Basic soil analysis in forestry farms in the provinces Colón, Chiriquí, Veraguas and Darién under the management of Futuro Forestal, Panamá

Report of a practical experience with Futuro Forestal

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1 Introduction

1.1 Futuro Forestal and their Generation Forest Concept

Futuro Forestal is a social business which was founded as a small family owned company in 1994. It expanded and has been the first in Panama to be FSC certified.

Owned by the "Community and Forest Foundation", Futuro Forestal offers management and establishment services for forest investments in the fields of forestry farms, natural forests and environmental compensatory measures. They "conceptualize, ensure feasibility, structure (legally and fiscally), establish, maintain and if required exit projects." (Futuro Forestal, 2012)

That way the company has got experience with reforestation of degraded lands using native species, as well as with managing teak plantations. They specialize in plantations of native, valuable hardwood species mixed with teak. The company counts with their own tree nursery.

Their ecological commitment includes that relatively large parts of the remaining secondary forests on the forestry farms are left untouched. In this context, secondary forests are within the meaning of forests which have been stripped of any hardwood trees or forests of natural succession, following the removal of primary forest. The concept applies especially to areas alongside streams, and in order to provide them as habitats for animals or acting as a green corridor between bigger forest areas.

On the social side Futuro Forestal aims to supply secure jobs, job training and safe working conditions which include regular lectures on, among others, occupational safety and hygiene.

As a response to the deficiencies of conventional forestry plantations, Futuro Forestal has developed the concept of the Generation Forest.

Natural forests produce too little hardwood trees to be economically viable. So it pays off better for the proprietors, in the short term, to cut their forests down and use the land as pasture, than to manage the forest. However this behavior has countless negative environmental effects.

Conventional plantations that are managed as monocultures are profitable but tend to be poor in biodiversity, are at risk from calamities and illnesses, and are usually planted with teak, which is a non-native species in Panama.

What is more, plantations are usually harvested by clear cutting. This leads to surplus nitrification because the organic materials in the soil are decomposed much faster than that is the case with more constant types of management. The change in soil temperature in the deforested area provokes excessive production of nitric acid in quantities that the remaining vegetation cannot absorb. This leads to a surplus of protons and acidification. In Addition, the sudden and direct exposition of the soil to strong rain can lead to erosion and nutrient leaching.

The Generation Forest concept intends to make plantations more ecologically sustainable while still remaining profitable.

The company plants 825 native precious hardwood trees per hectare on unsustainable and degraded pastureland. Thinnings are scheduled in the years 12, 20, 25 and 30. In total each year will be extracted a little less wood volume than the growth. After the thinnings only individual trees will be harvested. In contrast to conventional plantations the gaps resulting from the thinnings will be replanted, thus structuring the forest vertically as well as horizontally, creating a Permanent Forest.

The uninterrupted cover with trees leads to a significant improvement of soil conditions (Krieb 2012). There can be an increase of soil organic matter, N- fixation, enriched surface nutrients due to litterfall and root turnover, changes in the microclimate above and below ground, and an increase in microbiological activity in the root rhizosphere (Bolay 2009).

At the same time 30 percent of the area of the forestry farm, for example remnants of secondary forests alongside streams, are planned to be left untouched and serve as a conservation corridor (Futuro Forestal, "The Generation Forest- concept note").

1.2 Aim of the study

This basic soil analysis forms part of an environmental study, which was carried out in long term sampling areas in forestry farms under the management of Futuro Forestal.

A group of students from Earth University in Costa Rica measured the trees at the sampling areas, taking into account the species, diameter at breast height, commercial height, total height and sanity.

Meanwhile biologists from Ancón analyzed biodiversity based on understory vegetation and birds present in, and around the sampling areas.

On the one hand the soil analysis should give a good overview over the state of nutrient levels, profundity, soil type and pH-value of the forestry farms' soil. On the other hand the elaborated data should serve as a base for comparison for further soil samplings in the future, showing the effects of reforestation, especially under the application of the Generation Forest concept, on the soil over the years.

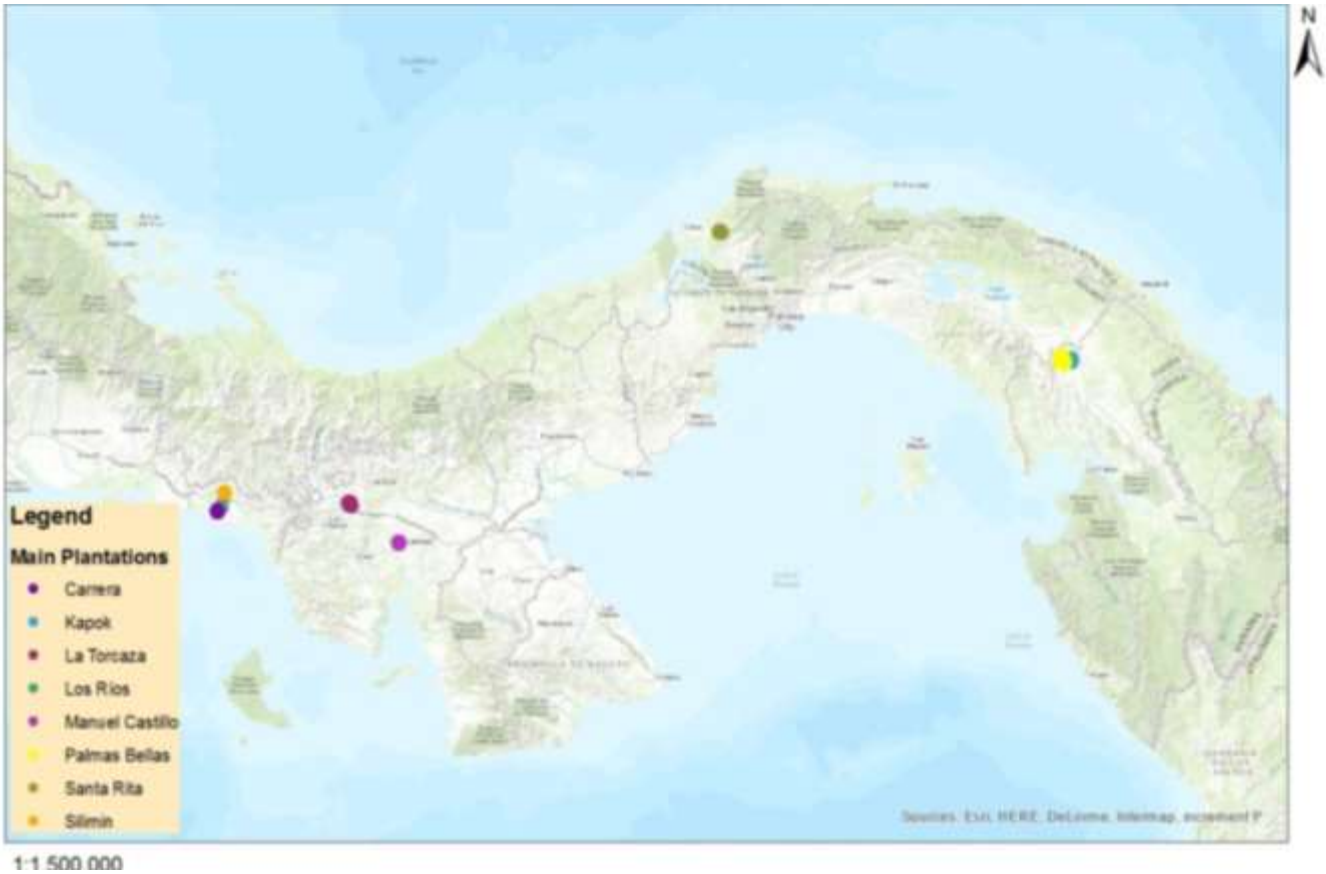

Table 1 Map - Panama

2 Methodology

2.1 Study areas

In total there were 206 samples from 13 forestry farms under the management of Futuro Forestal collected. They are located in the provinces Chiriquí, Veraguas, Colón and Darién. The samples were gathered over a period of two and a half months, from September 13th to November 4th.

Aproximate sizes of the forestry farms forming part of the project		
Province	Forestry Farm	Size in ha
Chiriqui	La Concordia	8,0
	Silimin	10,0
	Madera Fina	1,0
	Los Rios	5,0
	Carrera	40,0
Veraguas	La Torcaza	200,0
	Manuel Castillo	15,0
	Augustin Mendoza	30,0
Colón	Santa Rita	44,0
Darien	Palmas Bellas	200,0
	Kapok	54,0
	Reina	20,0

Table 2 Forestry farms

2.1.1 Sites in Veraguas

In the Veraguas Province I took samples from three forestry farms.

"Manuel Castillo", "La Torcaza" and " Augustin Mendoza" are all within humid tropical forest Life Zones with hilly topography and a dry season.

The annual precipitation in the area of "Manuel Castillo" is 2701- 3000 mm and the average annual temperature is 26,4-26,5 °C with the soil being classified as dystric cambisol.

Dystric means that the soil has a low base saturation of less than 50%.

Cambisols are soils with a beginning of soil formation and a weak differentiation of single horizons. They differ from parent material through changes in color, aggregate structure, carbon- or clay content. Furthermore, cambisols lack a layer of accumulated clay, humus, soluble salts, or iron and aluminum oxides.

"La Torcaza" and "Augustin Mendoza" experience annual precipitation of 3001-3300 mm and yearly temperatures of 26,1 -26,3 °C and the soils are declared as plinthic acrisols, with high levels of iron concentrated in rusty spots.

2.1.2 Sites in Chiriquí

Some of the forestry farms in Chiriquí province are among the first which Futuro Forestal established in 1995.

The five forestry farms I visited in this province are located in the area of Las Lajas on the pacific coast. This area is dominated by humid tropical forest with a topography that ranges from hilly to plane. The average temperature lays around 26,6-27 °C and annual precipitation ranges from 3001-3300 mm with a dry season (ANAM, "Atlas Ambiental" 2010).

According to the "Atlas de los suelos de América Latina y el Caribe" from 2014 published by the European Commission, the soils are classified as haplic acrisols (FAO nomenclature).

Acrisols are acidic soils with low fertility and nutrient retention abilities which have a subsurface layer of accumulated kaolinitic clays. They are soils from old landscapes, have a base saturation of less than 50% and may contain high and even toxic levels of aluminum (Gardi, C. et al 2014).

2.1.3 Sites in Colón

The forestry farm "Santa Rita" ubicated in the mountains near the city of Colón is a very humid premontane forest. Annual precipitation is 3001- 3300 mm and the average temperature lays around 24,6- 25 °C with a short dry season. The soil is classified as humic nitisol.

Nitisols are deep, well-drained red tropical soils with diffuse horizon boundaries and a subsurface horizon with more than 30 % clay and moderate to strong angular blocky structure elements that easily fall apart into characteristic shiny, polyhedric elements. Kaolinite, halloysite and iron oxides dominate their clay mineralogy.

Humic indicates that there is a high organic matter content in the A or/ and B horizon.

2.1.4 Sites in Darién

In Darién province I took samples from five forestry farms. They are located in the Life Zones of humid tropical forest and very humid premontane forest, the topography is slightly hilly, annual precipitation lays between 1801 and 2100 mm, yearly average temperature is 26,4-26,5 °C with a prolonged dry season and the soil is classified as haplic vertisol. These soils show high levels of clay and have strong expanding and shrinking properties. Haplic vertisols have a base saturation ecxeeding 50%.

2.2 Sampling design

Samples were gathered in most of the long term sampling areas, excepting those in the forestry farms "Palmas Bellas" and "Carrera", which lay right next to each other and did not seem to differ in any significant way. If the samples taken in the permanent sampling areas failed to entirely represent the forestry farm, additional samples were taken. It was essential to include all topographical expositions of the respective forestry farms. So, as there was no instrument available for measuring steepness, the area was divided into stratums like slope, hilltop etc. Other criteria that defined stratums were age of the reforested land and the species planted upon it. This applied only to those forestry farms where the trees were planted in plots separated by species or age. Further samples were extracted from areas where tree growth was poor. By comparing them with areas of better growth, which were otherwise similar, Futuro Forestal aimed at investigating causes for this reduced vitality. In order to see if there was a difference in nutrient levels of land that had been reforested and such that continued to serve as pasture, samples were gathered from adjacent meadows.

The reference consulted for the sampling procedure was the "Muestreo de suelos para análisis de fertilidad" publicized by the Instituto de Investigación Agropecuaria de Panamá (IDIAP) in 2012.

The selection of the sampling points was made by exploring the forestry farms with Futuro Forestal employees who had knowledge of areas of bad tree growth. Afterwards the forestry farms were divided into zones while taking into account exposition, coverage and specialties like bad growth. In each zone there were taken subsamples. The quantity varied according to the size of the sampling zones. However in the forestry farms of Colón and Darién only two subsamples were taken per zone. Before digging a hole, organic material was cleared away. After that earth from the first 20 cm and then from the depth of 40-50 cm was extracted using a post-hole digger. Finally all subsamples of 0-20 and 40-50 cm were separately combined with the intention to homogenize the samples. Approximately one kilo of each sample was filled into a clearly labeled zip locker plastic bag. Sampling points were always chosen within sufficient distance from roads and the edge of the plots. Additionally GPS coordinates of each subsample were written down and a photo of the sampling site was taken.

A one meter soil sampler was used to elaborate whether there was a compacted horizon and to test the profoundness of the ground.

2.3 Sampling sites

On forestry farms where the study was conducted mainly two different concepts were applied.

The first one was developed to provide ecological compensation. Exclusively native species suited for local soil conditions were planted on degraded pastureland in order to fulfill a variety of functions. Amarillo (*Terminalia amazonia*), cedro espino (*Pachira quintana*), zapatero (Hyeronima alchorneoides), cocobolo (*Dalbergia retusa*)and roble (*Tabebuia rosea*) among others, produce precious hardwood while trees like caña fistula (*Cassia grandis*) are nitrate fixers. Furthermore jagua (*Genipa americana*)and guacimo(*Guazuma ulmifolia*) for example, are intended to serve as a fruit source for animals and nance (*Byrsonma crassiflia*) in addition to that, provides litter which is rich in bases. These different species are planted in a mixed fashion, not in plots divided by species.

The land for reforestation is provided by a landowner free of charge. He signs a contract that allows him to make use of the trees after a certain amount of time, for example after 20 years, at the end of the contract. Futuro Forestal then establishes and manages the reforested land in the name of a company or institution that needs to provide ecological compensation.

In contrast to that stands the concept of planting trees in the form of plots separated by species. This method was applied for the teak dominated forestry farms Palmas Bellas, Pope and Reina as well as to Santa Rita, Kapok, Joya Verde, los Rios, Madera Fina and La Concordia which were reforested mainly with native species. In contrast to the selection of trees used for compensatory reforestation these native species distinguish themselves in particular through the value of their wood. Amarillo (*Terminalia amazonia*), cedro espino (*Pachira quintana*), zapatero (*Hyeronima alchorneoides*), cocobolo (*Dalbergia retusa*), almendro (*Dipteryx panamensis*) and caoba (*Swietenia nacrophylla*) are the most important ones. Often there were also plots of teak.
The forestry farm Santa Rita is special. Unlike the others the land hadn't been used as pasture for a time before Futuro Forestal started managing it. Also, there were large parts of secondary forest left. Before the plantation the plot designed for that purpose is usually cleared entirely. In this case however there were only rows cleared leaving strips of secondary forest or other vegetation in between the rows of planted trees. This strategy was also applied to the part of Joya Verde in Darien planted with native species.

2.4 Laboratory analysis

The chemical soil analysis was conducted by the soil laboratory of the Instituto de Investigación Agropecuaria de Panamá (IDIAP) in Divisa.

After I had delivered the samples, the laboratory proceeded by putting the earth in a clearly labeled, clean container made of wood or metal. The samples were then left to dry outside for three to four days, depending on soil moisture. The dried samples were then ground, previously removing any leftover stones and passed through a sieve with a 2 mm mesh.

Texture was determined by applying the Bouyoucos Hydrometer Method in a 10% solution of sodium metaphosphate. Particle sizes were classified following the indications of the International Society of Soil Science.

1) Sand = 0,02- 2 mm
2) Silt = 0,002- 0,02 mm
3) Clay = < 0,002 mm

In order to determine Soil Organic Matter (OM) the laboratory used the method described by Walkley-Black. For practical reasons 0, 5 and 0, 1 g of soil were each brought to reaction with a chromic acid/sulphuric acid mixture solution. The heat released by the dilution of the concentrated sulphuric acid oxidized the OM and converted it to CO_2 and H_2O.

After the oxidation the solution was titrated with ferrous sulfate in order to determine the amount of $K_2Cr_2O_7$ that didn't participate in the reaction. From this the total amount of organic matter could be derived. However, if the amount of OM is very high and exceeds 6% there are problems with this procedure. As that was never the case with my samples, the results deduced with the Walkley-Black method may be given credit.

To test soil for ph the lab made a solution with distilled water and applied an electronic ph meter.

The amounts of nutrients in the soil samples were assessed applying the Mehlich 1 procedure which uses a weak acid called Mehlich 1 extracting reagent comprised of a mixture of 0.05 N HCl and 0.025 N H2SO4, also referred to as dilute double acid or the North Carolina extractant. In this case it is used as a multi-element extractant for P, K, Ca, Mg, Cu, Fe, Mn, and Zn. This procedure is suited for acidic soils which show a ph that is less than 6.5, have a low cation exchange capacity (<10 mol/kg) and low organic matter contents (<5%). In alkaline soils the weak acidity of the Mehlich1 solutions is neutralized and thus the capability of the dilute acid to extract nutrients is reduced. *(Pierzynski, Gary M. 2000)* Especially the samples I extracted in Pallmas Bellas range from neutral to strongly alkaline. So these results should be treated with caution.

So in a first step the soil was always mixed with Mehlich 1 extractant.

Phosphorus content was determined by reacting with ammonium molybdate, using ascorbic acid as a reductant. The formed phosphomolybdic acid develops a blue color whose intensity depends on the solutions' concentration and was measured in a spectrophotometer at an appropriate wavelength (660-680mm). P measured by this method indicates available phosphorus that a plant can uptake.

For the determination of magnesium and calcium the capacity of concentrated salt solutions like, in this case, potassium chloride is used to replace exchangeable bases. Before that, the extract was mixed with a 1% lanthanum oxide solution to rule out interferences like the phosphates and oxides. The respective quantities of Mg and Ca were assessed with an atomic absorption spectrophotometer.

The lab claimed that it was not recommendable to determine Ca and Mg this way in soils with free carbonates, gypsum or soluble salts and that the results obtained could not be relied upon for interpretation.

The proportion of exchangeable aluminum and hydrogen is an indicator for soil acidity (Pagel H. et al, 1982) In order to extract them, a neutral salt solution was added, in this case a potassium chloride solution. Total acidity was then identified by titration with sodium hydroxide. Pagel H. et al, 1982 then proceeded by masking the AL3+ with sodium fluoride in order to obtain the respective values for H+ and Al 3+. The lab however didn't take H+ into consideration.

For the assessment of the micronutrients copper, iron, manganese, and zinc, Mehlich 1 extracting solution was added and the elements quantities determined with an atomic absorption spectrometer.

Potassium (K) was determined by flame photometry as nearly all potassium compounds are soluble. After adding a potassium free, concentrated diluent to the solution already containing Mehlich1 extractant, the lab measured the intensity of the colored light, produced by the activation of the potassium atoms as a result of the liberated energy of the reaction. The instrument used was a galvanometer. The intensity of the light waves stands in a direct relation to the concentration of potassium in the solution.

The results for K I received from the lab were indicated in the form of mg/l. In order to convert the values to cmol/kg (=meq/100 g) the IDIAP suggests the following formula:

$$\text{meq of } \frac{\text{K}}{100}\,\text{ml} = \frac{\frac{\text{mg}}{\text{l}} \text{ of K in the soil}}{391}$$

This would be needed to calculate Effective Cation Exchange Capacity (ECEC) as the other cations are indicated in cmol/kg (= meq/100g).

The IDIAP calculated the ECEC by adding up the quantities of the exchangeable cations Ca2+, Mg2+, Al3+ and K+ for each sample. According to Ross and Ketterings, 2011, A3+ should only be taken into account if the ph of a sample was below 6.

Base saturation was calculated as a percentage of CEC.

However the approach for the determination of K is different from the other exchangeable cations Ca2+, Mg2+ and Al3+. While the Mehlich 1 acid extract is used to identify potassium, the others quantities are deduced from the replacement with potassium chloride, which is a salt extract. Usually the amount of K liberated with an acid extract is higher than that would be possible applying a salt extract. Furthermore, the use of KCl makes it impossible to determine the amount of exchangeable K in the soil.

So, for lack of reliability, I didn’t use the ECEC and other information depending on it, provided by the lab like Base Saturation for interpretation.

Finally the lab did an interpretation of the values. Their classification system of low, medium and high is based on previous studies for critical values for the Mehlich 1 method. (IDIAP)

Values of the critical levels of each element analized in the soil laboratory(*)

element	symbol	low	medium	high
phosphorus	P	<18 µg/ml	19 a 54 µg/ml	> 55 µg/ml
potassium	K	<44 µg/ml	45 a 150 µg/ml	> 151 µg/ml
calcium	Ca	< 2 meq/100 ml	2.1 a 5 meq/100ml	> 5.1 meq/100ml
magnesium	Mg	< 0.6 meq/100 ml	0.7 a 1.5 meq/100ml	> 1.6 meq/100ml
aluminum	Al	< 0.5 meq/100 ml	0.6 a 1.0 meq/100ml	> 1.1 meq/100ml
manganese	Mn	<14 µg/ml	14.1 a 49 µg/ml	> 49.1 µg/ml
iron	Fe	<25 µg/ml	25.1 a 74 µg/ml	> 75 µg/ml
zinc	Zn	<4 µg/ml	4.1 a 14 µg/ml	> 14.1 µg/ml
copper	Cu	<2 µg/ml	2.1 a 6 µg/ml	> 6.1 µg/ml
soil organic matter	OM	< 2%	2.1 a 6 %	> 6.1%
the critical levels differ depeng on the pH. In the case of aluminum it is maybe more important to know the porcentage of aluminum saturation (calledexchangeable acidity), than the actual content of the exchangeable cation.				

Table 3 Critical levels of soil nutrients

Interpretation of the chemical reaction of the soil (Levels of pH in the soil)	
Values	**Interpretation**
4.0 to 5.1	strongly acidic
5.2 to 5.9	acidic
6.0 to 6.9	slightly acidic
7.0	neutal
7.1 to 8.0	slightly alkaline
8.1 to 9.0	moderately alkaline
>9.0	stronglyalkaline

Table 4 Critical values for pH

3 Results

As the main purpose of this study was to get a good overview of soil conditions of all the forestry farms, which differed in many ways like management, species and soil types , the results were very heterogeneous. This condition made it hard to apply comparative statisics to the set of data. Descriptive statistics was chosen as the better option. Data was divided into groups according to the soil types extracted from the “Atlas de los suelos de América Latina y el Caribe” ,2014, which coincided with spatial separation of the forestry farms. To describe the data, the median was used instead of the mean.

3.1 Manuel Castillo

The pH of Manuel Castillo ranged from 5 to 5,5 with no difference between depths (median: 5,3 each) [Table 5 Manuel Castillo - 0-20 cms; Table 6 Manuel Castillo - 40- 50 cms] and the soil could be classified a moderately acidic. The average of pasture was 5,4 and as was to be expected , there was as jet no significant difference between reforested land and pasture. Soil organic matter (OM) varied between low and medium, from 1,04% to 3,13%. The average amount for 40-50cm was 2,085% and a bit higher than OM of the layer above (2%), which may point at leaching processes. Levels of potassium were generally high with extreme differences between samples (24,1-582,9 mg/l). As natural levels of K depend on the parent material and, in this case, are always higher in the upper soil, it is safe to presume that the soil has been fertilized. This is especially true for the pasture samples which showed unnaturally high quantities of K like 582,9 mg/l. Phosphorous seems to be a limiting nutrient for plant growth because there was hardly any present (0-1 mg/l). Calcium levels were also rather low and ranged from 1,7 to 3,5 cmol/kg. Levels of aluminum were high with two exceptions,(0,2 and 0,5 mg/l). Magnesium levels are high as well and range from 1,7 to 3,6 cmol/kg with one rouge result of 35 cmol/kg. The Micronutrients Mn, Fe, Cu, Zn showed mostly medium levels and were never close to critically low amounts. In this respect Manuel Castillo stood out among the other forestry farms where especially the amounts of Cu and Zn were very low.

	Soil Organic Matter (%)	Ph	P (mg/l)	K (mg/l)	Ca (Cmol/kg)	Mg (Cmol/kg)	Al (Cmol/kg)	Mn (mg/l)	Fe (mg/l)	Zn (mg/l)	Cu (mg/l)
Max:	3,01	5,5	1	582,9	3,5	35	7,1	67,8	51	6,4	3,7
Median:	2	5,35	0,5	197,4	3	3,65	2,75	33,75	42,1	4,05	3,65
Min:	1,04	5	0	56,8	2,2	3,1	0,5	25,1	39,3	3,2	3,3
25th percentile	1,19	5,23	0	119,4	2,425	3,475	1,625	25,85	40,05	3,65	3,525
75th percentile	2,8225	5,43	1	336,6	3,5	11,525	4,4	48	45,68	4,825	3,7

Table 5 Manuel Castillo - 0-20 cms

	Soil Organic Matter (%)	Ph	P (mg/l)	K (mg/l)	Ca (Cmol/kg)	Mg (Cmol/kg)	Al (Cmol/kg)	Mn (mg/l)	Fe (mg/l)	Zn (mg/l)	Cu (mg/l)
Max:	3,13	5,5	1	60,4	2	1,9	9,9	24	29,9	5,6	2,9
Median:	2,085	5,3	0,5	42,25	1,85	1,8	5,7	20,5	28,35	4,05	2,7
Min:	1,04	5,1	0	24,1	1,7	1,7	1,5	17	26,8	2,5	2,5
25th percentile	1,5625	5,2	0,25	33,175	1,775	1,75	3,6	18,75	27,575	3,275	2,6
75th percentile	2,6075	5,4	0,75	51,325	1,925	1,85	7,8	22,25	29,125	4,825	2,8

Table 6 Manuel Castillo - 40- 50 cms

3.2 La Torcaza and Augustin Mendoza

In the forestry farms of la Torcaza and Augustin Mendoza pH ranged from slightly acidic to strongly acidic (4,6 to 6) with the upper soil showing a bit lower pH. [Table 7 La Torcaza/ Augustin

Mendoza - 0-20 cms; Table 8 La Torcaza/ Augustin Mendoza - 40-50 cms] Soil organic matter was clearly higher in the in the first 20 cm of the soil, but in overall rather low and ranged from 0,39% to 3,92%. The median of the first 20 cm was 2,19% while in the layer below OM was 1,3%. The low OM in general and the slightly higher acidity in the upper layer may hint at a process of topsoil acidification in combination with soil degradation. This coincides with observations at the site. Comparing results by exposition, it seemed that OM levels were highest on hilltops. K values indicated that there were locations which had been fertilized. Values diverged greatly and ranged from 11,8 mg/l to 4451,2 mg/l while K levels in general were higher in the upper soil, which also pointed at previous fertilization. The pasture sample showed extraordinarily high K values as well. High K values however, didn't always go along with the sites listed as fertilized. This could be explained by missing information on fertilization or misplacement of sampling points. Calcium levels were low, with one exception, and ranged from 0,2 to 8,3 cmol/kg with no real difference between layers. Magnesium quantities qualified as medium to high, lay between 0,9 to 4,3 cmol/kg and were slightly higher in the upper soil. Amounts of aluminum in the soil were high but varied greatly from 0,3 cmol/kg to 41,8 cmol/kg. Especially the results of one sampling point taken in "La Cantera" manifests strangely low values (0,1 and 0,2 cmol/kg), not only for aluminum but also for manganese, namely 6,1 and 8,4 mg/l. [see main table] with Growth there was observed as mediocre. The values for manganese ranged from 6,1 to 68,3 mg/l that is to say from low to high, but most were classified as medium by the lab. Levels of Mn were higher in the first 20 cm. The amounts of the other micronutrients were predominantly low. Particularly copper was mostly and zinc sometimes below a critical level, which is 0,6mg/l for Cu and 1,5 mg/l for Zn on loamy or clayey soils. (Pagel, Enzmann, & Mutscher, 1982)

Results for the sample taken from a neighbouring pasture plot differed from the reforested land in the respect of soil organic matter, which was notably lower while especially levels of P,K, Ca and Mg in the subsoil sample were way higher than of the other samples.

Locations of bad tree growth (samples No. 5, 7"La Torre") didn't differ much from average values. It could be remarked though that OM amounts were lower in the upper soil and that in comparison only with areas of good growth quantities of Fe and Mn are notably lower.

	Soil Organic Matter (%)	Ph	P (mg/l)	K (mg/l)	Ca (Cmol/kg)	Mg (Cmol/kg)	Al (Cmol/kg)	Mn (mg/l)	Fe (mg/l)	Zn (mg/l)	Cu (mg/l)
Max:	3,52	5,6	1	4451,2	8,3	4,3	9,1	68,3	31,3	4,3	4
Median:	2,19	5,2	1	40,5	0,6	2,6	4,5	37	22,9	0,5	0
Min:	0,39	5	0	22,3	0,4	1,8	0,2	8,4	17,9	0	0
25th percentile	1,24	5	0	35,65	0,5	2	1	30,55	19,4	0,15	0
75th percentile	2,705	5,4	1	66,2	1,15	2,95	6,45	51,8	30,6	2,55	0

Table 7 La Torcaza/ Augustin Mendoza - 0-20 cms

	Soil Organic Matter (%)	Ph	P (mg/l)	K (mg/l)	Ca (Cmol/kg)	Mg (Cmol/kg)	Al (Cmol/kg)	Mn (mg/l)	Fe (mg/l)	Zn (mg/l)	Cu (mg/l)
Max	2,64	6	2	720,6	1,5	3,9	41,8	45,3	27,1	3,8	2,7
Median	1,3	5,3	0	25,85	0,85	2,2	6,3	25,8	19,1	2	0
Min	0,48	4,9	0	11,8	0,2	0,9	0,1	6,1	14,3	0	0
25th percentile	0,66	5,3	0	13,83	0,35	1,475	1,9	20,5	16,15	1,2	0
75th percentile	1,9425	5,55	0,75	57,73	1,175	3,075	14,075	34,15	20,88	3,075	1,475

Table 8 La Torcaza/ Augustin Mendoza - 40-50 cms

3.3 Madera Fina, Los Ríos, La Concordia, Carrera and Silimin

Soils of the forestry farms in the proximity of Las Lajas classified almost always as strongly acidic with ph ranging from 4,2 to 5,3. [Table 11 Madera Fina/ Co. - 0-20 cms; Table 12 Madera Fina/ Co. - 40-50 cms] Quantities of OM were low to medium and showed a great variance of 0,3% to 4,7%, with slightly more OM in the first layers. Levels of OM were highest in Silimin and lowest in Madera Fina, even though the latter is the oldest forestry farm. The sample taken from the adjacent meadow had also higher amounts of OM in the upper soil than the reforested plot. [see main table] On the other hand, OM of the pasture sample next to Carrera was much lower than of the reforested area. Meanwhile the pasture sample of La Concordia didn't differ from the reforested area, but the Silimin pasture sample of 40-50 cm had remarkably elevated values of ph, P, K, Ca, Mg and Mn and it seems safe to presume that these do not represent natural soil conditions. Quantities of plant available phosphorus were very low and samples didn't exceed 4 mg/l while mostly there wasn't even any P detected. Potassium values were classified as low to medium and ranged from 8,4 to 79,4 mg/l. Overall K levels were slightly higher in the first 20 cm but varied greatly within the layer. Calcium was mainly low and ranged from 0,7 to 4,0 cmol/kg. There was no significant difference between layers or forestry farms. The third base, magnesium manifested amounts that were primarily medium but varied from 0,5 to 3,2 cmol/kg. Highest Levels of Mg were found in the zapatero (Hyeronima alchorneoides) plot of Los Ríos and lowest in a cocobolo (Dalbergia retusa) plot (sample No. 2) in La Concordia. Variance of aluminum values was large, namely from 0,1 to 2,6 cmol/kg. Levels in the upper soil were a little more elevated. The sampling spots that showed extremely low values were the teak (Tectona grandis) plot in Madera Fina, the cedro espino (Bombacopsis quinata) plot in Los Rios and sample No. 4 of Carrera. Those which manifested highest amounts were sampling spots No. 7,8 and 9 of Carrera, the zapatero plot of Los Ríos and of the forestry farms in general La Concordia. Sampling Spots No. 8 and 9 of Carrera showed also bad tree growth in comparison with the rest of that forestry farm. Manganese classified from low to high with values varying greatly, from 3,6 to 91,3 mg/l. There was more Mn present in the first 20 cm and overall amounts were remarkably low in Madera Fina. Levels of iron were qualified mostly as medium but varied from 21,5 to 114,7 mg/l. The quantities of Fe were higher in the sample extracted from a depth of 40-50 cms. Zinc ranged from low to medium namely from 0,4 to 8,37 mg/l. Even though the majority of Zn values were low, they very seldom went below the critical amount of 0,6 mg/l. Copper levels in general were low too and varied between 0 and 3,58 mg/l. In Madera Fina, Los Ríos and samples No. 1- 4 of Carrera there wasn't any Cu detected.

The sample extracted from secondary forest of La Concordia showed high values in comparison with the other samples for OM, K, Fe and especially zinc.

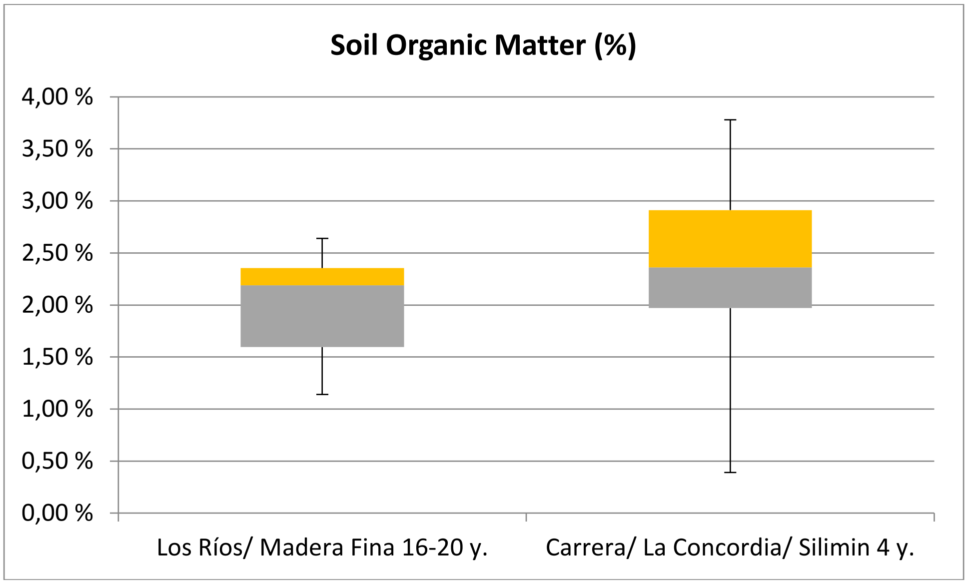

Table 9 Soil Organic Matter tendency

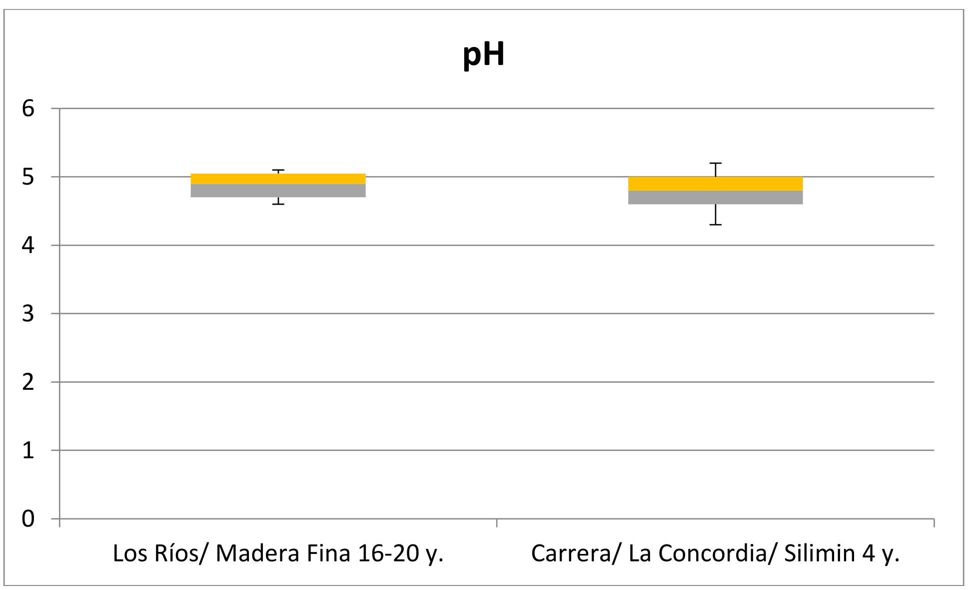

Table 10 pH tendency

	Soil Organic Matter (%)	Ph	P (mg/l)	K (mg/l)	Ca (Cmol/kg)	Mg (Cmol/kg)	Al (Cmol/kg)	Mn (mg/l)	Fe (mg/l)	Zn (mg/l)	Cu (mg/l)
Max:	3,78	5,2	3	79,4	3,5	3,2	3,5	80,3	57,8	8,73	3,58
Median:	2,245	4,9	0	37,2	2,35	1,15	1,3	24,15	31,2	1,7	0
Min:	0,39	4,3	0	8,5	0,7	0,5	0,1	4,3	14	0,4	0
25th percentile	1,89	4,7	0	31,23	2,05	0,975	0,85	9,775	21,48	1,075	0
75th percentile	2,67	5	0	53,33	2,725	1,425	1,7	39,65	44,68	2,25	1,35

Table 11 Madera Fina/ Co. - 0-20 cms

	Soil Organic Matter (%)	Ph	P (mg/l)	K (mg/l)	Ca (Cmol/kg)	Mg (Cmol/kg)	Al (Cmol/kg)	Mn (mg/l)	Fe (mg/l)	Zn (mg/l)	Cu (mg/l)
Max:	4,79	5,3	4	77,8	4	3,1	2,9	134	114,7	7,2	3,4
Median:	1,97	5	0	21,9	2,35	1,05	1	21,3	39,1	2,15	0,15
Min:	0,3	4,2	0	13,9	1,2	0,7	0,1	4,3	21,5	0,5	0
25th percentile	1,34	4,9	0	17,1	2,05	0,975	0,45	13,6	28,55	1,3	0
75th percentile	2,53	5	0	33,8	2,725	1,4	1,6	34,33	52,98	2,85	1,8

Table 12 Madera Fina/ Co. - 40-50 cms

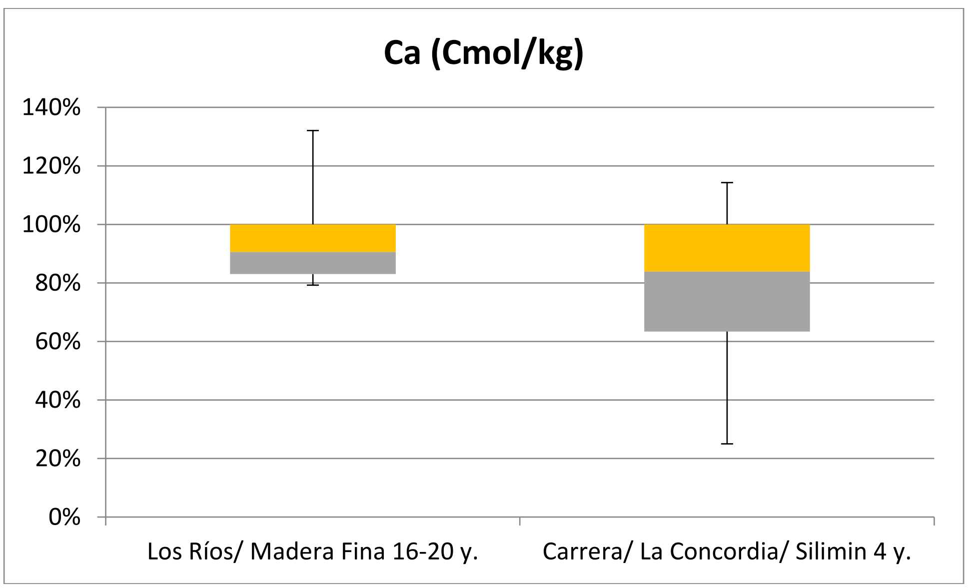

Table 13 Levels of Ca, older reforestations compared to younger ones

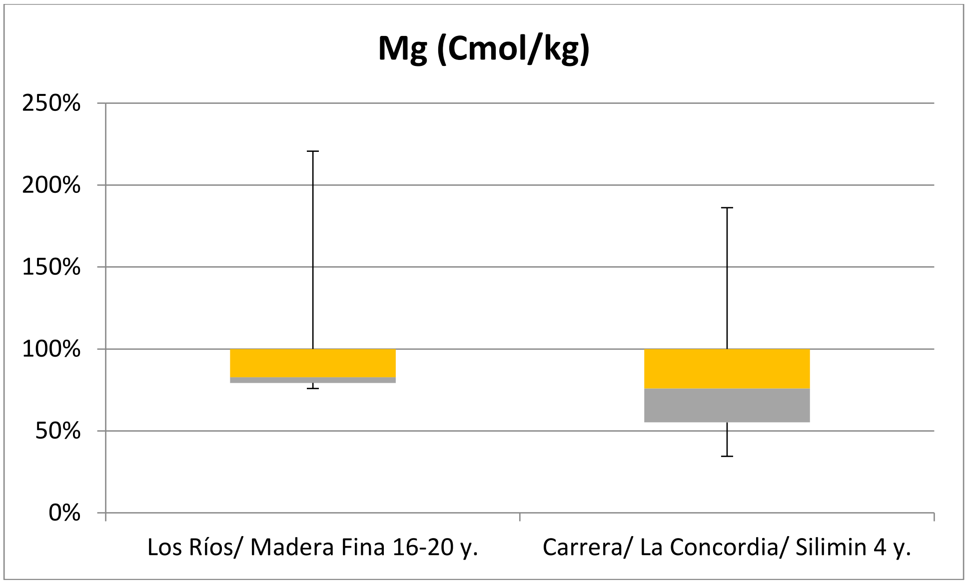

Table 14 Levels of Mg, older reforestations compared to younger ones

3.4 Santa Rita

Soils of the forestry farm near the City of Colón were characterized as strongly acidic. Ph lay between 4,4 and 5. Soil Organic Matter levels classified predominantly as medium and were between 0,48 to 4,49%. [Table 15 Santa Rita - 0-20 cms; Table 16 Santa Rita - 40-50 cms] Clearly higher amounts of OM were located in the upper soil. Only sample No. 11 taken from a plot of 4 year old nispero (Manilkara zapota) of comparatively bad growth showed extremely low amounts of OM (0,57 and 0,48%). Phosphorus was drastically underrepresented in Santa Rita. There was only one sample that had 1 mg/l of P while there was no P detected in any of the others. A lack of P may lead to a delay in plant development and growth. (Pagel, Enzmann, & Mutscher, 1982) Values of K ranged from low to medium and varied greatly from 10,6 to 86,2 mg/l. Upper soil was generally richer in K, which could point at previous fertilization. All values of Calcium were low and ranged from 0,4 to 2,7 cmol/kg. Amounts of Magnesium varied from low to high, namely from 0,4 to 3,1 cmol/kg. It was remarkable that sampling points No. 1 to 8 (and the 0-20 cm sample of No.9) had all high levels of Mg while the others' were low to medium, because the first 8 sampling points are, with the exception of sampling point No. 16, located in another part of the forestry farm then the others. Quantities of Aluminum varied a lot too and received classifications from low to medium. They ranged from 0,1 to 18,3 cmol/kg and there was hardly any difference between the soil layers. The highest values within the forestry farm were found in sample No.3 of amarillo planted in 2014. Al levels of the pasture sample were elevated in comparison with the average of the forestry farm. Manganese quantities varied from low to high. Outstandingly high values (151,2 and 211,4 mg/l) were shown by sample No.7 of a plot of cocobolo (Dalbergia retusa) mixed with amarillo (Terminalia amazonica) established in 2011. Iron values were principally medium und resided between 2 and 70,4 mg/l. The first layers had higher levels of Fe than the lower ones. Zinc values were low and ranged from 0 to 3,5 mg/l. Just like for Mg there seemed to be a local division with the values of Zn. The same sampling points No. 1 to 8 (and the 0-20 cms sample of

No.9) didn't have any Zn. Copper was mainly low as well and ranged from 0 to 3,1 mg/l. Sample No.7 of a plot of cocobolo (*Dalbergia retusa*) mixed with amarillo (*Terminalia amazonica*) showed the highest Cu values. Many times Cu amounts were below a critical level of below 2 mg/l for sandy and below 1,5 mg/l for loamy/clayey soils. (Pagel, Enzmann, & Mutscher, 1982)

	Soil Organic Matter (%)	Ph	P (mg/l)	K (mg/l)	Ca (Cmol/kg)	Mg (Cmol/kg)	Al (Cmol/kg)	Mn (mg/l)	Fe (mg/l)	Zn (mg/l)	Cu (mg/l)
Max:	4,49	5	1	86,2	2,7	3,1	2	211,5	70,4	3,5	3,1
Median:	3,52	4,8	0	49,5	1,7	2,3	0,6	48,5	44	0	1,2
Min:	0,57	4,4	0	23,4	0,5	0,6	0,1	17,9	24	0	0
25th percentile	3,07	4,7	0	36,5	1,15	1	0,2	28,25	32,6	0	0,85
75th percentile	3,85	4,8	0	63,05	2,35	2,45	0,9	63,6	49,95	1,6	1,5

Table 15 Santa Rita - 0-20 cms

	Soil Organic Matter (%)	Ph	P (mg/l)	K (mg/l)	Ca (Cmol/kg)	Mg (Cmol/kg)	Al (Cmol/kg)	Mn (mg/l)	Fe (mg/l)	Zn (mg/l)	Cu (mg/l)
Max:	3,92	5	1	55,3	2,2	2,3	18,3	151,4	46,2	2,8	2,4
Median:	2,3	4,7	0	32,65	1,35	2,05	0,7	25,3	32,05	0	1,4
Min:	0,48	4,4	0	10,6	0,4	0,4	0,1	12,3	2	0	0,1
25th percentile	1,7775	4,7	0	16,38	0,8	0,8	0,125	18,73	23,13	0	0,8
75th percentile	3,01	4,775	0	41,35	1,575	2,2	1,475	36,7	37,65	1,15	1,875

Table 16 Santa Rita - 40-50 cms

3.5 Palmas Bellas, Pope, Reina, Joya Verde and Kapok

Because of technical problems at the laboratory, I only received the results of OM, pH, P and Al of the samples extracted in Darien province. Overall soil organic matter was low with a few samples that classified as medium and values lying between 0,13 and 3,78%. [Table 19 Palmas Bellas/ Kapok - 0-20 cms; Table 20 Palmas Bellas/ Kapok - 40-50 cms] Upper soil manifested higher amounts of OM. The sampling points with the highest amounts of OM were No. 19 of a teak plot established in 2012 of Palmas Bellas and the sample taken in Pope of a 2011 teak plot. Within Joya Verde sample No.1 of a teak plot of 2010 and within Kapok sample No. 6 of a plot of sick zapatero with natural rejuvenation underneath showed the highest amounts of OM.[see main table] Sample No. 19 of a teak plot planted in 2012 and located in a depression manifested the highest values for OM of Palmas Bellas. Pope showed sufficient amounts of OM while all samples taken from Reina were low in OM. In comparison with the other forestry farms the soil in Darien province was much less acidic. Ph varied a lot and ranged from 5,2 to 8,1, that is to say from "strongly" acidic to strongly alkaline. There was a detectable difference between forestry farms concerning pH. Palmas Bellas was least acidic and most values were either slightly acidic or slightly alkaline. Joya Verde for another was predominantly moderately acidic while Kapok, Pope and Reina were mainly slightly acidic. PH in the first layers was slightly lower than in the one below. Between tree species planted at the same time (2008) of Palmas Bellas and Kapok there was no significant influence of the different species on ph detectable. It has to be noted that there sometimes was only one sample for a species available, so maybe a more conclusive statement could be obtained by a more precise and expedient study. Quantities of phosphorus were also higher than that was the case with the other forestry farms. However, while amounts of P in Palmas Bellas, Reina and Pope mainly either classified as medium or high, P in Kapok and Joya Verde was mostly low. P within Palmas Bellas, Pope and Reina ranged from 0,1 mg/l to 326 mg/l and within Kapok and Joya Verde from 2 to 17 mg/l. Amounts of P within Palmas Bellas were lowest (2 mg/l in both depths) in sample No. 12 extracted in Sabanita, an area where trees didn't grow well. However the other samples of Sabanita had medium or high amounts of P. Again, unlike the forestry farms of other provinces, Aluminum levels were very low and with two exceptions , had only 0,1 mg/l. On the basis of the laboratory results of the Darien forestry farms I couldn't detect any significant difference in soil chemistry between the areas of good and bad tree growth.

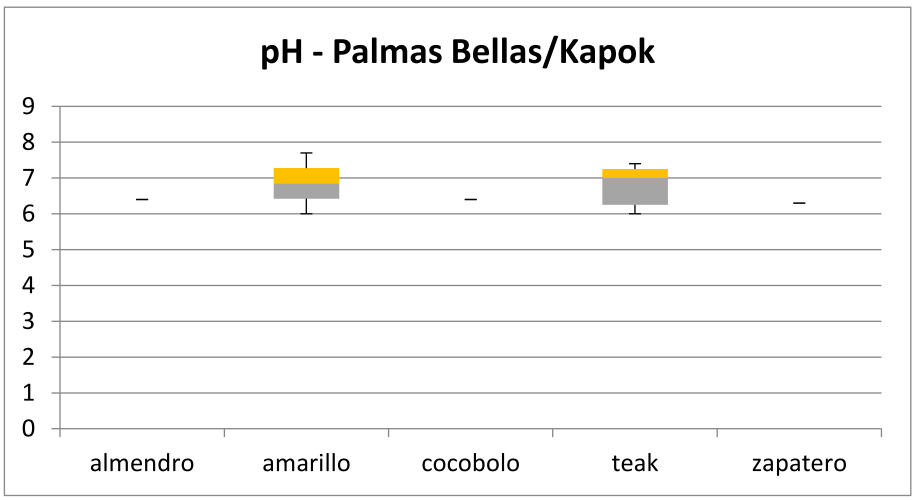

Table 17 pH of Palmas Bellas/ Kapok

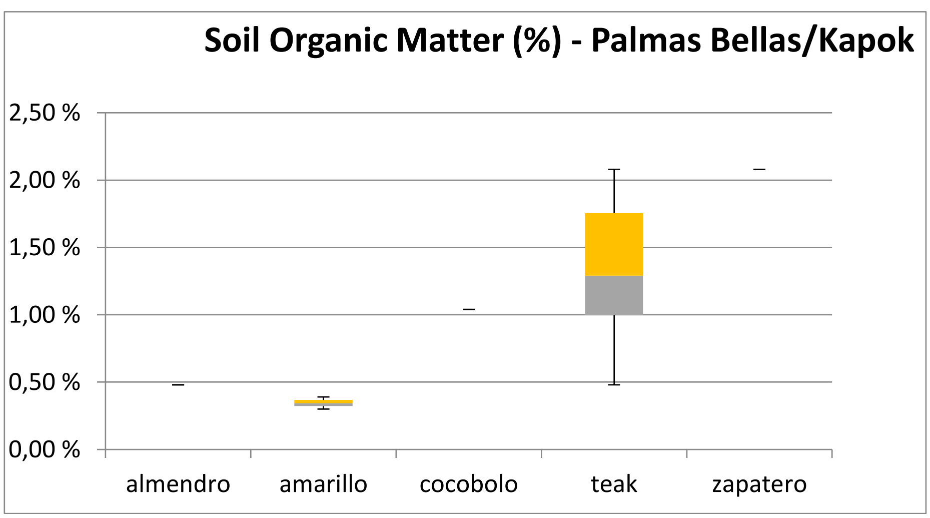

Table 18 Soil organic matter of Palmas Bellas/ Kapok

	Soil Organic Matter (%)	Ph	P (mg/l)	Al (Cmol/kg)
Max:	3,78	7,7	326	0,1
Median:	1,39	6,6	22	0,1
Min:	0,3	5,6	0,1	0,1
25th percentile	0,85	6,2	6	0,1
75th percentile	1,8875	7,2	68	0,1

Table 19 Palmas Bellas/ Kapok - 0-20 cms

	Soil Organic Matter (%)	Ph	P (mg/l)	Al (Cmol/kg)
Max:	3,39	8,1	248	2,7
Median:	0,615	6,9	19	0,1
Min:	0,13	5,2	2	0,1
25th percentile	0,4125	6,3	6	0,1
75th percentile	0,925	7,6	82	0,1

Table 20 Palmas Bellas/ Kapok - 40-50 cms

3.6 Soil organic matter in relation to topographical exposition

As it isn't common to apply soil tillage to pasture land Land that isn't treated by soil tillage, a usually has higher levels of soil organic matter in the first soil horizon, I only took the results of the 0-20 cm sample into consideration. Regarding all the forestry farms, there was no clear answer to the question whether there was a relationship between soil organic matter concentration and topographical exposition. Looking at the forestry farms locations separately , some tendencies could be identified. Manuel Castillo showed highest amounts of OM if the exposition was a plateau [Table 21 Soil organic matter of Manuel Castillo], while values for OM of La Torcaza and Augustin Mendoza were most elevated at hilltops. [Table 22 Soil organic matter of La Torcaza and Augustin Mendoza] The forestry farms of Darien manifested highest amounts of OM if the exposition was plain. [Table 23 Soil organic matter of the forestry farms of Darien] For Santa Rita and the forestry farms in the proximity of Las Lajas however, there was no clear result [Table 24 Soil organic matter of the Las Lajas forestry farms; Table 25 Soil organic matter of Santa Rita].

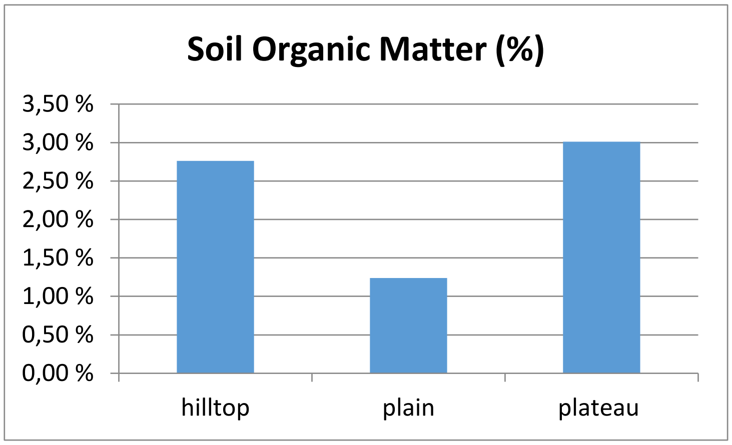

Table 21 Soil organic matter of Manuel Castillo

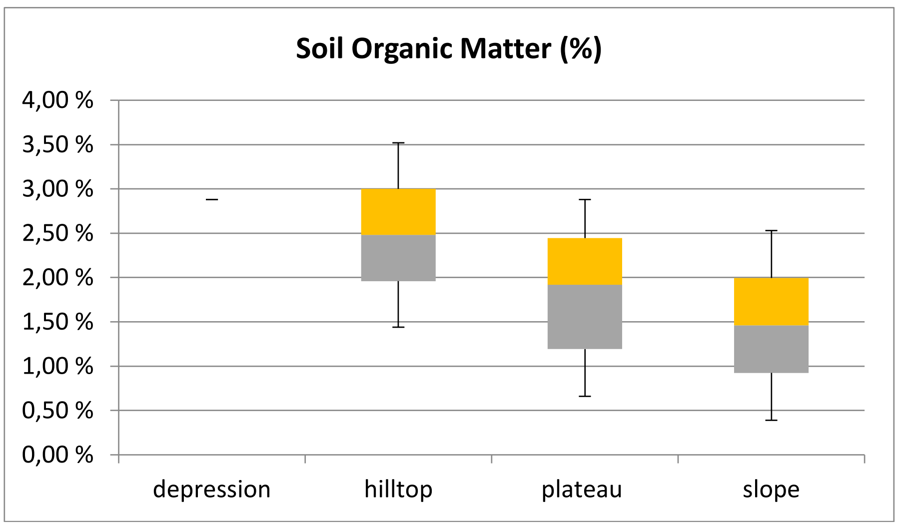

Table 22 Soil organic matter of La Torcaza and Augustin Mendoza

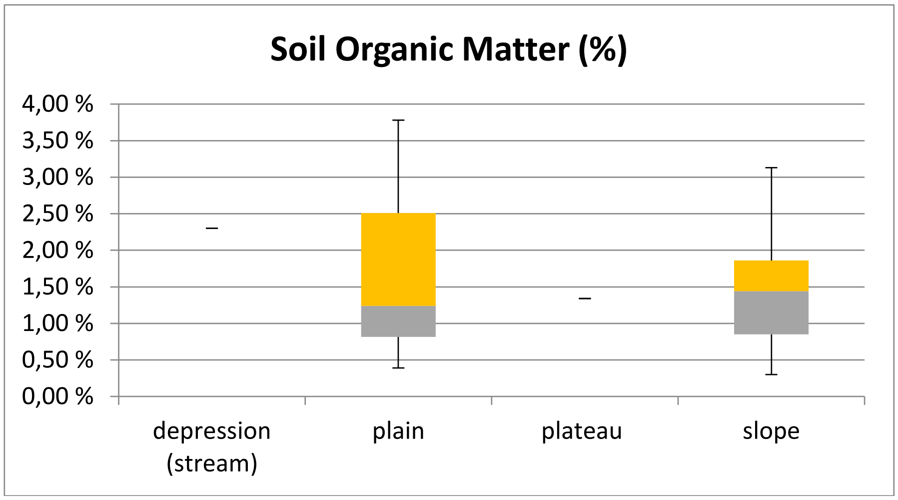

Table 23 Soil organic matter of the forestry farms of Darien

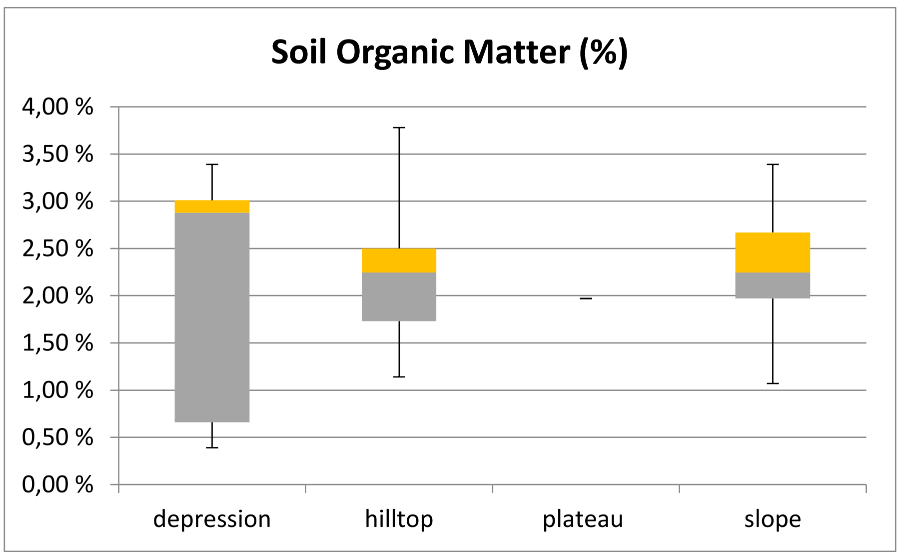

Table 24 Soil organic matter of the Las Lajas forestry farms

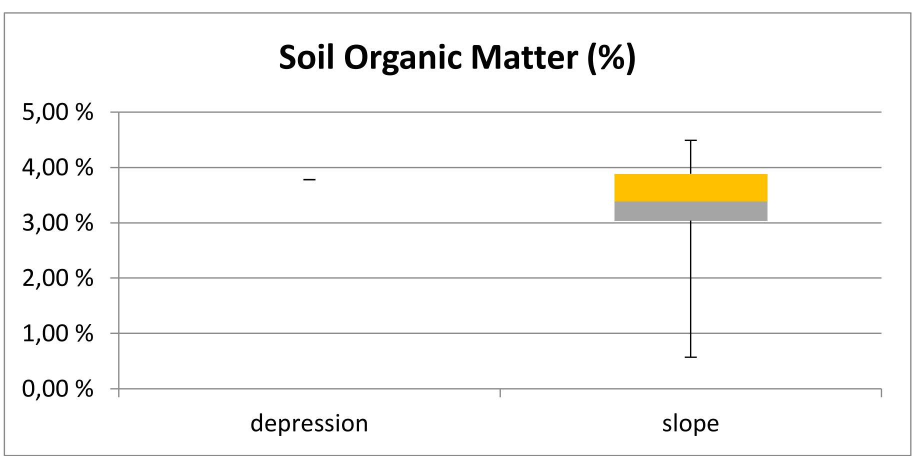

Table 25 Soil organic matter of Santa Rita

4 Discussion

Behind the study stood the following hypotheses.
First, reforestation was thought to have a positive effect on the content of organic matter (OM) and plant available phosphorus (P) in the soil as well as on base saturation and effective cation exchange capacity (ECEC). This was supposed to be shown by comparison with plots that continued to serve as pasture and plots of secondary forest. Unfortunately ECEC and base saturation could not be taken into consideration in this study.
Second, supposedly the different tree species planted on the degraded land had different effects on OM and pH.
Third, negative effects through cattle ranching practices would still be detectable in the reforested plots.
Fourth, a connection between bad tree growth and chemical soil conditions was suspected.
Furthermore, the study aimed at investigating whether a difference in soil organic matter could be detected between areas of different expositions.
Finally, it was of interest to find out which nutrients were lacking in which areas and forestry farms and possibly led to impaired tree growth.

4.1 Changes in organic matter an nutrients though reforestation

Reforestation can improve soil conditions in many ways. Root dynamics can cause an improvement in soil aggregation by loosening and breaking up compacted soil. This improves soil aeration and creates pore space on the aggregates that can be occupied by base cations. (Irslinger, 2014) Studies have also shown that on the long term root growth in older reforested plots can lead to stabilization of aggregates because root exudates that act as cementing agents. (Denef, 2002)
As the predominant clay mineral in tropical soils, kaolinite, is unable to store nutrients well OM plays a vital role for the sorption of cations and is also essential for the improvement of aggregate stability. The plant availability of nutrients however also strongly depends on the pH. (Irslinger, 2014)
Phosphorus accumulates in the OM, so there was an increase of P expected in the upper soil in comparison with the lower horizon. (Pagel, Enzmann, & Mutscher, 1982)
Highest amounts of OM of all the forestry farms were found in Santa Rita [see main table] even though the first trees there were only planted in 2011, which can be explained by the fact that the land hadn't been used as pasture for a considerable time before. The sample of secondary forest didn't stick out among the reforested plots and the only remarkable thing about the pasture sample was that, OM in the upper soil was lower than in the lower one. More surprisingly, the forestry farms of La Carrera and Silimin which had been reforested only four years previously and had served as pasture land before, showed relatively high amounts of OM. [see main table] Concerning La Carrera there was even a clear improvement of OM content, especially in the upper soil compared to the sample of a neighboring meadow. Meanwhile the two oldest forestry farms in this study, Madera Fina (20 years) and Los Rios (16 years), manifested opposing trends. Levels of OM in Los Ríos were satisfactory, OM in Madera Fina was even lower than in the

adjacent pastureland. The forestry farms in the proximity of Las Lajas were best suited for a direct comparison between older and younger forestry farms to see if a process of accumulation of OM and in relation to that an increase of Mg and Ca could be observed. In contrary to what was expected, amounts of OM were a little lower in the older plots though values in the younger forestry farms manifested a wider distribution. [Table 9 Soil Organic Matter tendency] However quantities of the basic cations Ca and Mg were sightly higher in the older reforested plots, which could be caused by the positive effect of root activity [Table 13 Levels of Ca, older reforestations compared to younger ones; Table 14 Levels of Mg, older reforestations compared to younger ones].
Levels of Phosphorus were negligible and so didn't serve to support the hypotheses in the Chiriquí province. In Darien Province, where P levels were higher the was no connection between age, OM and P observed [see main table].

4.2 Effects of different tree species on the soil

In order to find a difference between the different tree species concering the effects on soil chemestry four fincas were taken into account. The reforestations in the forestry farms of Kapok and Plamas Bellas in Darien Province, which had plots of different species established in 2008 and the forestry farms Madera Fina (1995) and Los Rios (1999) ubicated in Chiriquí Province.
Amounts of OM in Teak varied a lot in all the forestry farms. As Teak is the fastest growing species, it was expected to clearly accumulate highest amounts of OM through litterfall.
Lowest levels of OM were observed in Amarillo plots in Darien, followed by Almendro. Cocobolo was almost at a level with teak and Zapatero manifested highest amounts of OM. The case of the Zapatero plot could be explained by the illness that had befallen the trees and led to increased litterfall. The amounts of OM demonstrated by the plot in Chririquí province were relatively high but were surpased by the Teak and Amarillo plot [Table 18 Soil organic matter of Palmas Bellas/ Kapok].
So there were differences in the quantities of OM accumulated on plots of different species. However there was sometimes only one sample to represent a species which is very little.
Concerning pH, there was no difference to be observed between the tree species.

4.3 Lingering signs of soil degradation in younger reforestations

Soils of more recently established reforestations were expected to show remaining signs of degradation in soil chemistry through previous land use practices. This could be observed in the forestry farm of Manuel Castillo where levels of OM were higher in the lower horizons. Contrary to what was expected levels of Ca and Mg were again higher in the upper layer [Table 5 Manuel Castillo - 0-20 cms; Table 6 Manuel Castillo - 40- 50 cms].

4.4 Bad tree growth and soil chemistry

It was suspected that there were connections between soil chemistry and areas where trees showed less growth. However, the samples from those areas didn't differ much from the others. In La Torcaza the samples taken from "La Torre" showed lower levels of OM in the upper soil. Which could hint at leaching processes. In the zones of bad growth of the forestry farm Carrera there were no abnormalities detectable. At Santa Rita the sample of a Nispero plot of less vitality

manifested unusually low amounts of OM while the plot of many dead cocoa trees was very low in Al, Cu and P [see main table].
One of the samples taken from badly growing "Sabanita" in Palmas Bellas destinguished in very low P levels while the others didn't stick out from the other samples. Neither did the other samples of bad growth from an area that was planted in 2012. But as the data on this forestry farm isn't complete there can be not be drawn a definite conclusion.

4.5 Soil organic matter and different expositions

Contrary to what was expected there was no clear result looking at all the forestry farms as to whether exposition was linked to amounts of OM. This could be explained by the fact that most reforestations are still young and that as yet there wasn't a significant accumulation of biomass to be observed [see 3.6].

4.6 Nutrient deficiencies

All the forestry farms except for those of Darien province manifested very low levels of P [see main table]. A lack in P may impaired growth and development in plants (Pagel, Enzmann, & Mutscher, 1982). Overall amounts of Ca were low too which probably manifests in a low ECEC. On the part of micronutrients, the forestry farms of Carrera, La Torcaza, parts of La Concordia, Los Rios and Madera Fina had deficiencies in Cu and though levels of Zn were generally low a part of Santa Rita showed a complete lack in Zn. Levels of Fe and Mn were for the greater part fine.
Amounts of Mg were mostly medium or high. When pH is very low as is the case in the majority of forestry farms apart from those of Darien province, there may be an antagonism between Mg and K which leads to the displacement of K cations. (Pagel, Enzmann, & Mutscher, 1982) This and the low pH in general can explain the low amounts of K except in areas which were probably fertilized and therefore manifest higher amounts of K.
Especially elevated levels of Al in some samples can be found in La Torcaza. If the relation of basic cations (Na, K, Ca, Mg) and Al are below the critical value of 1, impairment of the vegetation through damages to the roots and obstruction of nutrient uptake are getting ever more probable. (Linus Früh, 2015)

5 Conclusion

A fundamental knowledge of soil conditions may be of aid for long and short term planning and findings of a soil analysis demonstrate where there are deficiencies in plant available nutrients which can lead to economic losses as a consequence of impaired tree development. It may also serve as reference in areas of bad tree growth to show whether the planted tree's poor condition is due to chemical soil conditions or possibly a fault of badly executed planting. Within the context of pending worldwide problems concerning soil degradation, loss in species and arable land and climate change forestry plantations have gained importance and it has become of even more interest to improve the current system of forestry plantations and make it more ecologically sustainable. The generation forest concept developed by Futuro Forestal is aiming to meet this demand and undermine it with different studies. For that purpose long term sampling areas were installed all over the forestry farms under their management. As the forestry farms are very diverse in their types of soil, anterior land use, planted tree species and management concept, studies bear the potential of supplying a wide range of information that may serve as a base for long term strategies for the management of forestry farms even beyond Panama. In combination with the study of biodiversity , the study of soils and the measurement of the trees within the long term sampling areas it may possibly be ascertained if the application of the generation forest concept to forestry farms is the best compromise between biodiversity, soil improvement and economic interests.

However this soil analysis fails to meet some of the requirements for a scientific study aiming at making viable statements. For that It would have been essential to identify one specific problem and look for an approach which meets statistical and scientific requirements rather than give a good overview. Data for the three different studies of biodiversity, tree measurement und soil chemistry were evaluated principally within permanent sampling areas. These however haven't always been distributed following one single strategy and therefore do not serve well to stratify the forestry farms. The installation of permanent sampling areas standardizes and simplifies the realization of consecutive studies. For that purpose it might be recommendable to revise the distribution and quantity of the permanent sampling areas and to create a GIS based map of the same.

Regarding future studies further improvements could be made compared to the study at hand. For one, in order to identify a problem a pre study should be conducted within one forestry farm and help deciding on stratums and hypotheses for the main study. Another option might be a sampling design based on a fixed grid. For another, instead of noting down the name of the exposition of a sample it might be preferable to measure inclination. Finally, selecting a different method for chemical soil analysis ought to be considered. Because the Mehlich 1 used for this study didn't allow to make use of results for effective cation exchange capacity and values derived from it like base saturation for interpretation. Meanwhile this information is important in order to compare the samples directly and to be able to make statements about the development of soil conditions after the reforestation of degraded land.

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