# TROPICAL MONTANE CLOUD FOREST SOILS

## A soil study in Cloudbridge Nature Reserve


### Abstract

This research looks at the influence that deforestation and farming activities have on tropical soil properties. To do so, nine soil profiles, around the Cloudbridge Nature Reserve in Costa Rica were studied. This Reserve has three types of habitats: a primary forest, a secondary forest that regenerated naturally from deforestation and farming activities, and a secondary forest that struggled to recover on its own and had to be helped through tree planting actions. Three soils were studied on every type of habitat. Hypothesis were made regarding the influence that deforestation, farming activity and slope influence the thickness of the topsoil, the humus, the organic matter content, and the water retention. No statistically significant conclusion was drawn from the research data, but multiple trends could be recognized. Further studies are needed.



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# Table of Contents



# 1) Introduction:

Soils are natural materials located on the Earth's surface, they are composed of solids (minerals and organic matter), fluid (water, dissolved salts, acids bases, and ions), and gases (soil $CO_2$, $O_2$, $N_2$,

and $CH_4$). To study a soil (or pedon), a vertical soil section of the pedon from the surface to the bedrock is considered; this is called the soil profile.

Looking at a soil profile one can notice several different horizons or horizontal layers. These horizons distinguish from each other in texture, colour, structure, organic matter and or presence of carbonates (Orgiazzi et al., 2016, p.10).

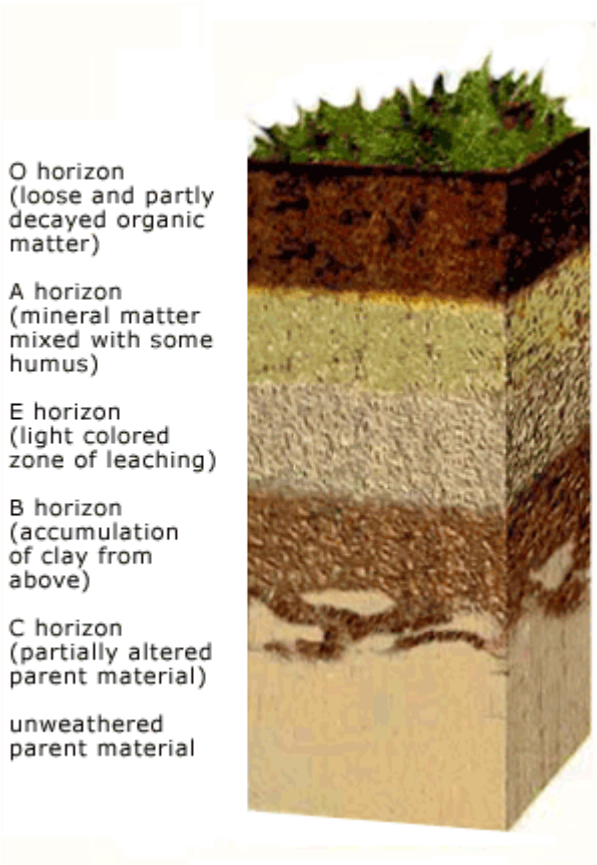


*Figure 1. Illustration of convention for soil horizons (Groundspeak, 2017).*

As Figure 1 illustrates, there are 5 master horizons: O, A, E, B, and C. A soil may have all of the above layers present or lack some depending on the soil forming factors and processes. To be considered as a soil though it must have at least a C and an A horizon.

The O horizon is the surface organic layer. It consists of organic residues in distinct stages of decomposition (litter, fermented or humus).

The A horizon, or topsoil, consists of a mixture of mineral and organic matter with strong eluviation (strong movement of the organic matter within the soil caused by rainfall). This layer is the most fertile.

The E horizon is characterized by the loss of silicate, clay, iron, and/or aluminium and therefore an enrichment of more erosion-resistant materials (like quartz and sand).

The B horizon, or subsoil, consists of accumulated materials such as silicate clay, iron, aluminium, carbonates, and/or gypsum.

The C horizon is weathered, loose bedrock (Tawwhid, 2013, p. 9).

In the report, we will also talk about the Epipedon, the Soil Survey Staff (2014) define it as follows: “The Epipedon (Gr. epi, over, upon, and pedon, soil) is a horizon that forms at or near the surface and in which most of the rock structure has been destroyed”.

Moreover, soil is a natural resource, and as such it is limited and must be managed in a sustainable way. For a productive soil to form from the parent material it can take from 10,000 to 100,000 years (Towwhid, 2013, p. 14) so it is very important to protect them from degradation.

There are basically 5 soil forming processes:

1. Physical weathering: the destruction of rocks without changing the chemical composition. This process produces loose material from parent rocks.
2. Chemical weathering: reaction of the parent material with acid or water, that leads to the destruction of the rock and to the formation of secondary minerals.
3. Biochemical and biophysical weathering: chemical or physical weathering caused by biologically produced substances or by organisms’ movements.
4. Leaching: the downwards flow of water dissolves soil particles and transports them to deeper soil layers.
5. Clay destruction: clay is an unstable mineral and its disintegration releases aluminium, and silica. This process lowers the soil pH. (Orgiazzi, et al., 2016, pp. 20).

The type of soil that will form is determined by these processes that are influenced by the so-called soil forming factors: climate, organisms, topography, parent material, time, and human activity.

Climate: temperature and precipitation are the main climatic factors that determine soil formation. Temperature regulates the rate of chemical reactions, and water is the main reactant in soil, as well as the medium of translocation of soil particles.

Organisms: organisms living in the soil or exploiting it cause several changes in its composition and structure. “Among the changes [organisms] cause are addition and decomposition of organic matter, addition and losses of plant nutrients, biogeochemical cycling, soil mixing, and changes in soil structure and porosity.” (Tahwwili, 2013, p.11).

Topography: the form of the land greatly influences the development of the soil. Position on the hill, slope, altitude, and aspect determine the degree of erosion, deposition, drainage, infiltration, runoff, and exposure to sunlight and wind.

Parent material: The bedrock from which the soil will form has properties, such as texture and chemical composition, that will be inherited by the resulting soil.

Time: Soils form and mature over the years, so the type of soil potentially changes overtime.

Human activity: Humans can cause profound changes in soil properties in very short times. The effects can be either direct (i.e.: through soil sealing, liming, and cropping) or indirect (through changing the soil forming factors through processes such as irrigation, drainage, or deforestation) (Towwhid, 2013, pp.9). In this paper, we will try to understand, what consequences the switch from forest to pasture-land can have on soil properties.

The topic of deforestation, its causes and consequences, is very well studied and environmentalists keep raising people's awareness about this global problem. What is often left aside and overlooked is desertification. Desertification is the degradation of the soil due to human activities, such as deforestation, agriculture, settlement and climate change.

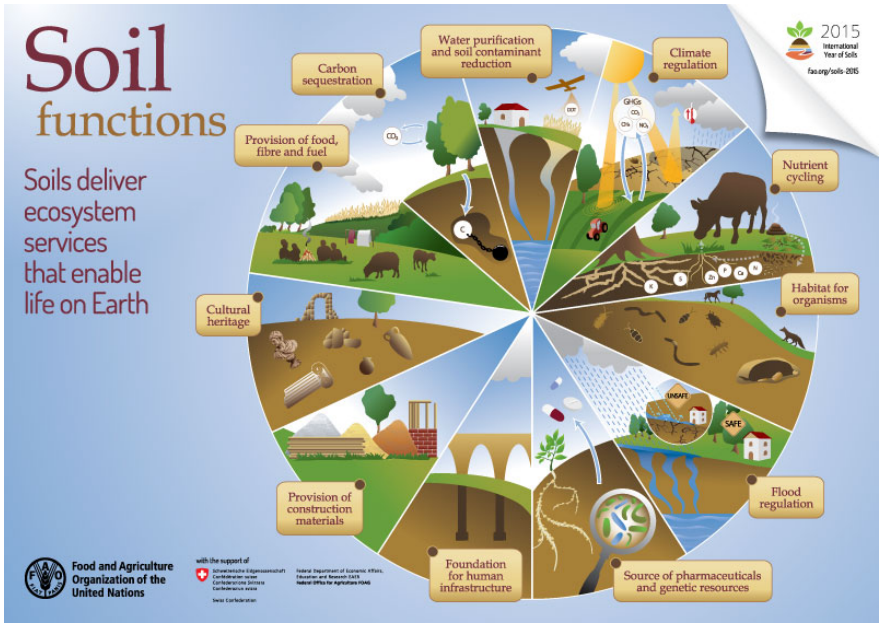


*Figure 2. Soil functions (FAO, 2015).*

Figure 2 shows all the functions that soils fulfil and the huge amount of ecosystem services they provide us with. Soil degradation costs the world annually up to $10.6 trillion, according to a report published by the Economics of Land Degradation Initiative (ELD Initiative, 2015).

Forests protect the soil from erosion, increase the organic content, decrease the pH, and improve water retention.

The purpose of my research is to study and understand to what degree deforestation and farming activities change the properties of the soil and if it can recover after deforestation. Cloudbridge Nature Reserve happens to be the perfect location for such a study. While part of the reserve's forests are primary (i.e. uncut), most of the reserve was used for farming until 2002, when it was acquired by Cloubridge and allowed to regrow into a Tropical Montane Cloud Forest, either through (unassisted) regeneration, or active planting.

Some parts of the forest in the reserve struggled to recover on their own, so reserve staff and volunteers have planted trees to help the regrowth. The goal of the study was to find out if soil degradation has contributed to these sites struggling to regrow forest on their own.

## 2) Hypothesis

According to Towwhid (2013, pp. 157) deforestation has an impact on: the erosion of the soil through water and sun, organic content of the soil, soil aggregates, hydrologic processes (infiltration, retention etc.), and nutrient content. With the collected information, we can make the following hypotheses on what we will find in the soils of the reserve:

1. Farming activities relate to a negative biomass balance, leading to a loss of organic material in the soil (Tawwhid, 2013, p.165). Therefore, the thickness of the A and O horizons are expected to be smaller in planted and naturally regenerated areas than in the primary areas.
2. Forests protect the topsoil and the organic matter from erosion (Tawwhid, 2013, p.165). Because planted areas are the one where trees struggle to grow, I hypothesize that they tend to have a less widespread forest cover than the naturally regenerated ones. It is expected the thickness of the A and O horizons will be smaller in planted areas than naturally regenerated areas.
3. The primary areas are expected to have a higher organic matter content (see hypothesis 1), hence a darker colour.
4. Farming often causes the compacting of the soil and the destruction of the soil aggregates, thus limiting the water retention capacity of the soil (Tawwhid, 2013, p. 165). Therefore, it is expected the water retention in planted areas will be worse than in naturally regenerated areas, which will be worse than in primary areas.
5. The elevated temperatures in deforested areas raise the soil organic matter decomposition rate (Tawwhid, 2013, p.165). It is expected that the humus will tend to be at a higher stage of decomposition in planted areas than in primary and regenerated areas.
6. The slope influences the soil texture as finer particles are more easily washed downslope, accumulating in flatter areas (Orgiazzi et al., 2016, p. 13). Therefore, finer soil particles are expected in the flatter study areas.
7. The bigger the slope the less water is retained (Orgiazzi et al., 2016, p.13), therefore areas with larger slopes are expected to have lower soil humidity.
8. The greater canopy cover in primary areas prevents the sun from warming up the soil (Tawwhid, 2013, p. 165). It is expected that soils in planted areas will have higher temperatures than those in the regenerated or primary areas. The temperatures might also depend on the direction of the slope, with soils facing south expected to have higher temperatures.
9. The texture of the planted and regenerated areas are expected to be coarser, because soil erosion, which is greater in deforested areas, tends to carry away the finer particles (Orgiazzi et al., 2016, p.128).

## 3) Materials

- Shovel
- Plastic bags
- Measuring tape (5 m long)
- Sticks
- Luster Leaf Rapitest: soil moisture, temperature, pH
- iPhone 4 “Compass” app

# 4) Methods

## 4.1) Study location

Cloudbridge Nature Reserve has 3 several types of forest areas: primary forest, natural regrowth, and planted.

The primary forest has not been destroyed, nor directly affected by human activities, since at least 1946. The natural regrowth was once either pasture or farm-land, and, depending on the area, the land was removed from agricultural use between 2002 and 2008, allowing the forest to regenerate. Like the natural regrowth areas, the planted areas had been cleared and used for pasture/scrub pasture or farmland until 2002, 2006, or 2008. As many of the planted areas had struggled to regenerate on their own local staff and volunteers have been helping the land recovery by planting native, local tree species.

## 4.2) Plots

The Reserve has set up 24 study Plots on their land, that have been used for a variety of different studies (from forestry to bird watching). We chose 9 of these plots for our study, 3 for every different ecosystem. The Plots were chosen to be well distributed around the reserve, and so that the planted and natural regrowth areas were of similar ages (Figure 3).

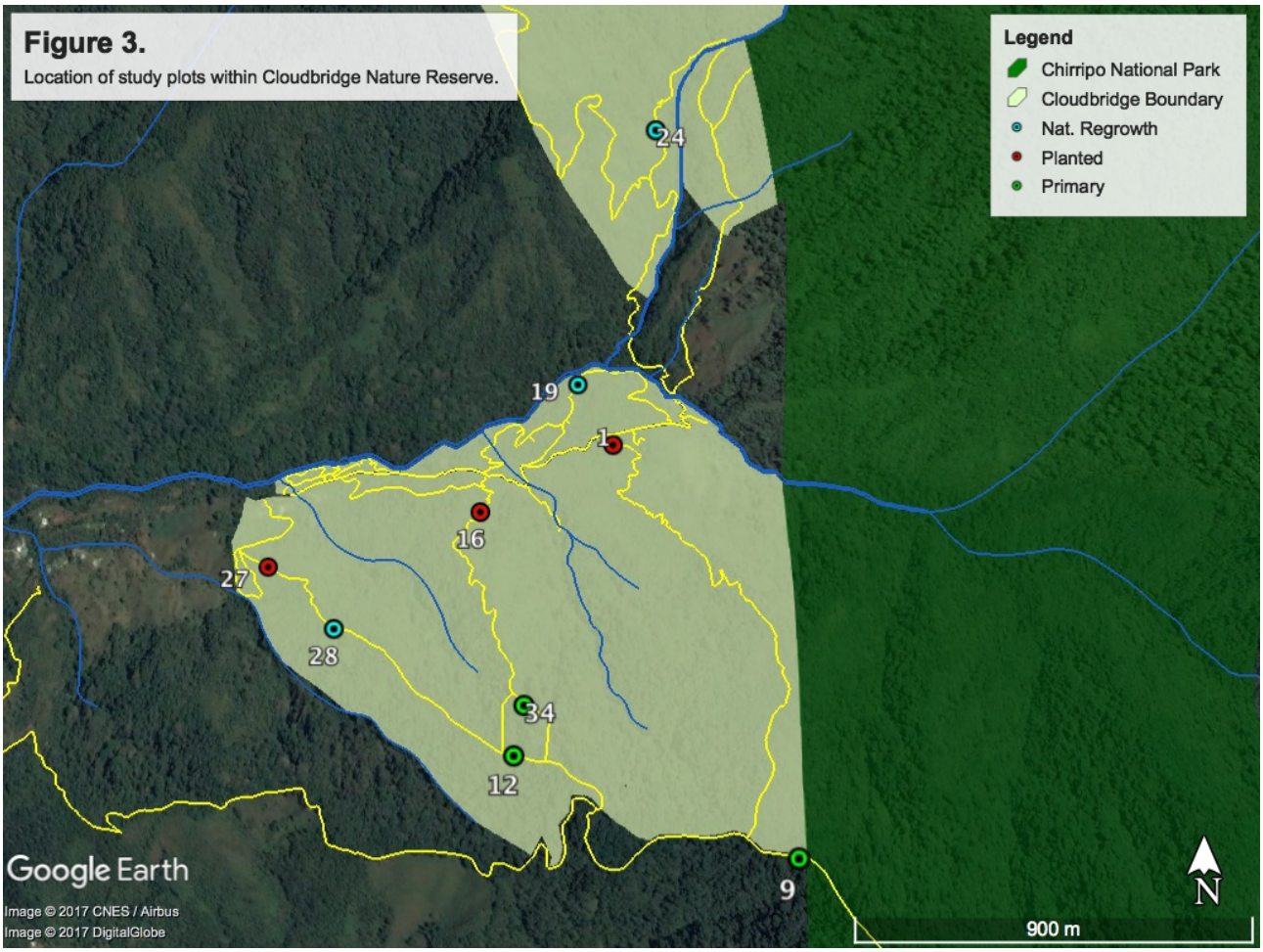


*Figure 3. Map of the Cloudbridge Nature Reserve, with plot locations*

## 4.3) Soil analysis

The soil analysis was always performed over a 110 cm deep vertical profile, by digging a test pit. For some plots, this depth was not reached due to the impossibility of digging any further (i.e. hitting big stones or bedrock).

First, the profile was studied and the different horizons separated. After marking the layers with some sticks, their depth and thickness were recorded in the field book. The amount of gravel and roots in each layer was recorded, as well as the humus form, and the general hydraulic situation. At this point, a soil sample from each horizon was collected in separated plastic bags, to be studied later in the laboratory.

Right next to the hole, the soil pH, moisture and temperature were measured with the help of the Rapitest meters. The slope was also measured, using the compass app on an iPhone 4.

Before leaving the plot, the hole was filled in again, to prevent small animals from falling into it and to minimize habitat disturbance.

In the laboratory, the samples were tested for their texture by feel (USDA, 2017).

When the sample could be rolled until being thinner than a pencil it was taken that the main component was clay. To estimate the percentage of coarse matter, pages 9 and 10 of the Munsell soil colour chart (Munsell Albert Henry,1994) were used.

The colour of the soil samples was studied with the help of the “Revised standard colour charts” (Munsell Albert Henry, 1994, revised edition) on a computer with 100% luminosity. The soil was put on the screen and lighted with a supplementary flashlight.

## 4.4) Statistical analysis

The data that was collected in the field was later entered into an excel sheet. For every soil studied a profile paper with all the data was produced (see Appendix 1).

To analyse the data Minitab 18 was used and, depending on the variable, the proper analysis method was chosen. The texture of the soil in function of the vegetation type (primary, natural regrowth or planted) was tested for normality. In case of normal data distribution the ANOVA test would have been the best choice, otherwise a Kruskal-Wallis test was preferred. As no data showed a normal distribution, a Kruskal-Wallis test was applied for the analysis of the influence of the vegetation type on the humus type, water retention, A-and O-horizon thickness.

To analyse the influence of the slope on moisture, temperature, clay percentage and organic matter content a scatterplot analysis was the best option. To show the correlation between the A-horizon thicknesses and the vegetation type, a chart comparing the means was created.

## 5) Results

Photographs of the soil profiles at each station are presented in Figures 4-6 (planted), Figures 7-9 (natural regrowth), and Figures 10-12 (primary forest). Soil temperature, moisture, and slope at each plot is summarized in Table 1, while the thicknesses of the horizons, texture of the A-horizon, and colour of the A- and B-horizons is shown in Table 2.

None of the comparisons done were statistically significant, although some trends can be identified. Therefore, only the results that showed a trend will be discussed in detail.

*Table 1 Temperature, moisture, and slope of the soil, measured at the plot location*

| Habitat | Plot | Temp [°F] | Temp [°C] | Moisture [1-9.9][1] | Slope [%] |
|---|---|---|---|---|---|
| Planted | 1 | 59 | 15.0 | 3.3 | 21 |
| | 16 | 56 | 13.3 | 1.8 | 31 |
| | 27 | 59 | 15.0 | 5.5 | 31 |
| Primary | 9 | 55 | 12.8 | 3.1 | 70 |
| | 12 | 57 | 13.9 | 4.0 | 45 |
| | 34 | 56 | 13.3 | 4.0 | 40 |
| Natural Regrowth | 19 | 54 | 12.2 | 1.8 | 14 |
| | 24 | 57 | 13.9 | 1.5 | 97 |
| | 28 | 59 | 15.0 | 3.3 | 42 |

1: Numbers from 1 to 9.9 signify increasing wetness.

*Table 2. Horizon thickness, texture of the A horizon, and darkness of A and B horizons.*

| Habitat | Plot | Horizon Thickness [cm] | | | | Texture of A-Horizon [%] | | | Darkness of Horizon [1-8][1] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | A | O | AB | B | Clay | Coarse | Gravel | A [1-8][1] | B [1-8][1] |
| Planted | 1 | 4 | 1 | 0 | 18 | 85 | 15 | 0 | 4 | 5 |
| | 16 | 6 | 3 | 0 | 7 | 95 | 5 | 0 | 3 | 6 |
| | 27 | 10 | 4 | 0 | 30 | 0 | 100 | 0 | 4 | 7 |
| Primary | 9 | 18 | 2 | 0 | 13 | 100 | 0 | 0 | 3 | 4 |
| | 12 | 17 | 2 | 0 | 10 | 95 | 5 | 0 | 5 | 6 |
| | 34 | 28 | 2 | 0 | 42 | 90 | 10 | 0 | 4 | 8 |
| Natural Regrowth | 19 | 3 | 12 | 1 | 30 | 99 | 0 | 1 | 4 | 5 |
| | 24 | 12 | 2 | 50 | 20 | 43 | 7 | 50 | 4 | 5 |
| | 28 | 21 | 5 | 33 | 7 | 99 | 1 | 0 | 3 | 4 |

1. Numbers from 1 to 8 signify increasing darkness.

*Figure 4. Plot 2 soil profile, planted.*

*Figure 5. Plot 16 soil profile, planted.*

*Figure 6. Plot 27 soil profile, planted.*

*Figure 7. Plot 19 soil profile, natural regrowth.*

*Figure 8. Plot 24 soil profile, natural regrowth.*

*Figure 9. Plot 28 soil profile, natural regrowth.*

*Figure 10. Plot 9 soil profile, primary forest.*

*Figure 11. Plot 12 soil profile, primary forest.*

*Figure 12. Plot 34 soil profile, primary forest.*

## 5.1) Soil temperature

A trend could be seen in the soil temperature between the different habitat types with planted areas having the warmest temperatures (average 14.4°C), followed by natural regrowth (average 13.7°C) and primary areas the coolest (average 13.3°C) (Table 1).

## 5.2) Effect of slope on soils

Looking at Table 1, we could recognize a correlation between the slope and the moisture, with the moisture degree decreasing as the slope increases. For example, the steepest plot (24), with a slope of 97%, was the driest one (only 1.5 out of 9). Figure 13 shows how these two variables correlate negatively.

We can recognize a trend in the O-horizon thickness in relation to the slope as well (Table 1 and 2), where the O-horizon narrows with increasing slope (Figure 14).

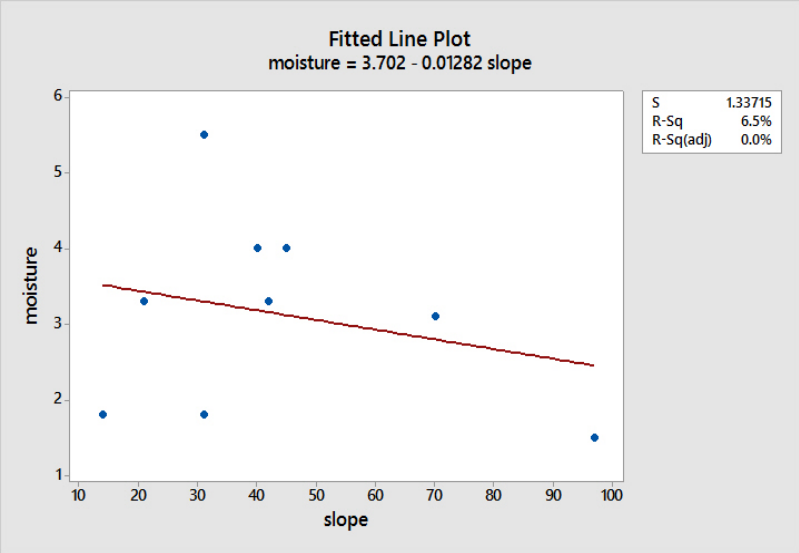


*Figure 13. Moisture [1-9] vs slope [%].*

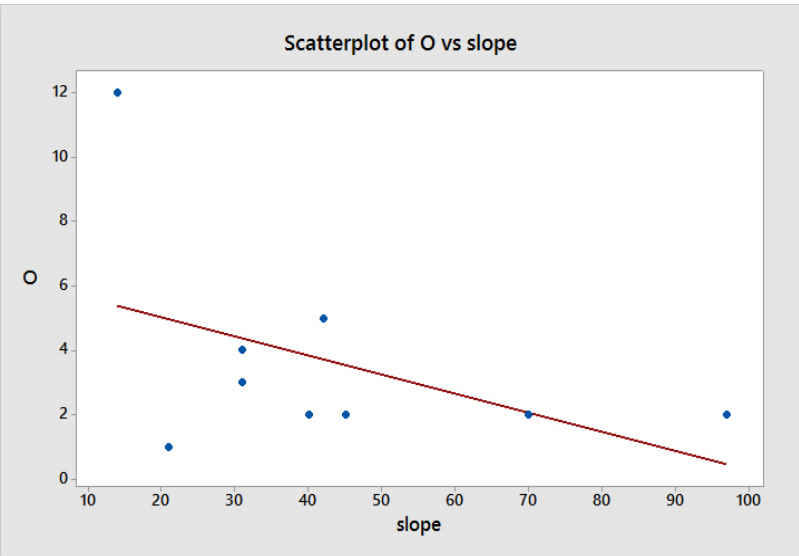


*Figure 14. O thickness [cm] vs slope [%].*

## 5.3) Colour of horizons

Just from looking at the soil profiles (Figures 4 to 12) we can see that soils in planted areas have lighter colour in the deeper horizons (AB and B) than natural regrowth and primary areas.

## 5.4) Plot 19

Plot 19 was very exceptional, I expected it to have a finer texture and to have thicker horizon because it is located at the foot of the hill, where finer material is supposed to be deposited rather than eroded, but it was the one with the most gravel and the shallowest soil (only 50 cm deep, Table 2).

## 5.5) Soil texture

As Table 2 shows, primary forest tends to have the finer texture (with a percentage of clay always over 90%), planted is the only one that presented a soil (Plot 27) with just sand and no clay. Natural regrowth plots presented a wider range of textures, varying from very fine textured plot (99% clay in Plot 19 and 28) to rather coarse ones (Plot 24).

## 5.6) A-horizon thickness

The A horizon tends to be thicker in primary areas (mean 21 cm) than in natural regrowth (mean 12 cm), and both were thicker than in the planted areas (mean 6.7 cm) (Table 2). This was not statistically significant but, as Figure 15 show, we can see that there is a trend in the mean A thickness.

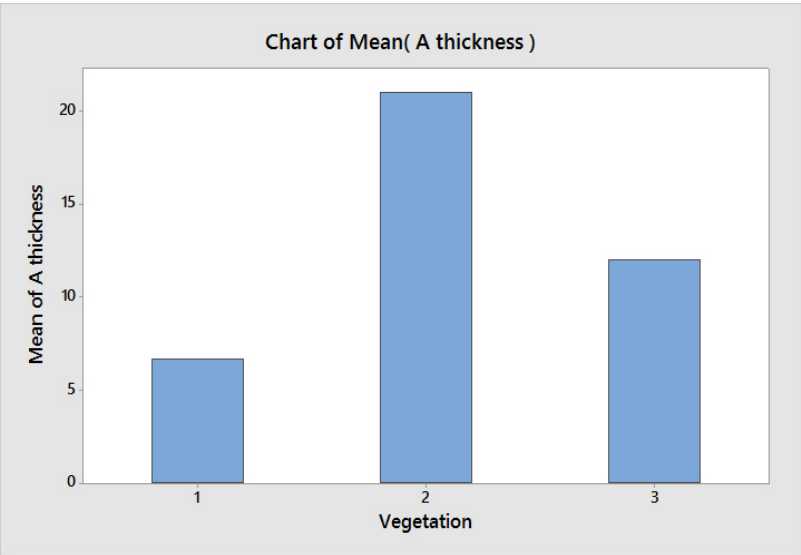


*Figure 15. Mean A horizon thickness [cm] in (1) planted, (2) primary, and (3) naturally regenerated areas.*

## 6) Discussion

The statistical analysis of the data did not provide any statistically significant result, meaning that some trends could be recognized, but the P-value was never smaller than 0.05. This can be attributed to the fact that the data set was very small (only 9 plots) and highly variable. Would we have had a bigger sample size, the variance would play a smaller role and the chance of getting statistically significant results would increase.

Planted and naturally regenerated areas tend to have a smaller canopy cover so more sunlight can reach the soil and warm it up. Temperature seems to show a trend to be higher in planted areas (Section 5.1), however the exposure and slope degree might play a key role as well. In fact, the exposure influences the number of hours that the soil is exposed to direct sunlight and the slope the intensity of the sunlight influence.

The slope seems to correlate negatively with both soil moisture and the O horizon thickness. The water retention seems to be smaller the greater the slope, because the soil struggles to keep its water from flowing downhill. The flowing of more water downhill also causes more soil erosion, which is likely the cause of the narrower O layer in steeper areas.

Planted and naturally regenerated areas show a lighter colour in the deeper horizons, this suggest a lower organic matter content. This could be caused by agricultural and farming activities. In fact, agriculture impoverishes the soil by carrying away nutrients (biomass export) and pasture makes the soil more compact so it’s easier for the organic matter to be washed away. This could mean that organic matter and nutrients accumulate on the upper layer, but the regeneration has not gone on to deeper soil, which is still poor in organic matter.

The soil compacting through farming activities (ex. soil churning from cattle hooves) could also be the main cause of the trend we see between the soil texture and the different vegetation types. The soil compaction might have increased the erosion and a larger number of finer particles may have been washed away from these areas compared to the primary areas.

## 7) Conclusions

From the sampled data, we can draw no statistically significant conclusion, because a larger number of samples is needed. However, some potential trends were identified in the data already and those should be studied further.

The fact that none of the hypothesis was statistically significant could also mean that the deforestation and farming activities did not affect the soil too much, and/or that the soil recovered well from the damage. This would be very good news for the reserve, but further study must be conducted to confirm such a hypothesis.

## 9) References


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# Appendix 1: Soil Profile Papers