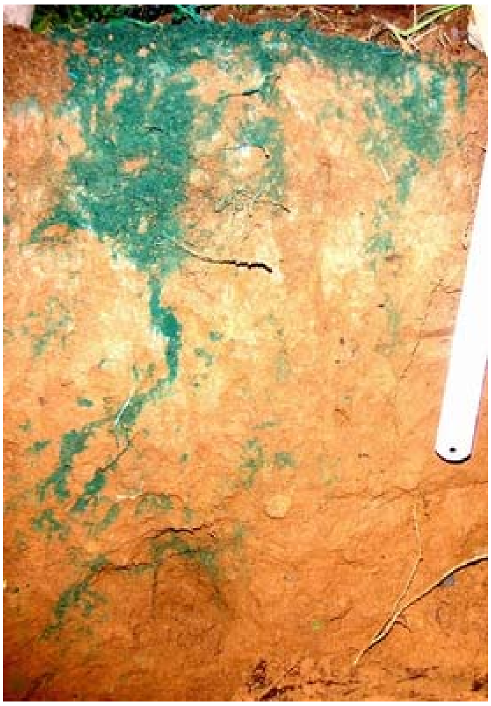
3D

3F

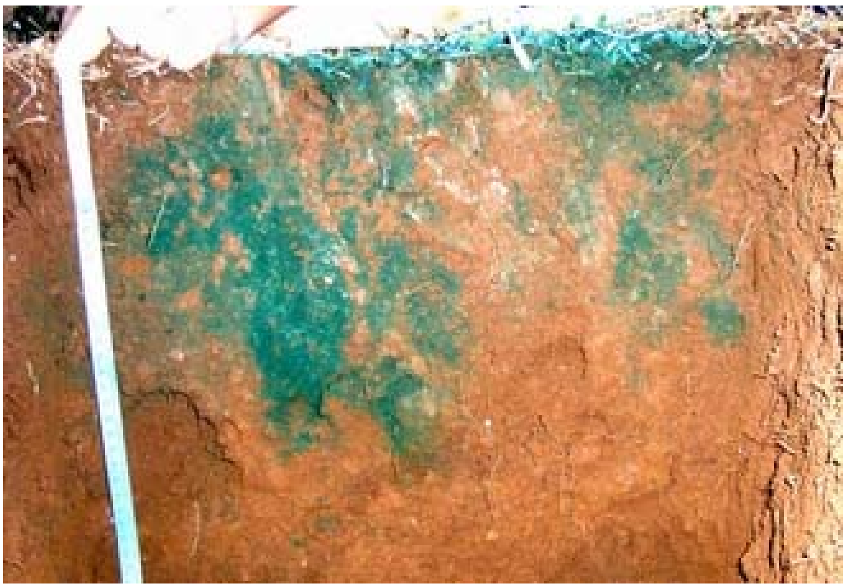
D. Blue dye tracer experiment in <u>cropland</u>, cross sections.



4A



4C



4F