Suitability of native tree species for reforestation in the tropical dry forest of Costa Rica

Short version of the thesis for diploma of Martin Czarnowski
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1 Introduction

The conservation area Guanacaste (*ACG*, Área de Conservación Guanacaste) created in 1989 with the financial help of the Swedish government was a great research project for the preservation of the dry forests (*Sub-Programa de Restauración de Masas Arbóreas*). The most important aim was the restoration of the degraded areas and the silvicultural research concerning valuable wood species.

Within the scope of this project, experimental forest plantations were established for the first time in the area of the *Forest Research Station Horizontes* (*Estación Experimental Forestal Horizontes: EEFH*). The Research Station especially works on forest tree breeding of native tree species of the dry forest. Among other things young trees are cultivated and planted in different mixtures. The investigated area belongs to such a terrain. The forest plantation was established in 1991 and belongs to the oldest experimental areas of the *EEFH*. There were ten tree species in different combinations on a total area of 29 ha planted. Since the establishment of the plantation, there were measurements taken of the height and diameter of the trees once each year in permanent sample tests.

The forest plantation shows different micro sites. In this way the growth of the trees can be influenced. Besides, an effect of the different mixtures of tree species on the thriftiness and the growth form can be possible. In this study there were detailed examinations in tree growth and condition of the soil carried out in small sample tests in August and September of 2001. Furthermore the water content and the resistance to penetration of the soil were determined. In particular humid years there is found stagnant moisture in some parts of the area. The soil profiles of these micro sites were compared with those ones of drier sites. With these examinations the reasons for differences in tree growth should be described.

2 Results

2.1 Soil

2.1.1 Soil fertility

Tab. 2-1 shows the results of a soil analyses, which was carried out in 1999 within the scope of an examination of the *EEFH* on the forest plantation of 1991. In the following the data should be interpreted. The soil characteristics of the examination area are compared with general facts of soils with average soil fertility in Costa Rica. This general data originates from soil classifications for agricultural crops, therefore it is a limited acceptance for a comparison with a forest plantation. But up to now there is no information towards the soil requirements of the examined forest plants.

The results point at soils with middle to good fertility. The pH-values on the examined area vary between 6,3 and 6,8. So it refers to little acid until neutral soils. Thus, the danger to find aluminium in soluble form and in poisonous quantity decreases. This attribute is typical for the alluvial soils resp. soils with volcanic origin in this region (*Spittler*, 2001).

The determined values of the nutrients show a high base saturation with middle to high amounts on exchangeable cations (potassium, magnesium, calcium) and on microelements (iron, phosphorus, copper). Only manganese and zinc occur in little amounts. According to *Scheffer and Schachtschabel* (1992) it is possible that there is a lack of manganese in weak acid until alkali soils. This phenomenon is widespread in the dry zones. The zinc content is also dependent on the pH-value and arises at a decreasing pH. You can observe a specially high deviation of the single parcel values around the determined arithmetic mean of the elements phosphorus and iron.

The content of organic matter varies on the forest plantation of 1991 between 0,14 % (weakly humous) and 7,94 % (strongly humous). The arithmetic mean of all plantations is 3,1 %, that means the soils are middling humous.

Table 2-1: Soil characteristics of the forest plantation of 1991 (Gutierrez, 2001) in comparison to soil characteristics of average fertility in Costa Rica (Bertsch, 1987, quoted from Spittler, 2001).

parameter /element		values at average fertility in Costa Rica	values on the forest plantation	arith. means of the forest plantation	assessment
pH	[H_2O 1:2.5]	5.5 - 6.5	6.3 - 6.8	6.6	middle
Ca	[$Cmol_{[+]}/l$]	4.0 - 20.0	10.5 - 17.4	13.4	middle
Mg	[$Cmol_{[+]}/l$]	1.0 - 5.0	2.4 - 4.7	3.9	middle
K	[$Cmol_{[+]}/l$]	0.2 - 0.6	0.5 - 1.8	1.2	high
P	[mg/l]	10.0 - 20.0	5.0 - 66.0	16.4	middle to high
Cu	[mg/l]	2.0 – 20.0	3.2 - 16.6	6.7	middle
Mn	[mg/l]	5.0 - 50.0	0.5 - 11.0	2.9	low
Zn	[mg/l]	2.0 – 10.0	0.5 - 8.9	2.3	little to middle
Fe	[mg/l]	10.0 - 100.0	14.5 - 137.6	79.7	middle to high

2.1.2 Soil profile

Figure 2-1 shows a typical soil profile of the forest plantation of 1991. The slope of this micro site amounts to approximately 3 % (in the surroundings it varies between 2 and 8 %). It is a convex slope. The parent material is formed by ignimbrites. According to the

US-American soil classification the soil belongs to the inceptisols, detailed to the group of typical ustropepts. There are no stones in the profile, and erosion occurs rarely. The soil is well drained with continuous moisture. In the upper three horizons many fine roots are visible. The portion of them predominates in the Ah- and B-horizon. The texture belongs to clayey loam.

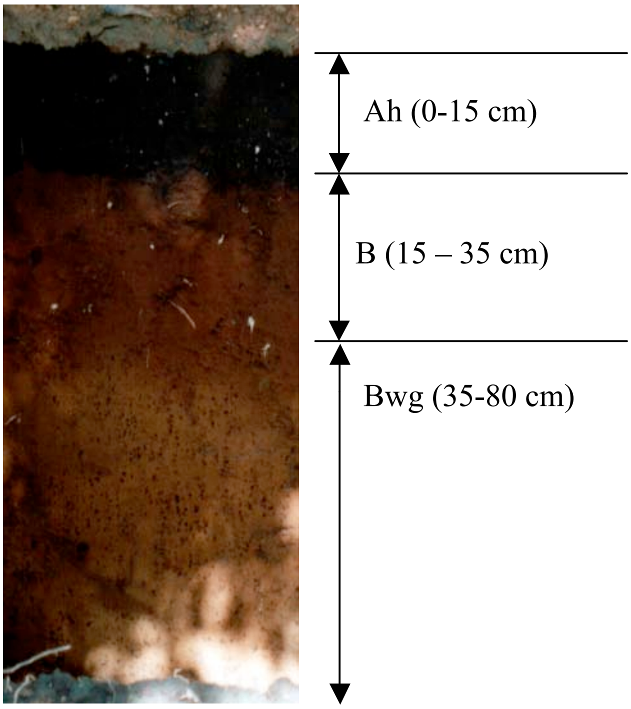

Figure 2-1: Typical soil profile of the forest plantation of 1991 (the bright spots in the lower field are caused by the sunshine).

The Ah-horizon shows in a moist condition a blackish-brownish colour. It occurs between 0 and 15 cm depth. The B-horizon is situated between 15 and 35 cm depth and shows in a moist condition a reddish-brownish colour. The third layer is formed by the Bwg-horizon. It is placed between 35 and 80 cm depth and shows in a moist condition a yellowish-brownish colour. This horizon is marbled which is a pointer for temporary influence through backwater. There occur reddish iron and black manganese concretions. The elements iron and manganese are mostly bound in silicates, they are released at the weathering under anaerobic conditions. A few of the coarse pores of the Bwg-horizon are filled with Ah-material.

The R-horizon, which is called *saprolitic ignimbrite* (*Winters*, 1997), presents the lower horizon. It occurs at approximately 80 cm depth. Weathering and leaching influence this mixed horizon.

2.1.3 Correlations of the soil values

Table 2-2 presents the interrelation of the soil indices. A high amount of the data is significantly correlated. The reason is, that there are many values for each parameter in this calculation (about 1400). In order to increase the effectiveness of the results, there was a significance level determined with a very small significance probability ($p < 0,001$). But even in this confidence belt there are a lot of significant correlations. For a better review the higher correlations ($r > 0,6$) are marked yellow.

In this examination the data of the measurements with the penetrometer and the soil sampling cylinder of the sample plots were distinguished and assigned to each tree of the sample. In each sample plot with 12 trees there were two soil samples taken with the soil sampling cylinder. So there could be one value of the cylinder assigned to six trees. There were more measurements taken with the penetrometer. Therefore it was possible to assign to each tree of the sample plot one value of the penetrometer.

The values of the resistance to penetration of the soil show no high correlations to the other values. A reason could be the high amount of steps of the cattle on the total examination area. The cattle breeding on the forest plantation is carried out in a relative small dimension compared with other pastures in *Guanacaste*. Nevertheless, there is noticeably an influence to the soil compression. Thereby the importance of the results of measurements with the penetrometer decreases. Declarations of other examinations (*Alfaro*, 1999) confirm that the soil compression of the natural forest is considerably less than the soil compression of pastures.

The tendency is visible that with an increasing portion of sand in the soil the resistance of penetration decreases. With increasing resistance of penetration the nutrient supply increases because of the higher proportion of clay (with the exception of manganese).

The dry matter density shows a high relation to the gravimetric water content of the soil. It depends on the proportion of the dry matter mass (dry content of the soil sampling cylinder) on the total volume. At a high dry matter density you can notice a high portion of dry matter mass and a little gravimetric water content. As was to be expected you can observe a relatively high positive correlation between the gravimetric water content and the volumetric water content.

The available field capacity increases with increasing humus portion of the soil. It correlates negatively with the clay portion and positively with the sand portion. Because of the high portion of fine pores the clay minerals have less available water than the sand minerals.

The fine soil was subdivided into three classifications: sand (Sa), silt (Si) and clay (C). Although silt is classified in regard of its grain size between sand and clay, it resembles in its attributes more like sand than like clay. As a new soil characteristic the sum of the relative mass portions of sand and silt was formed (Sa + Si). Besides the relative mass portions of sand and the sum of sand and silt was set in proportion to the clay (Sa/C and (Sa+Si)/C). These new formed characteristics show higher correlations to the other soil values than the single soil fractions and resemble in the strength of their correlations. There are strong relations between the soil types. This is especially emphasized by the high negative correlation between Sa+Si and C (r = -0,94). Because of the large pores the sandy soils contain during the rainy period a higher water content than the clayey soils.

Most of the nutrients are positively correlated with the clay and negatively with the sand and silt content. The strongest positive correlations to the clay portion present the nutrients calcium and phosphorus. The microelements iron and manganese show a reverse relation. On sandy substrates they have bigger contents than on clayey soils. This connection is also visible at the relation between the available field capacity and the portion of nutrients. Of all examined nutrients only iron and manganese are positively correlated with the available field capacity, that means these nutrients occur more frequently on sandy soils than on clayey soils. According to *Scheffer and Schachtschabel* (1992) the iron and manganese content of a soil is dependent on the humus content. They are often fixed in organic complexes. The content of organic matter is higher in sandy soils than in clayey soils. Less contents of nutrients in sandy soils effect an inhibited humus decomposition and an enrichment of organic matter. In tab. 2-2 you can notice a positive correlation between the humus content and the sand portion.

It is remarkable that the pH-value is higher in clayey soils than in sandy soils. With a decreasing pH (that means with decreasing clay content) the availability of iron, copper and manganese in the soil arises. But the nutrients calcium and potassium are positively correlated with the pH-value.

Table 2-2: Correlation between the single soil values (according to Spearman).

correlation after Spearman
pairwise exemption of missing data, N = 1392
red marked correlations: significant ($p < 0.001$), yellow mark: $r > 0.6$

	RP	DMD	WC_g	WC_v	aFC	Hu	pH	Sa	Si	C	Sa+Si	(Sa+Si)/C	Sa/C	Ca	Mg	K	P	Cu	Mn	Zn
resistence to penetration (N/mm^2) (RP)																				
dry matter density (g/cm^3) (DMD)	0.05																			
gravimetric water content (m %) (WC_g)	-0.15	-0.74																		
volumetric water content (V %) (WC_v)	-0.19	-0.09	0.72																	
available field capacity (V %) (aFC)	-0.18	-0.36	0.43	0.24																
humus content (m %) (Hu)	-0.11	-0.15	0.11	0.01	0.60															
pH-value (in H_2O 1:2.5) (pH)	-0.11	0.21	-0.06	0.16	-0.09	0.03														
sand portion (m %) (Sa)	-0.06	-0.39	0.41	0.20	0.51	0.14	-0.14													
silk portion (m %) (Si)	-0.10	-0.37	0.38	0.16	0.55	-0.10	-0.05	0.11												
clay portion (m %) (C)	0.11	0.41	-0.41	-0.16	-0.78	-0.09	0.15	-0.62	-0.70											
sand and silk portion (m %) (Sa+Si)	-0.11	-0.48	0.51	0.23	0.71	0.03	-0.08	0.67	0.68	-0.94										
(Sa+Si)/C	-0.11	-0.41	0.42	0.17	0.78	0.09	-0.14	0.62	0.70	-0.99	0.95									
Sa/C	-0.12	-0.41	0.43	0.20	0.75	0.16	-0.18	0.86	0.46	-0.91	0.86	0.91								
Ca-content (Cmol[+]/l) (Ca)	0.20	0.42	-0.48	-0.23	-0.72	-0.21	0.30	-0.54	-0.50	0.76	-0.73	-0.76	-0.73							
Mg-content (Cmol[+]/l) (Mg)	0.33	0.28	-0.44	-0.35	-0.29	0.08	-0.06	-0.24	-0.44	0.32	-0.34	-0.32	-0.31	0.43						
K-content (Cmol[+]/l) (K)	0.05	0.32	-0.30	-0.09	-0.72	-0.49	0.26	-0.57	-0.28	0.56	-0.48	-0.56	-0.65	0.60	0.16					
P-content (mg/l) (P)	0.16	0.42	-0.44	-0.19	-0.63	-0.17	0.01	-0.40	-0.62	0.70	-0.68	-0.70	-0.62	0.56	0.51	0.42				
Cu-content (mg/l) (Cu)	0.03	0.08	-0.14	-0.12	-0.46	-0.18	-0.31	-0.41	-0.27	0.43	-0.42	-0.43	-0.45	0.09	0.15	0.35	0.41			
Mn-content (mg/l) (Mn)	-0.25	-0.33	0.45	0.33	0.56	0.38	-0.20	0.26	0.34	-0.34	0.35	0.35	0.38	-0.40	-0.51	-0.42	-0.51	-0.06		
Zn-content (mg/l) (Zn)	0.25	0.41	-0.49	-0.30	-0.81	-0.38	0.02	-0.60	-0.52	0.73	-0.74	-0.74	-0.74	0.70	0.61	0.54	0.70	0.53	-0.67	
Fe-content (mg/l) (Fe)	-0.00	0.01	-0.03	-0.05	0.17	-0.21	-0.23	0.23	0.23	-0.37	0.30	0.37	0.35	-0.42	-0.05	-0.30	0.00	0.03	-0.18	-0.11

With calcium, potassium, phosphorus and zinc a relatively high negative correlation occurs to the available field capacity, that means a positive correlation to the clay portion. This indicates a stronger fixation of the nutrients in the lattice of the clay minerals. The clay and humus ingredients effect good sorptional and buffering properties. With the microelement zinc there are visible relatively strong relations to the other elements. The zinc supply in the soil arises with the increase of other nutrients in the soil. There is only a negative correlation with manganese.

2.2 Correlation between the soil values and the growth

In the following the correlation between the calculated soil values and the thriftiness of the different tree species should be presented. The prerequisite for the calculation was a minimum of 30 trees of one species and an appearance on at least four different micro sites. Three tree species could not comply with this condition: *Albizia adinocephala* (two mixtures, two micro sites), *Diphysa americana* (two mixtures, three micro sites) and *Tabebuia impetiginosa* (two mixtures, two micro sites). Therefore, these tree species are not listed in the correlation table. A unit of a parcel with a size of one ha is designated as micro site. The soil values of a former soil examination which was done in order of the *EEFH* connect with these size units. A parcel with two ha size also forms two micro sites. The tree species on the forest plantation are combined in different mixtures. In the case in which the number of mixtures corresponds with the number of micro sites, the tree species solely occurs on parcels with one ha size.

Dalbergia retusa shows in the thriftiness a positive correlation to the dry matter density and a negative correlation to the gravimetric water content and the available field capacity. That means this tree species grows better in clayey minerals than in sandy minerals. There A relatively strong negative correlation occurs there in regard to the humus content, which is more indication for the preference of clayey soils. Phosphorus and iron especially improve the growth of this tree species.

Enterolobium cyclocarpum also shows a better growth potential at a higher dry matter density and a less gravimetric water content. In regard to the nutrients there are negative correlations between growth and the contents of iron and copper in the soil.

With ***Hymenea courbaril*** you can notice a better growth in soils with less humus content and less available field capacity. The growth is positively correlated with the clay portion and negatively correlated with the sand and silt portion. The nutrients potassium and zinc have a specially meaning for the growth.

Samanea saman shows a single species of the examined tree species in the height growth significant correlations to the soil density and to the pH-value. It is a positive correlation. The growth behaviour reduces at increasing available field capacity and increasing humus content. The nutrients calcium, potassium and zinc have a especially important role for this tree species and advance the growth.

Simarouba glauca presents in the height growth a negative correlation to the portion of organic matter. The zinc content of the soil promotes the growth, and the content of magnesia and iron in the soil reduces the growth.

The thriftiness of ***Swietenia macrophylla*** is positively correlated with the dry matter density and negatively correlated with the gravimetric water content, the available field capacity and the humus content. Consequently, this species grows better at an increasing clay content of the soil. There is a relatively big relation noticeable to the nutrients copper, potassium and phosphor, which promote the growth.

Table 2-3: Correlation (according to Spearman) between the soil values and the growth, separated concerning tree species (pairwise exemption of missing data, red marked: correlation significant from p < 0,05).

tree species	A	B	C	D	E	F	G
soil parameter	**height**	**height**	**height**	**height**	**height**	**height**	**height**
resistance to penetration (N/mm²)	0,18	0,09	0,04	0,27	0,06	0,06	0,05
dry matter density (g/cm³)	0,46	0,43	0,06	-0,10	-0,08	0,25	-0,19
gravimetric water content (g %)	-0,32	-0,30	-0,02	-0,09	0,09	-0,31	0,31
volumetric water content (V %)	-0,07	-0,03	0,05	-0,18	0,09	-0,15	0,26
available field capacity (V%)	-0,50	0,05	-0,19	-0,40	-0,11	-0,35	0,23
humus (m %)	-0,62	-0,14	-0,18	-0,42	-0,29	-0,22	0,19
pH-value (in H2O 1:2,5)	-0,04	0,01	0,02	0,30	0,08	0,04	-0,26
sand portion (m %), Sa	-0,53	0,11	-0,10	-0,35	-0,12	-0,35	-0,25
silk portion (m %), Si	-0,11	-0,06	-0,13	0,15	0,10	0,01	0,07
clay portion (m %), C	0,31	-0,05	0,15	0,28	0,02	0,31	0,22
S+U (m %)	-0,31	0,05	-0,15	-0,19	-0,04	-0,31	-0,22
(S+U)/T	-0,35	0,06	-0,14	-0,33	-0,02	0,29	-0,22
S/T	-0,41	0,11	-0,11	-0,40	-0,05	-0,36	-0,23
Ca [Cmol(+)/l]	0,29	0,19	0,08	0,44	0,13	0,29	-0,11
Mg [Cmol(+)/l]	0,19	0,13	0,06	-0,01	-0,29	-0,05	0,25
K [Cmol(+)/l]	0,24	0,08	0,28	0,47	0,00	0,40	-0,07
P [mg/l]	0,52	0,17	0,18	0,05	0,05	0,36	-0,05
Cu[mg/l]	0,08	-0,29	0,19	0,20	0,13	0,38	0,20
Mn [mg/l]	-0,09	0,21	-0,02	-0,18	0,11	-0,11	0,34
Zn [mg/l]	0,26	-0,21	0,24	0,47	0,25	0,33	0,01
Fe [mg/l]	0,46	-0,28	-0,11	-0,19	-0,38	-0,23	-0,17

A: *Dalbergia retusa* (N=72, 5 mixtures, 7 micro sites)
B: *Enterolobium cyclocarpum* (N=85, 10 mixtures, 10 micro sites)
C: *Hymenea courbaril* (N=236, 8 mixtures, 12 micro sites)
D: *Samanea saman* (N= 65, 5 mixtures, 7 micro sites)
E: *Simarouba glauca* (N=98, 6 mixtures, 8 micro sites)
F: *Swietenia macrophylla* (N=105, 8 mixtures, 8 micro sites)
G: *Tabebuia rosea* (N=53, 3 mixtures, 4 micro sites)

Tabebuia rosea is the single species of all the examined tree species which presents a significant positive correlation to the gravimetric water content of the soil. All the other tree species show better growth potentials at increasing clay content. The growth behaviour of this species seems to be advanced through an increasing content of sand. Moreover, the growth is promoted by an increasing manganese content.

Height and volume

The following figures show in the form of *Box-Whisker-Plots* the arithmetic mean and the volume per ha and per parcel for each tree species. In this sort of presentation it is possible to compare the measures of location and deviation. The length of each box characterizes the standard deviation and the centre of the box points out the arithmetic mean. At the end of the boxes are so-called *whiskers* which present the minimum and the maximum. Consequently the total length of the box with both whiskers demonstrates the range of variation.

There is an important soil parameter given in relation to the height growth of each tree species. The mean height is presented in each graphic.

The volume per ha is dependent on the DBH and the height. Besides, the mortality rate has an influence because the number of individuals per ha of a tree species reduces at high shattering losses. Thereby the volume per ha decreases.

In order to reach a high effect of the correlations only seven of the ten tree species are shown. The three remaining tree species are given too little values.

With *Dalbergia retusa* it is conspicuous that the bigger is the humus supply in the soil is, so worse is the thriftiness. The humus content diminishes at the increase of clay content. That means that *Dalbergia retusa* can reach greater heights on clayey subtrates.

On parcel 1.1 occurs a high range of variation. The best mean heights are observed on parcel 1.2 and parcel 11.

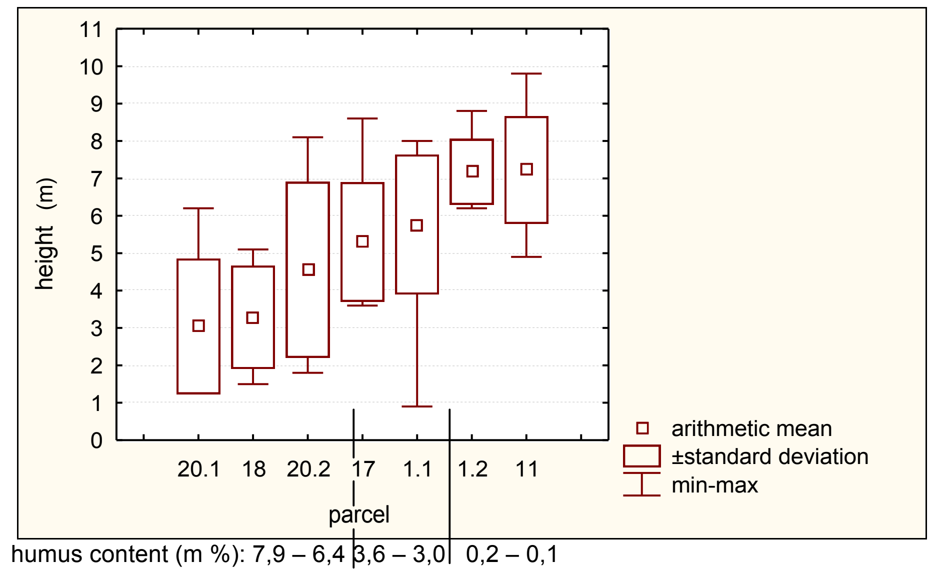

Figure 2-2: Mean heights of Dalbergia retusa in dependence of the humus content of the soil.

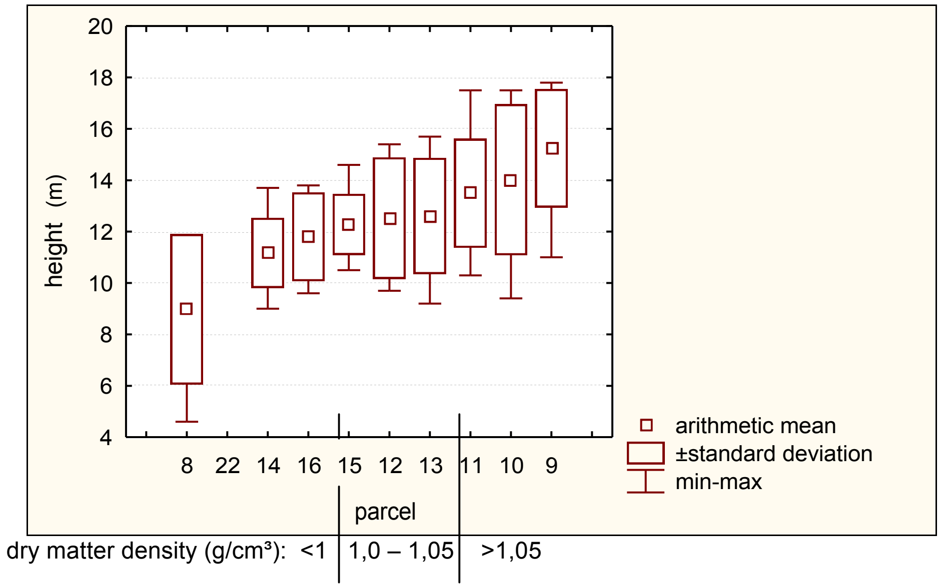

Figure 2-3: Mean heights of Enterolobium cyclocarpum in dependence of the dry matter density.

The growth of *Enterolobium cyclocarpum* improves with an increase of the dry matter density. On parcel 22 it wasn't possible to form mean heights due to of a very high mortality rate (96 %). Parcel 9 is the best site for this tree species.

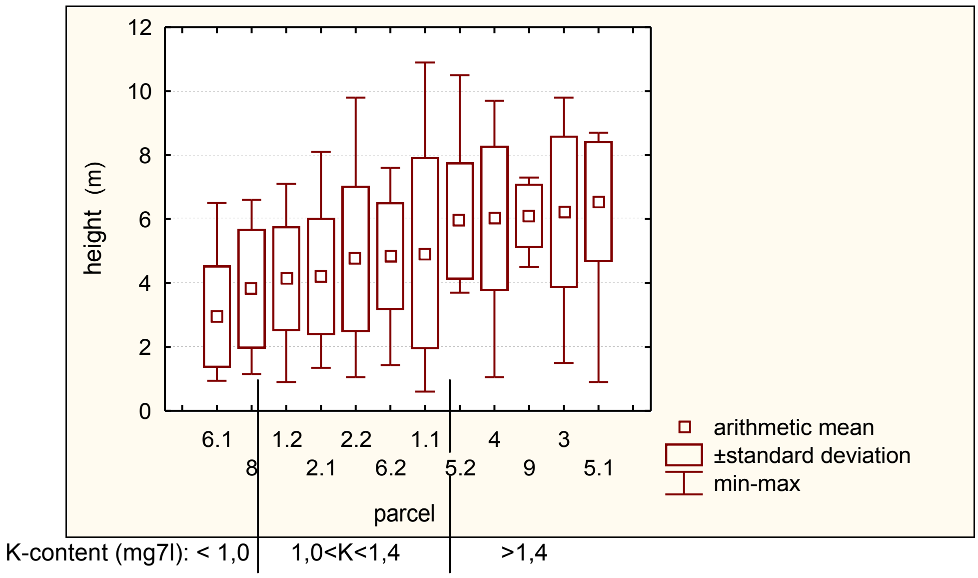

Figure 2-4: Mean heights of Hymenea courbaril in dependence of the potassium content of the soil.

With an increasing potassium content of the soil, the growth of *Hymenea courbaril* improves. You get the impression that the range of variation arises with increasing mean heights.

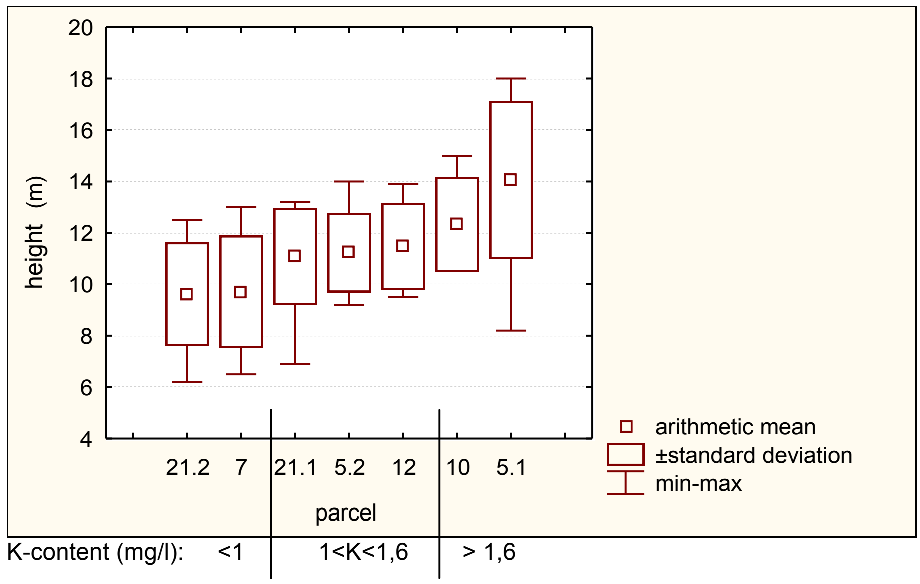

Figure 2-5: Mean heights of Samanea saman in dependence of the potassium content of the soil.

The growth behaviour of *Samanea saman* is influenced by the potassium content of the soil. The best mean heights are given on parcel 5.1., but parcel 5.1 also has the highest deviations too. However on parcel 5.2 there are at the same mixture considerably less height values noticeable. That means that the soil conditions have a bigger importance for the growth than the mixture does with another tree species.

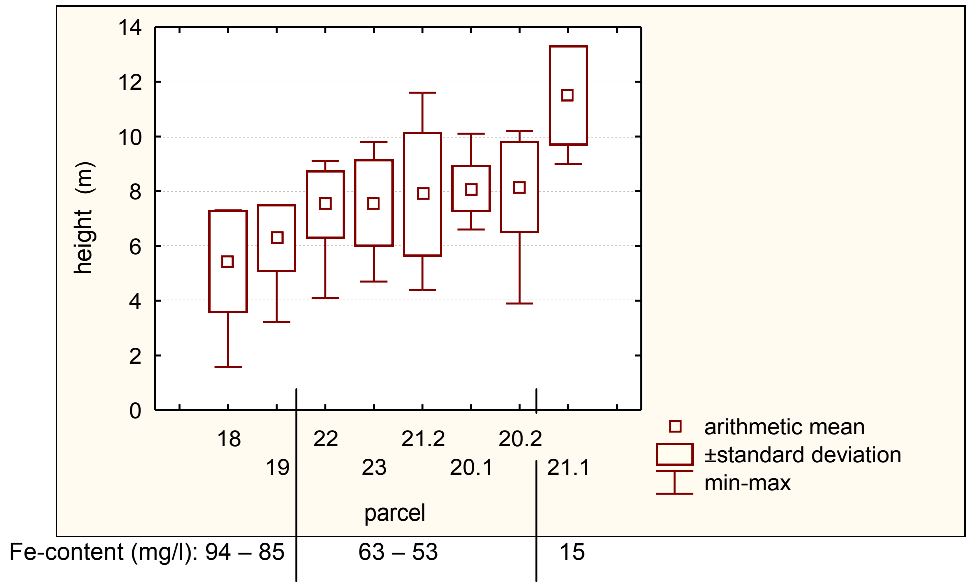

Figure 2-6: Mean heights of Simarouba glauca in dependence of the iron content of the soil.

There is a negative correlation between the iron content and the growth of *Simarouba glauca*. The trees can grow better with less iron in the soil. The best values of the mean heights are presented on parcel 21.1.

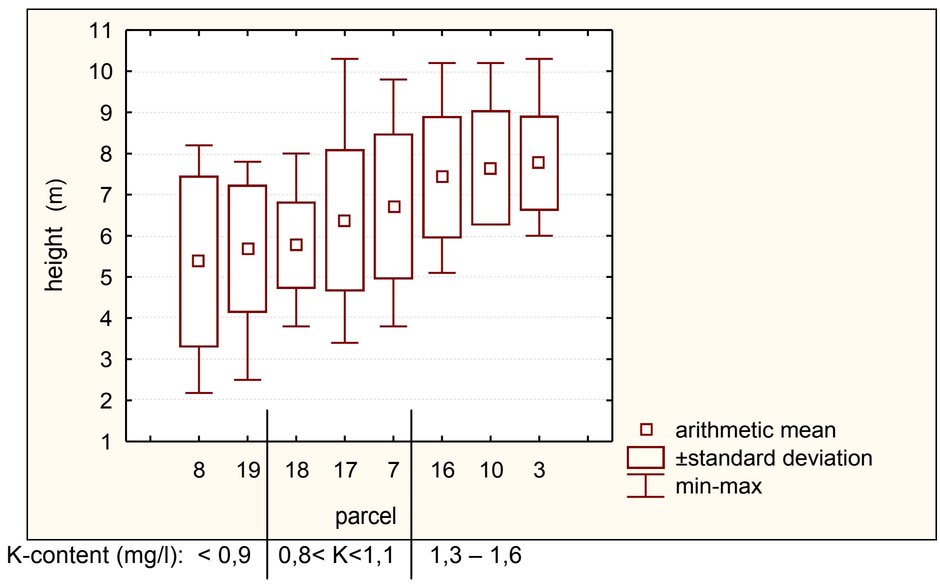

Figure 2-7: Mean heights of Swietenia macrophylla in dependence of the potassium content of the soil.

The growth of *Swietenia macropylla* increases with the increase of potassium. The best mean heights per ha are in parcel 3 and 10.

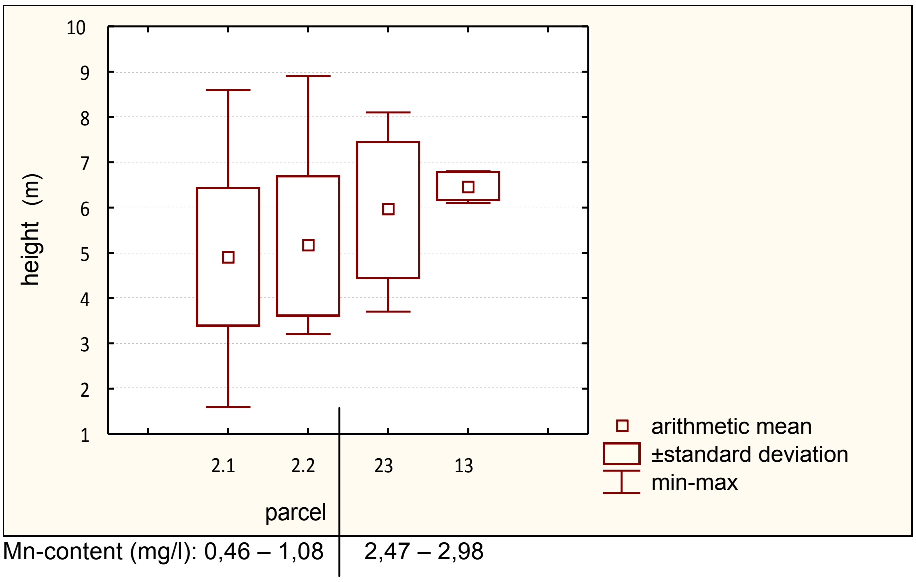

Figure 2-8: Mean heights of Tabebuia rosea in dependence of the manganese content of the soil.

The tree species *Tabebuia rosea* only occurs at four different micro sites. Therefore a general conclusion with the data of this tree species is problematically. There is a better growth at increasing manganese content of the soil. The best values of the mean heights are reached at parcel 13.

2.3 Influence of backwater

In the examination area climate anomalies (*El* Niño and *La Niña*) occur in irregular intervals. Relating to the tree growth on the examined forest plantation especially *La Niña* is of importance. At the last La Niña-phenomenon on some parcels of the forest plantation developed high water during the rainy period. This period continued two to three months and reached heights of 1,50 m. Probably the influence of backwater was during a longer period. The soil measurements with the penetrometer, the soil sampling cylinder and also the growth performance permit no conclusions of the backwater. Only the soil profiles of the concerned parcels show visible signs of the water influence (reduction in colour, rusty mottles, concretions, marbling).

It is also possible to ascertain the influence of backwater with the help of the mortality rate of the tree species on the concerned micro sites. Fig. 2-9 shows the temporary flooded areas on the forest plantation of 1991.

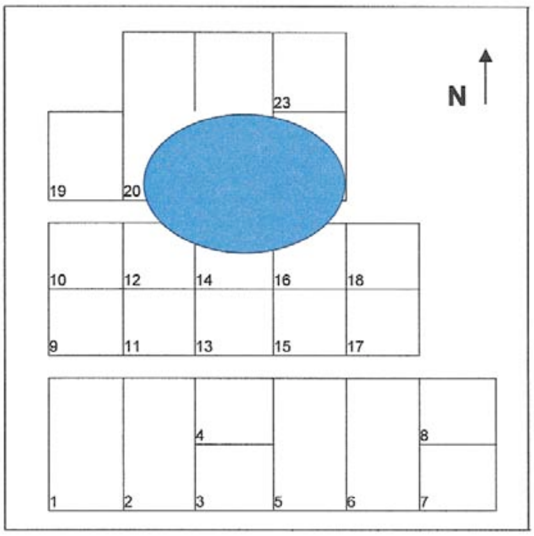

Figure 2-9: Sketch of the forest plantation of 1991 with the areas temporary influenced by backwater (blue mark).

Tab. 2-4 shows the mortality rate of the tree species in the concerned area. Also given are the sample means of the four plots of each parcel unit because there are some differences of the values on the smallest space.

The influence of the backwater can only be examined at these six tree species because the remaining tree species are located on drier sites. Furthermore, it is noticeable that the intensity of the backwater is probably not the same on all of these parcels. The tree species *Samanea saman* and *Swietenia macrophylla* are unsensitive to backwater. The middle mortality rate of *Samanea saman* on all parcels is 18 %. The middle mortality rate of this species on parcel 21.1 is only a little bit more with 21 %. With *Swietenia macrophylla* the middle mortality rate of all parcels amounts to 37 %. This value even remains under at the backwater influenced site. But three tree species react sensitively on the backwater. The middle mortality rate of *Enterolobium cyclocarpum* on all parcels is 35 %. The mortality rate of this species passes over on the wet sites in most of the cases. On parcel 22 are especially high shattering losses. *Dalbergia retusa* shows an equally a high sensitivity concerning backwater. The mean mortality rate of all parcels (54 %) is highly overpassed. With *Diphysa americana* the mean mortality rate of all parcels is at 68 %. But this species only occurs at three sites. The values of the backwater influenced parcels are mostly over this value. *Simarouba glauca* reacts differently. The middle mortality rate of all parcels (46 %) is only passed over at a few samples.

Table 2-4: Mortality rate of the tree species on the areas influenced by backwater.

tree species	parcel	plot	mortality rate (%)
Diphysa americana	14	1	83
Diphysa americana	14	2	100
Diphysa americana	14	3	100
Diphysa americana	14	4	50
Enterolobium cylocarpum	14	1	33
Enterolobium cylocarpum	14	2	50
Enterolobium cylocarpum	14	3	50
Enterolobium cylocarpum	14	4	17
Enterolobium cylocarpum	16	1	33
Enterolobium cylocarpum	16	2	50
Enterolobium cylocarpum	16	3	67
Enterolobium cylocarpum	16	4	83
Sw ietenia macrophylla	16	1	33
Sw ietenia macrophylla	16	2	0
Sw ietenia macrophylla	16	3	0
Sw ietenia macrophylla	16	4	33
Dalbergia retusa	20,1	1	67
Dalbergia retusa	20,1	2	80
Dalbergia retusa	20,1	3	100
Dalbergia retusa	20,1	4	67
Simarouba glauca	20,1	1	33
Simarouba glauca	20,1	2	17
Simarouba glauca	20,1	3	17
Simarouba glauca	20,1	4	20
Samanea saman	21,1	1	17
Samanea saman	21,1	2	17
Samanea saman	21,1	3	0
Samanea saman	21,1	4	50
Simarouba glauca	21,1	1	100
Simarouba glauca	21,1	2	100
Simarouba glauca	21,1	3	100
Simarouba glauca	21,1	4	33
Enterolobium cyclocarpum	22	1	83
Enterolobium cyclocarpum	22	2	100
Enterolobium cyclocarpum	22	3	100
Enterolobium cyclocarpum	22	4	100
Simarouba glauca	22	1	50
Simarouba glauca	22	2	50

2.4 Tree parameter

2.4.1 Quantitative values

(1) Basal area and volume

Tab. 2-5 and 2-6 show the basal area and the standing volume of each tree species per ha. The classification happens in blocks. In each block is a main tree species which occurs in all parcels of this block with 50 %. Furthermore the table presents the admixture tree species which is in combination with the main tree species. These are one or two species types. For a better understanding, this analysis is proceeding on the assumption that the concerned species occur in pure stand. This is only a theory and doesn't happen on the examination area. Therefore the basal area and the standing volume per ha are set forth moreover in consideration of the mixture. Besides the relative portion of each tree species on the total basal area resp. of the total volume is shown.

The aim of this consideration is to test how the basal area and volume of a tree species change when it grows in combination with a different tree species. The behaviour of the four main tree species was analysed.

It makes the impression that in combination with one of the both fast-growing tree species (*Enterolobium cyclocarpum* and *Samanea saman*) in any case there are higher total volumes. Only with the mixture of *Simarouba glauca* with *Enterolobium cyclocarpum* occur less volumes per ha than with *Simarouba glauca* in pure standing. This case is caused by the high mortality rate of *Enterolobium cyclocarpum* on this micro site.

Table 2-5: Basal area (BA) per ha in consideration of the mixture (A: main tree species (see below), B and C: admixture tree species with the relative portion of mixture).

block	parcel	BA_{ha} A	admixture tree species 1 B	BA_{ha} B	admixture tree species 2 C	BA_{ha} C	BA_{ha} total	BA_{ha} (%) A	BA_{ha} (%) B	BA_{ha} (%) C
I	1.1	4.1	Dalbergia retusa (50 %)	5.0			4.6	45	55	
I	1.2	2.8	Dalbergia retusa (50 %)	4.6			3.7	38	62	
I	2.1	4.2	Tabebuia rosea (50 %)	4.0			4.1	51	49	
I	2.2	4.6	Tabebuia rosea (50 %)	3.9			4.3	54	46	
I	3	7.8	Swietenia macrophylla (50 %)	17.3			12.2	35	65	
I	4	9.5	Tabebuia impetiginosa (50 %)	2.5			6.0	80	21	
I	5.1	4.4	Samanea saman (50 %)	22.4			13.4	16	83	
I	5.2	2.9	Samanea saman (50 %)	20.2			11.6	13	87	
I	6.1	2.0	Diphysa americana (50 %)	3.0			2.5	40	60	
I	6.2	5.1	Diphysa americana (50 %)	2.2			3.7	70	30	
II	7	8.0	Samanea saman (50 %)	22.7			15.4	26	74	
II	8	6.5	Enterolobium cyclocarpum (25 %)	19.8	Hymenea courbaril (25 %)	2.4	8.3	37	54	8
II	17	14.2	Dalbergia retusa (50 %)	2.2			7.6	63	15	
II	18	6.2	Dalbergia retusa (25 %)	1.4	Simarouba glauca (25 %)	7.1	5.2	60	7	34
III	9	41.0	Hymenea courbaril (50 %)	3.7			22.4	92	8	
III	10	26.2	Samanea saman (25 %)	15.6	Swietenia macrophylla (25 %)	5.8	18.4	71	21	8
III	11	31.3	Dalbergia retusa (50 %)	3.8			17.5	89	11	
III	12	9.3	Samanea saman (50 %)	13.3			11.3	41	59	
III	13	33.1	Tabebuia rosea (50 %)	1.6			17.4	95	5	
III	14	34.3	Diphysa americana (50 %)	1.1			17.7	97	3	
III	15	31.4	Tabebuia impetiginosa (50 %)	2.5			16.9	93	7	
III	16	21.1	Albizia adinocephala (25 %)	1.5	Swietenia macrophylla (25 %)	12.2	13.9	76	3	22
IV	19	5.5	Swietenia macrophylla (50 %)	5.8			5.6	49	51	
IV	20.1	19.3	Dalbergia retusa (50 %)	0.4			9.8	98	2	
IV	20.2	16.9	Dalbergia retusa (50 %)	1.6			9.3	91	8	
IV	21.1	5.5	Samanea saman (50 %)	26.8			16.1	83	17	
IV	21.2	7.5	Samanea saman	12.5			10.0	38	62	
IV	22	11.7	Enterolobium cyclocarpum	3.6			7.6	77	23	
IV	23	11.9	Tabebuia rosea	7.1			9.5	63	37	

block I: main tree species *Hymenea courabaril* (50 %)
block II: main tree species *Swietenia macrophylla* (50 %)

block III: main tree species *Enterolobium cyclocarpum (50 %)*
block IV: main tree species *Simarouba glauca (50 %)*

Table 2-6: Volume (V) per ha in consideration of the mixture (A: main tree species (see below), B and C: admixture tree species with the relative portion of mixture)

block	parcel	V_{ha} A	admixture tree species 1 B	V_{ha} B	admixture tree species 2 C	V_{ha} C	V_{ha} total	V_{ha} (%) A	V_{ha} (%) B	V_{ha} (%) C
I	1.1	12.6	Dalbergia retusa (50 %)	13.2			12.9	49	51	
I	1.2	5.9	Dalbergia retusa (50 %)	13.2			9.6	31	69	
I	2.1	9.1	Tabebuia rosea (50 %)	8.6			8.8	51	49	
I	2.2	11.6	Tabebuia rosea (50 %)	9.4			10.5	55	45	
I	3	23.3	Swietenia macrophylla (50 %)	56.4			38.4	33	67	
I	4	28.1	Tabebuia impetiginosa (50 %)	5.4			16.7	84	16	
I	5.1	12.7	Samanea saman (50 %)	135.3			74.0	9	91	
I	5.2	7.9	Samanea saman (50 %)	94.2			51.0	8	92	
I	6.1	3.7	Diphysa americana (50 %)	8.2			5.9	31	69	
I	6.2	12.2	Diphysa americana (50 %)	5.6			8.9	68	32	
II	7	23.7	Samanea saman (50 %)	95.0			59.4	20	80	
II	8	17.7	Enterolobium cyclocarpum (25 %)	80.8	Hymenea courbaril (25 %)	5,0	28.4	30	65	5
II	17	40.7	Dalbergia retusa (50 %)	5.5			20.7	66	13	36
II	18	14.8	Dalbergia retusa (25 %)	2.3	Simarouba glauca (25 %)	18,1	12.5	59	5	36
III	9	260.3	Hymenea courbaril (50 %)	9.4			134.8	97	3	
III	10	157.9	Samanea saman (25 %)	79.1	Swietenia macrophylla (25 %)	19,1	103.5	76	19	5
III	11	175.5	Dalbergia retusa (50 %)	11.5			93.5	94	6	
III	12	47.5	Samanea saman (50 %)	62.3			54.9	43	57	
III	13	178.9	Tabebuia rosea (50 %)	4.1			91.5	98	2	
III	14	157.5	Diphysa americana (50 %)	2.9			80.2	98	2	
III	15	160.2	Tabebuia impetiginosa (50 %)	4.7			82.5	97	3	
III	16	103.9	Albizia adinocephala (25 %)	3.3	Swietenia macrophylla	38,1	62.3	83	1	15
IV	19	14.6	Swietenia macrophylla (50 %)	15.0			14.8	49	51	
IV	20.1	62.8	Dalbergia retusa (50 %)	0.8			31.8	99	1	
IV	20.2	59.1	Dalbergia retusa (50 %)	4.6			31.9	93	7	
IV	21.1	25.9	Samanea saman (50 %)	121.1			73.5	18	82	
IV	21.2	26.3	Samanea saman (50 %)	52.6			39.4	33	67	
IV	22	37.0	Enterolobium cyclocarpum (50 %)	15.3			26.2	71	29	
IV	23	38.4	Tabebuia rosea (50 %)	18.6			28.4	67	33	

block I: main tree species *Hymenea courabaril* (50 %)
block II: main tree species *Swietenia macrophylla* (50 %)
block III: main tree species *Enterolobium cyclocarpum (50 %)*
block IV: main tree species *Simarouba glauca (50 %)*

The tree species *Hymenea courabaril* shows a higher volume per ha in combination with *Dalbergia retusa, Swietenia macrophylla* and *Samanea saman.* Less value occurs in combination with *Tabebuia impetiginosa* and *Tabebuia rosea*. In this combination, *Hymenea courabaril* has a higher relative portion on the total volume than the mentioned tree species.

Swietenia macrophylla presents in combination with *Dalbergia retusa* and *Hymenea courbaril* a less total volume. As expected, the total volume per ha increases with one of the both fast-growing tree species.

Enterolobium cyclocarpum shows only in combination with *Samanea saman* a higher total volume per ha. At mixture with other tree species the volume per ha decreases.

For *Simarouba glauca* there is noticeabley a higher total volume per ha in combination with *Samanea saman.* Mixtures with *Dalbergia retusa* and *Tabebuia rosea* effect a reduction of the total volume.

(2) Slenderness

The slenderness (H/D-value) is the quotient of tree height and breast-height diameter (DBH). Usually the vitality and resistance of a tree increases when the slenderness decreases. Above all, the slenderness is dependent on the social position and the growth of a tree. During the stand development at first you can observe an increase of the slenderness of the single trees because of the canopy closure. In the following development the height growth diminishes in a bigger manner than the diameter growth. This results in a reduction of the slenderness (*Kramer*, 1988). This phenomenon was also noticeable on the examination area. There could be ascertained a significant negative correlation between H/D-value and DBH (r = -0,64***). The H/D-values of the fast-growing tree species *Enterolobium cyclocarpum* and *Samanea saman* were obviously under the values of the other tree species.

The slenderness varies in dependence of the stand treatment. Although, there were only a few thinning operations on the examined forest plantation, there is a light influence on the slenderness that is identifiable. Fig. 2-10 presents the relation between the slenderness and the thinning intensity. The graphic refers to all examined tree species. In chap. 2.5 the situation of the single tree species is shown.

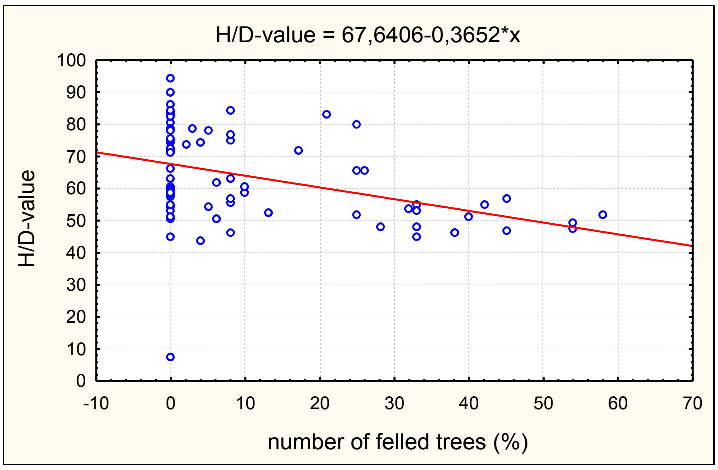

Figure 2-10: Slenderness in dependence to the intensity of thinning (N = 62, R^2 = 0,14).

(3) Height curves

The following figures show with help of logarithmic and polynomial equalization functions the height-diameter-relations for each tree species. There are narrow relations visible between both parameters in most of the cases. The single height values have certain deviations. With the help of the graphic equalization, it is possible to estimate a height value at an appointed diameter and reverse.

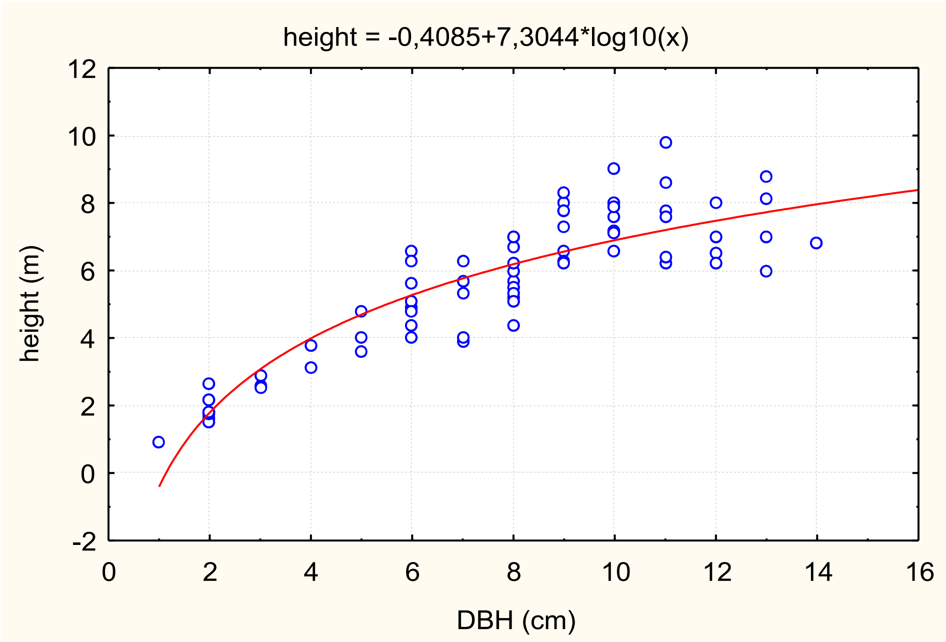

Figure 2-11: Stand height curve (according to logarithmic equalization function) of Dalbergia retusa (N = 72, R^2 = 0,77).

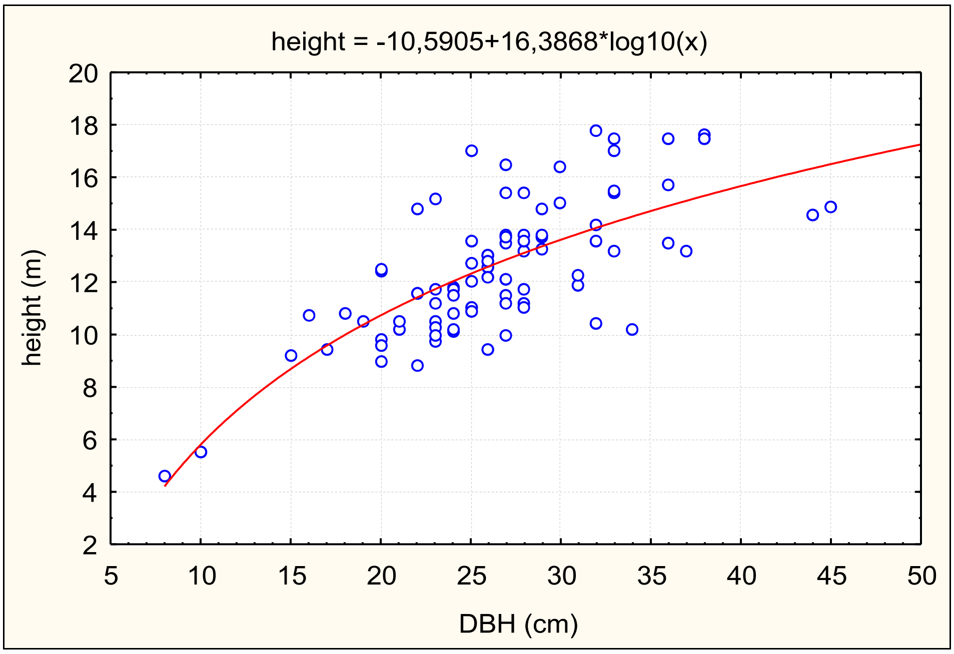

Figure 2-12: Stand height curve (according to logarithmic equalization function) of Enterolobium cyclocarpum (N = 85, R^2 = 0,45).

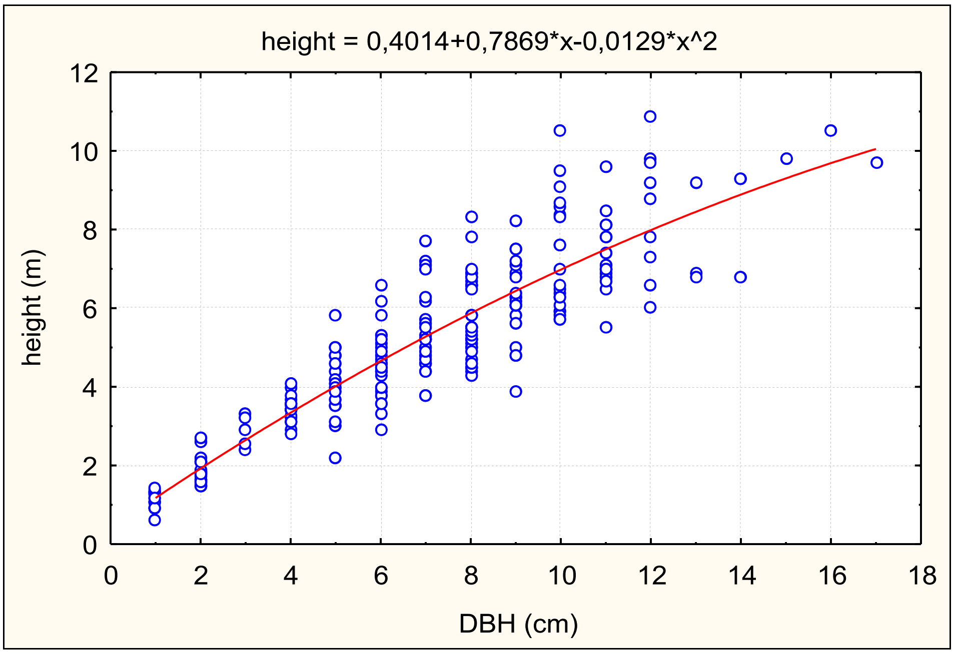

Figure 2-13: Stand height curve (according to polynomial equalization function) of Hymenea courbaril (N = 236, R² = 0,81).

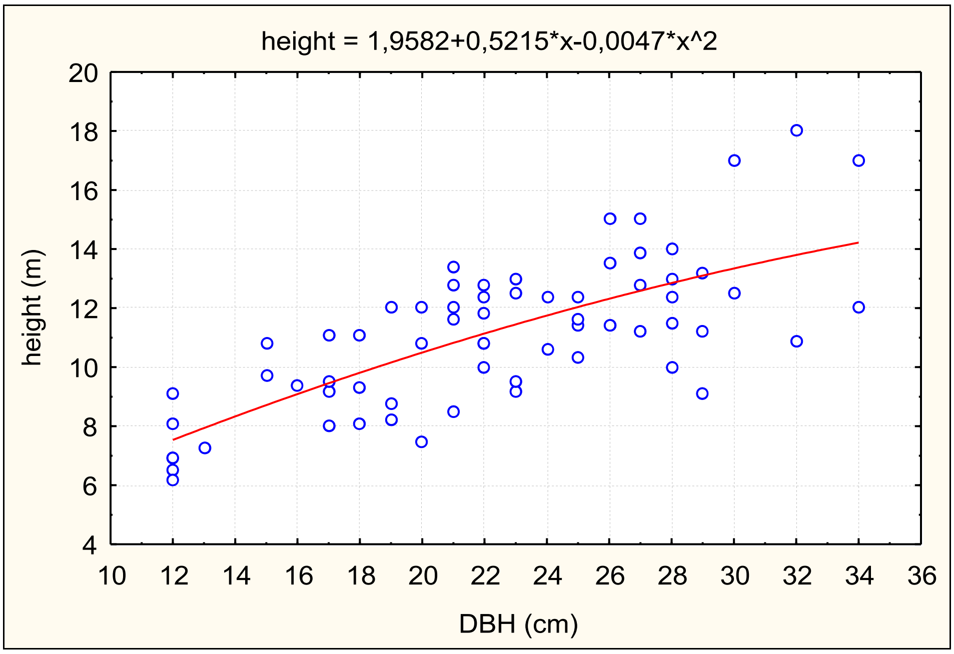

Figure 2-14: Stand height curve (according to polynomial equalization function) of Samanea saman (N = 65, R² = 0,52).

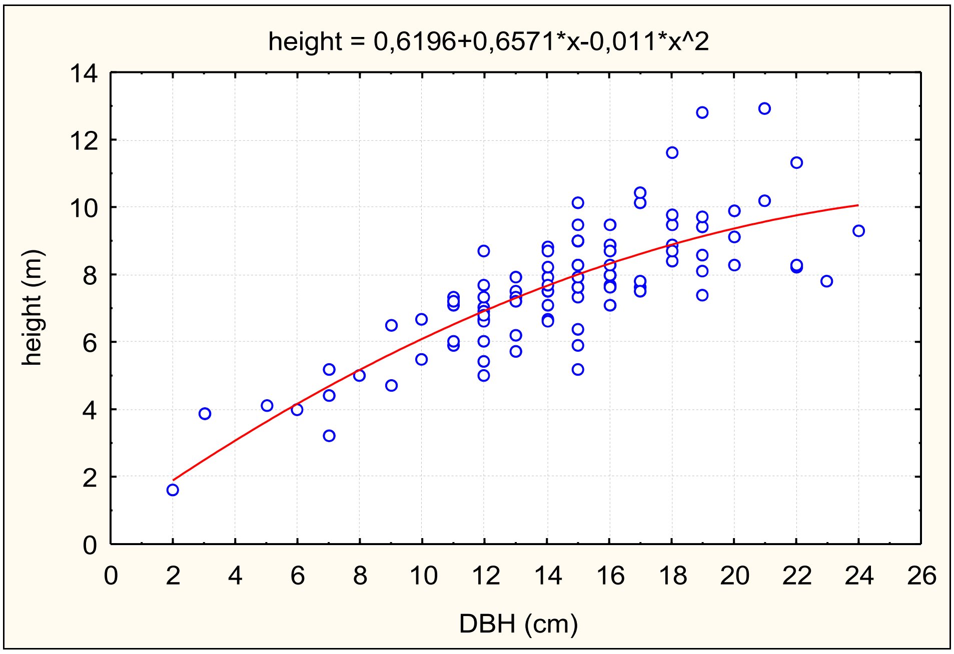

Figure 2-15: Stand height curve (according to polynomial equalization function) of Simarouba glauca (N = 98, R^2 = 0,62).

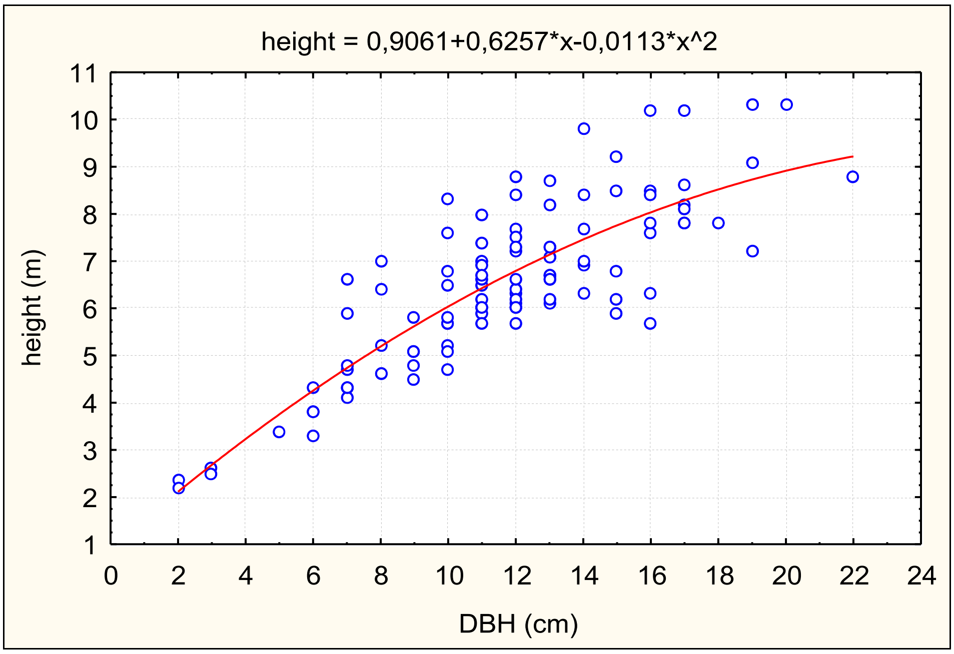

Figure 2-16: Stand height curve (according to polynomial equalization function) of Swietenia macrophylla (N = 105, R^2 = 0,68).

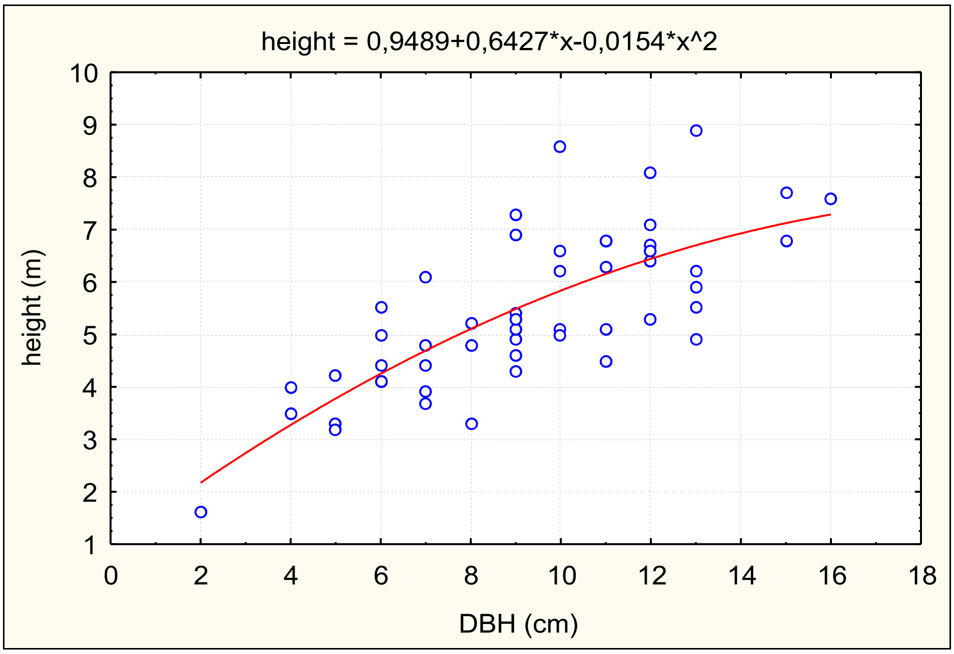

Figure 2-17: Stand height curve (according to polynomial equalization function) of Tabebuia rosea (N = 53, R^2 = 0,60).

(4) Crown width

The crown width is an important index for the characterization of the crown. It has a in narrow relation to the vitality of the trees. With increasing DBH and increasing height the crown width increases as well.

The following figures are concerned with the values of all the examined tree species. The single crown parameter of each tree species is described in chapter 2.5 ff.

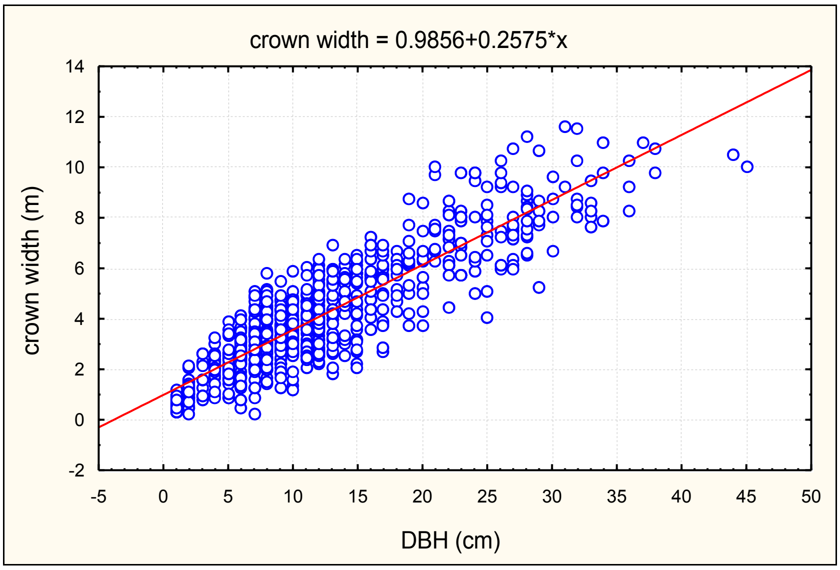

Figure 2-18: Crown width in dependence of DBH (N = 761, R^2 = 0,79).

The values of the crown width and the crown length per individual of the examined tree species are quite close to each other (fig. 2-19).

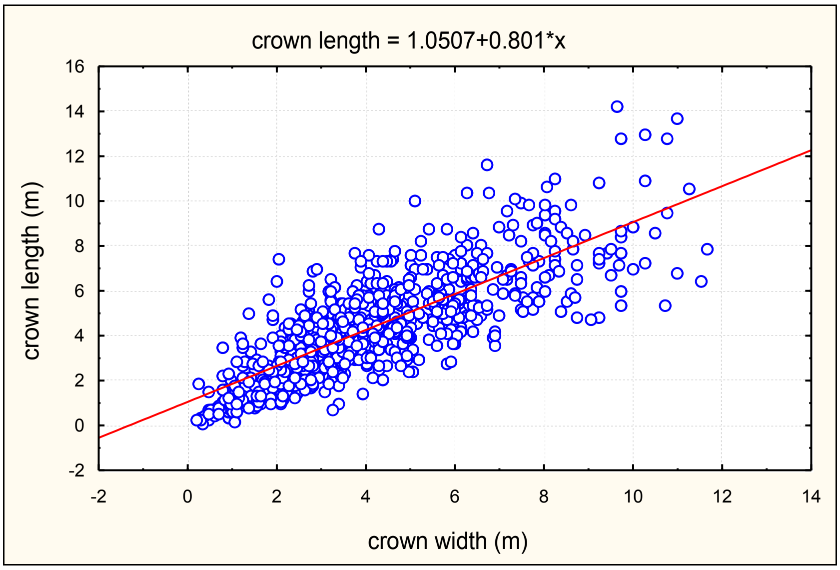

Figure 2-19: Relation between crown width and crown length (N = 761, R^2 = 0,64).

(5) Crown projection area

Analogous to the relation between DBH and crown width, the crown projection area increases with increasing DBH. The polynomial function describes the development of the crown projection area in dependence of the DBH.

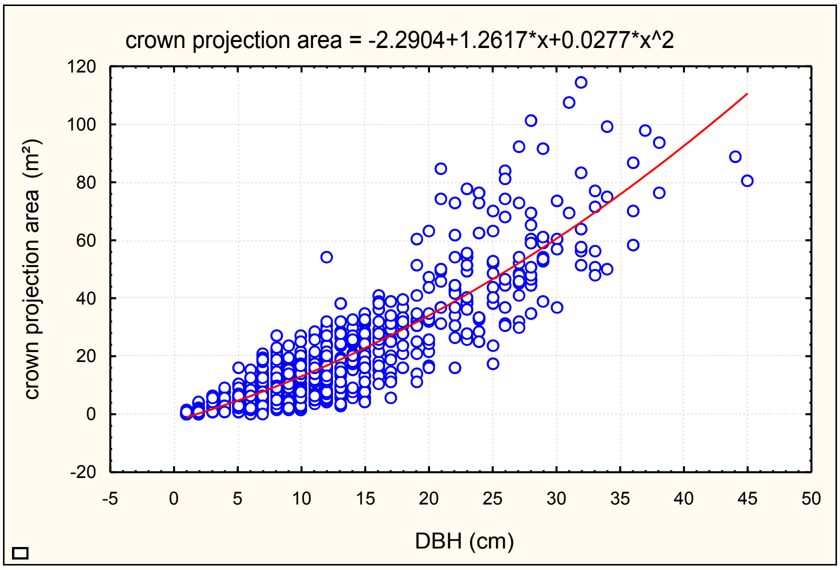

Figure 2-20: Relation between DBH and crown projection area (N = 761, R^2 = 0,76).

2.4.2 Qualitative characteristics

(1) Vitality

The vitality determination was distinguished between three classes: stunted, normal and luxuriantly developed trees. In the analyses appeared a relation between the vitality and the crown parameter, crown width and crown length. With increasing values of these two crown parameters the number of trees with stunted growth decreases. As expected there is also a relation to the crown form. The categories 4 and 5 of the crown form (bad resp. very bad crown form) are positively correlated with the vitality classes 1 (stunted developed crown). The relative portion of luxuriantly developed crowns increases with increasing values of diameter and height.

(2) Crown form

The interpretation of the crown form is similar to the interpretation of the vitality. The portion of trees with badly developed crowns increases with decreasing crown ratio. It is possible to notice that there are better stem forms at very good crown forms. Furthermore you can deduce outgoing from a high number of bad until very badly developed crowns a high mortality rate on the concerning site.

(3) Crown density

The crown density, given in percent, shows the portion of the canopy cover on the soil. There is visible a correlation of the crown density to the basal area per ha (fig. 2-21).

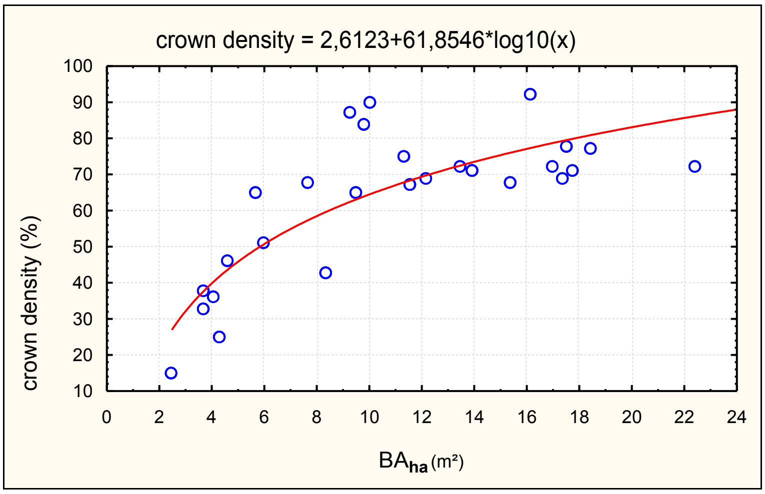

Figure 2-21: Crown density in dependence of the basal area (BA) per ha (N = 57, R^2 = 0,49).

As expected there is also a significant correlation between crown density and crown projection area (fig. 2-22).

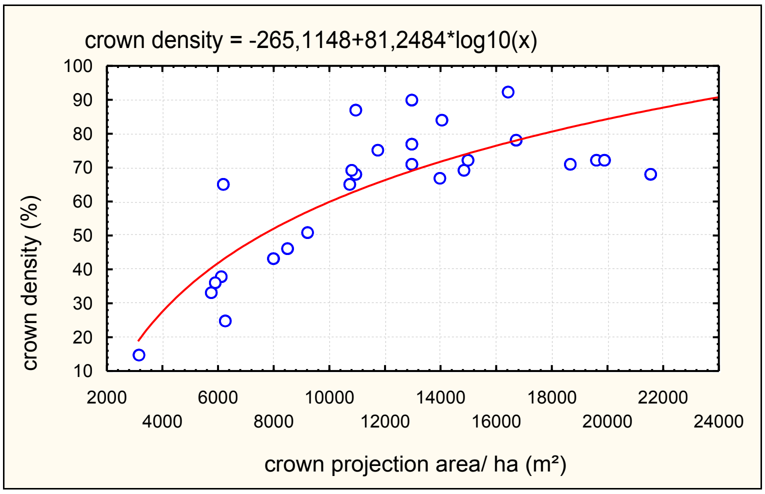

Figure 2-22: Crown density in dependence of the crown projection area per ha (N = 57, R^2 = 0,52).

(4) Browsing and peeling damage

Browsing and peeling damages are caused not only by the cattle farming but also by the wildlife. You have to expect damages by the wildlife because there is a game reserve. Statements to the game density are not possible. At this type of damages there was a detectable relation to the vitality. There are relatively many trees with stunted developed crowns at high browsing and peeling damages.

2.4.3 Growth form in dependence of the mixture

It was expected that besides of the soil characteristics, the form of mixture also has a influence on the growth potential. Dependent on their stem form the trees were distributed to one of four classes. During the analysis two more classes were added. The relative portions of stem form 1 (straight-stemmed) and stem form 3 (inclined straight-stemmed) were summed up. They present trees with middling to good conditions. Furthermore, stem form 2 (crooked-stemmed) and stem form 4 (inclined crooked-stemmed) were added to one class, which represents trees with bad growth form (tab. 2-7).

One aim of this examination was to test if the combination of a tree species with one or two fast growing tree species (*Enterolobium cyclocarpum, Samanea saman* or *Simarouba glauca*) has an influence to forked growth and / or to the stem form. There could be determined a higher crown density on parcels with fast growing trees. That means there are worse light conditions.

There were no differences identifiable on the relative portion of crotches of one tree species effected through the combination with one or two fast-growing tree species. Only with *Dalbergia retusa* was a little influence of the canopy cover found. For this species the relative portion of bad stem forms arises in combination with fast-growing tree species (s. tab. 2-7). At the combination with a slow-growing tree species (e.g. *Hymenea courbaril*) there is a visible raising portion of better stem forms. This result is contradictory to the analysis of *Molina* et al. (1996) and *Gutiérrez* (2000). In their opinion *Dalbergia retusa* can reach better stem forms in combination with a fast-growing tree species. At a high light intensity the relative portion of the ramificatin of *Dalbergia retusa* raises.

It can be assumed that on the examination area the differences in the stem form of *Dalbergia retusa* are not caused by the form of mixture but by other site conditions.

For most of the tree species you can notice no relations between crown density and growth potential. Only *Hymenea courbaril* and *Enterolobium cyclocarpum* occur with higher canopy cover higher tree heights. There is no detectable influence of the crown density to the mortality rate. The mortality rate depends on many different factors, like soil, provenience and diseases.

Table 2-7 a: Frequency of crotches and type of stem per tree species and parcel.

tree species (A)	parcel	in mixture with:	frequency of crotches (%) (A)	type of stem (TS) of A (%)					
				TS 1	TS 2	TS 3	TS 4	TS 1+3	TS 2+4
Dalbergia retusa	1,1	Hymenea courbaril	67	20	67	7	7	27	73
Dalbergia retusa	1,2	Hymenea courbaril	64	18	73	0	9	18	82
Dalbergia retusa	11	Enterolobium cyclocarpum	46	0	62	0	38	0	100
Dalbergia retusa	17	Swietenia macrophylla	73	9	73	0	18	9	91
Dalbergia retusa	18	Simarouba glauca,	63	0	75	0	25	0	100
		Swietenia macrophylla							
Dalbergia retusa	20,1	Simarouba glauca	0	0	100	0	0	0	100
Dalbergia retusa	20,2	Simarouba glauca	44	0	56	0	44	0	100
Diphysa americana	6,1	Hymenea courbaril	83	0	100	0	0	0	100
Diphysa americana	6,2	Hymenea courbaril	46	8	62	0	31	8	92
Diphysa americana	14	Enterolobium cyclocarpum	100	0	100	0	0	0	100
Enterolobium cyclocarpum	8	Hymenea courbaril,	100	50	25	25	0	75	25
		Swietenia macrophylla							
Enterolobium cyclocarpum	9	Hymenea courbaril	82	45	9	36	9	82	18
Enterolobium cyclocarpum	10	Samanea saman,	89	33	11	44	11	78	22
		Swietenia macrophylla							
Enterolobium cyclocarpum	11	Dalbergia retusa	90	30	10	60	0	90	10
Enterolobium cyclocarpum	12	Samanea saman	100	50	25	0	25	50	50
Enterolobium cyclocarpum	13	Tabebuia rosea	82	9	18	45	27	55	45
Enterolobium cyclocarpum	14	Diphysa americana	86	29	14	36	21	64	36
Enterolobium cyclocarpum	15	Tabebuia impetiginosa	100	45	9	36	9	82	18
Enterolobium cyclocarpum	16	Albizia adinocephala,	100	25	13	38	25	63	38
		Swietenia macrophylla							
Enterolobium cyclocarpum	22	Simarouba glauca	100	100	0	0	0	100	0
Hymenea courbaril	1,1	Dalbergia retusa	63	53	37	11	0	63	37
Hymenea courbaril	1,2	Dalbergia retusa	36	27	59	9	5	36	64
Hymenea courbaril	2,1	Tabebuia rosea	70	30	48	13	9	43	57
Hymenea courbaril	2,2	Tabebuia rosea	57	9	78	9	4	17	83
Hymenea courbaril	3	Swietenia macrophylla	75	8	71	13	8	21	79
Hymenea courbaril	4	Tabebuia impetiginosa	67	13	63	4	21	17	83
Hymenea courbaril	5,1	Samanea saman	21	11	47	26	16	37	63
Hymenea courbaril	5,2	Samanea saman	31	15	46	31	8	46	54
Hymenea courbaril	6,1	Diphysa americana	72	17	72	0	11	17	83
Hymenea courbaril	6,2	Diphysa americana	70	13	65	17	4	30	70
Hymenea courbaril	8	Enterolobium cyclocarpum,	46	31	54	15	0	46	54
		Swietenia macrophylla							

Table 2-7 b Frequency of crotches and type of stem per tree species and parcel.

tree species (A)	parcel	in mixture with:	frequency of crotches (%) (A)	type of stem (TS) of A (%)					
				TS 1	TS 2	TS 3	TS 4	TS 1+3	TS 2+4
Samanea saman	5,1	Hymenea courbaril	100	67	22	11	0	78	22
Samanea saman	5,2	Hymenea courbaril	67	33	33	33	0	67	33
Samanea saman	7	Swietenia macrophylla	94	38	25	31	6	69	31
Samanea saman	10	Enterolobium cyclocarpum, Swietenia macrophylla	75	25	25	0	50	25	75
Samanea saman	12	Enterolobium cyclocarpum	86	14	0	57	29	71	29
Samanea saman	21,1	Simarouba glauca	100	0	27	45	27	45	55
Samanea saman	21,2	Simarouba glauca	100	0	22	33	44	33	67
Simarouba glauca	18	Dalbergia retusa, Swietenia macrophylla	63	25	63	0	13	25	75
Simarouba glauca	19	Swietenia macrophylla	45	36	36	0	27	36	64
Simarouba glauca	20,1	Dalbergia retusa	44	50	33	11	6	61	39
Simarouba glauca	20,2	Dalbergia retusa	56	44	39	17	0	61	39
Simarouba glauca	21,1	Samanea saman	75	50	25	0	25	50	50
Simarouba glauca	21,2	Samanea saman	36	55	9	18	18	73	27
Simarouba glauca	22	Enterolobium cyclocarpum	29	50	50	0	0	50	50
Simarouba glauca	23	Tabebuia rosea	50	36	29	14	21	50	50
Swietenia macrophylla	3	Hymenea courbaril	76	71	29	0	0	71	29
Swietenia macrophylla	7	Samanea saman	72	39	56	6	0	44	56
Swietenia macrophylla	8	Enterolobium cyclocarpum, Hymenea courbaril	69	46	46	8	0	54	46
Swietenia macrophylla	10	Enterolobium cyclocarpum, Samanea saman	50	33	67	0	0	33	67
Swietenia macrophylla	16	Albizia adinocephala, Enterolobium cyclocarpum	78	33	56	0	11	33	67
Swietenia macrophylla	17	Dalbergia retusa	93	50	43	7	0	57	43
Swietenia macrophylla	18	Dalbergia retusa, Simarouba glauca	73	60	40	0	0	60	40
Swietenia macrophylla	19	Simarouba glauca	85	38	46	8	8	46	54
Tabebuia impetiginosa	4	Hymenea courbaril	17	0	75	17	8	17	83
Tabebuia impetiginosa	15	Enterolobium cyclocarpum	88	12	71	0	18	12	88
Tabebuia rosea	2,1	Hymenea courbaril	60	80	20	0	0	80	20
Tabebuia rosea	2,2	Hymenea courbaril	73	73	13	13	0	87	13
Tabebuia rosea	13	Enterolobium cyclocarpum	5	25	50	25	0	50	50

2.5 Comparison of the tree species

Table 2-8 shows a survey of the most important tree parameter for each tree species. The arithmetic means with their standard deviation are represented. At the parameter height and diameter the coefficient of variation is additional given.

The tree species *Enterolobium cyclocarpum* and *Samanea saman* show the highest values in DBH, height and volume. As a result of thinning operations these two tree species present a relatively small number of trees per ha. In reality, the tree species occur in different mixtures. The declarations in table 2-8 refer to each tree species in pure stand, in order to get a better comparison between the different species. The tree species *Diphysa americana* and *Dalbergia retusa* show the highest mortality rate (68 resp. 54 %). Therefore their number of individuals per ha is quite small. All the values vary between 356 (Diphysa americana) and 995 individuals per ha (*Swietenia macrophylla*). *Dipysa americana, Tabebuia impetiginosa* and *Dalbergia retusa* show the smallest stores per ha.

The crown parameter are an important index for the thriftiness. With their help it is possible to discuss the vitality and the stability of a tree. The slenderness varies between 48 % (*Enterolobium cyclocarpum)* and 79 % (*Hymenea courbaril*). As expected, the slenderness decreases with increasing DBH. The base of crown depends on the tree height. The means of the base of crown of the examined tree species varies between 1,7 m (*Diphysa americana*) and 5,4 m (*Enterolobium cyclocarpum).*

As mentioned in figure 2-19, there is a strong dependence between crown width and crown length. The values of these two parameter are near to each other at each tree species. The relation between crown length and crown width can be expressed with the **crown index**. With most of these tree species it is between 0,9 and 1,1. Only the tree species *Tabebuia rosea* (1,3) and *Swietenia macrophylla* (1,5) show bigger crown length than crown width.

The **crown ratio** declares the relative part of the crown length on the tree height. The values are between 48 % (*Diphysa americana*) and 70 % (*Simarouba glauca*). The small-growing tree species *Hymenea courbaril* has with 63 % a relatively high crown ratio.

The **crown diameter ratio I** expresses the ratio of the crown width to the diameter. It varies from 28 (*Tabebuia rosea*) until 49 (*Hymenea courbaril*). *Hymenea courbaril, Tabebuia impetiginosa* and *Dalbergia retusa* have in comparison to their small DBH a relatively wide crown. However, *Tabebuia rosea* is provided with a relatively small crown in comparison to its DBH. The fast-growing tree species have relatively small values in the crown diameter ratio I.

The **crown diameter ratio II** declares the ratio of the crown width to the tree height. It varies between 0,5 und 0,7. Because of the little crown width, *Diphysa americana* and *Tabebuia rosea* show the smallest values.

As the most frequent **crown form** occurs with the tree species on the examined plantation crown form 3, that means inclined straight-stemmed individuals. With the tree species *Enterolobium cyclocarpum, Simarouba glauca* and *Swietenia macrophylla*, the most frequent stem form is form 2. These are crooked stems.

Table 2-8: Survey of the most important tree parameter for each tree species (arithmetic means with standard deviations (S_x); height and diameter additional with the coefficient of variation (S_x %), BA_{ha}= basal area per ha).

tree species	N / ha	DBH (cm)	S_x	S_x %	height (m)	S_x	S_x %	BA_{ha} (m^2)	S_x	V_{ha} (m^3)	S_x	H / D - value	S_x	crown base (m)	S_x	crown width (m)	S_x
Dalbergia retusa	519	7,6 ±	3,4	44	5,6 ±	2,1	38	2,7 ±	2,4	7,3 ±	7,1	78,0 ±	16,1	2,3 ±	0,9	3,1 ±	1,3
Diphysa americana	356	6,6 ±	5,8	88	3,9 ±	2,7	68	2,0 ±	2,2	5,6 ±	6,1	78,8 ±	29,3	1,7 ±	0,9	2,0 ±	1,7
Enterolobium cyclocarpum	415	26,6 ±	6,3	24	12,5 ±	2,6	21	25,3 ±	18,5	134,9 ±	111,1	48,2 ±	8,0	5,4 ±	1,4	7,6 ±	2,0
Hymenea courbaril	950	6,8 ±	3,3	49	5,1 ±	2,2	44	4,4 ±	3,4	11,8 ±	11,6	79,0 ±	18,8	1,8 ±	0,7	3,3 ±	1,4
Samanea saman	463	22,3 ±	5,8	26	11,1 ±	2,5	23	19,1 ±	11,0	91,3 ±	63,5	51,0 ±	9,3	4,1 ±	1,2	7,7 ±	1,9
Simarouba glauca	606	14,0 ±	4,2	30	7,6 ±	1,9	25	10,7 ±	7,0	35,2 ±	27,2	54,9 ±	12,2	2,3 ±	0,6	5,4 ±	1,3
Swietenia macrophylla	695	12,0 ±	3,9	33	6,5 ±	1,7	27	9,5 ±	5,5	28,1 ±	19,3	58,7 ±	13,5	2,3 ±	0,5	3,2 ±	1,4
Tabebuia impetiginosa	672	6,1 ±	2,8	45	4,1 ±	1,5	38	2,5 ±	1,9	5,1 ±	4,3	73,6 ±	25,7	1,8 ±	0,5	2,8 ±	1,3
Tabebuia rosea	614	9,3 ±	3,1	34	5,4 ±	1,5	28	4,2 ±	3,4	10,2 ±	9,6	61,8 ±	14,5	2,3 ±	0,5	2,9 ±	1,5

tree species	crown length (m) S_x	crown ratio S_x	crown index S_x	crown diameter ratio I S_x	crown diameter ratio II S_x	most frequent crown form	mortality rate (%)	felled trees (%)
Dalbergia retusa	3,3 ± 1,6	56,6 ± 13,5	1,1 ± 0,4	41,3 ± 14,1	0,6 ± 0,2	3	54	5
Diphysa americana	2,2 ± 1,8	47,8 ± 19,5	1,0 ± 0,4	32,7 ± 10,3	0,5 ± 0,2	3	68	0
Enterolobium cyclocarpum	7,2 ± 2,0	56,8 ± 8,9	1,0 ± 0,3	28,4 ± 5,7	0,6 ± 0,2	2	35	28
Hymenea courbaril	3,3 ± 1,8	62,6 ± 10,4	1,0 ± 0,3	49,3 ± 14,5	0,7 ± 0,2	3	15	3
Samanea saman	7,0 ± 2,4	62,0 ± 10,2	0,9 ± 0,3	33,1 ± 6,7	0,7 ± 0,2	3	18	40
Simarouba glauca	5,4 ± 1,6	69,7 ± 6,3	1,0 ± 0,3	37,9 ± 9,7	0,7 ± 0,2	2	46	0
Swietenia macrophylla	4,3 ± 1,5	64,1 ± 9,8	1,5 ± 0,5	26,6 ± 7,5	0,5 ± 0,2	2	37	10
Tabebuia impetiginosa	2,3 ± 1,3	52,9 ± 13,0	0,9 ± 0,4	44,3 ± 13,8	0,7 ± 0,2	3	40	2
Tabebuia rosea	3,2 ± 1,4	55,6 ± 12,6	1,3 ± 0,9	27,9 ± 9,9	0,5 ± 0,2	3	47	6

tree species	crotches (%)	base of crotches (BC) (m) SX	BC<1.3 m (%)	BC>2.8 m (%)	vitality (%) V 1	V 2	V 3	stem form (%) SF 1	SF 2	SF 3	SF 4	SF 1+3	SF 2+4	browsing and peeling damage (%)
Dalbergia retusa	56	2,2 ± 0,8	8	20	31	65	4	8	69	1	21	9	90	5
Diphysa americana	65	2,0 ± 0,9	20	27	30	65	4	4	96	0	0	4	96	11
Enterolobium cyclocarpum	90	3,2 ± 1,3	5	64	2	83	14	34	13	39	14	73	27	0
Hymenea courbaril	58	1,7 ± 0,6	20	5	5	86	8	22	57	13	8	35	65	2
Samanea saman	91	2,8 ± 1,0	0	41	5	74	22	26	23	32	18	58	41	3
Simarouba glauca	47	2,8 ± 1,1	7	50	1	65	34	44	36	9	11	53	47	0
Swietenia macrophylla	76	2,5 ± 0,7	4	26	3	72	25	49	46	4	2	53	48	0
Tabebuia impetiginosa	59	1,9 ± 0,5	12	0	24	69	7	7	72	7	14	14	86	4
Tabebuia rosea	71	2,1 ± 0,6	5	5	33	59	8	73	18	8	0	81	18	19

The **mortality rate** varies between 15 % (*Hymenea courbaril*) and 68 % (*Diphysa americana*). Thinning operations were only carried out with the fast-growing tree species *Enterolobium cyclocarpum* (28 %) and *Samanea saman* (40 %). With *Diphysa americana* and *Simarouba glauca* there were no stumps visible. The thinning intensity of the remaining tree species varies between 2 % (*Tabebuia impetiginosa*) and 10 % (*Swietenia macrophylla*), at which only sick individuals were cut down. Therefore the mortality rate contains the portion of the cut down trees.

The tree species on the forest plantation show altogether a high portion of **crotches.** The least occur with *Simarouba glauca* (*47 %)* and the most frequent with *Samanea saman* (91 %) and *Enterolobium cyclocarpum* (90 %). In order to determine the degree of depreciation, the base of the crotch was measured. It depends strongly on the tree height and varies with the arithmetic mean between 1,7 m height (*Hymenea courbaril)* and 3,2 m height (*Enterolobium cyclocarpum).* With *Diphysa americana* and *Hymenea courbaril* 20 % of the crotches are located under 1,30 m. This results in a high depreciation. With *Samanea saman* no crotches could be noticed under 1,3 m height. With the remaining tree species the portion of crotches varies between 4 and 12 %. As an additional mark there was determined a height of crotches about more than 2,80 m. In this manner, it is possible to use the minimum length of the lower stem for commercial utilization about 2,55 m. These values are dependent on the tree height. Therefore the biggest portion is founded with the tree species *Enterolobium cyclocarpum* (64 %) and *Simarouba glauca* (50 %). With *Hymenea courbaril* and *Tabebuia rosea* only 5 % of all crotches are located over 2,80 m height.

As **measure for vitality** the development of the crown was used. The portion of stunted crowns amounts with the species *Dalbergia retusa, Diphysa americana* and *Tabebuia rosea* around a third part, at *Tabebuia impetiginosa* appoximately a fourth. With the remaining tree species a portion of this category lies between 1 and 5 %. A luxuriantly developed crown is most frequently visible at *Simarouba glauca* (34 %). *Samanea saman* and *Swietenia macrophylla* also show with 22 respectively 25 % relatively high portions on luxuriantly developed crowns. Whereas with *Dalbergia retusa* and *Diphysa americana* appear with 4 % the minor portions on luxuriantly developed crowns.

Stem form: The best results in regard of straight-stemmed trees show *Tabebuia rosea (73 %), Swietenia macrophylla* (49 %) and *Simarouba glauca* (44 %). The worst values in this category occur with *Diphysa americana* (4 %). If you take the sum of the relative portion of the type of stem 1 and 3 as a measure of good form, *Enterolobium cyclocarpum* and *Samanea saman* also show relatively high values. The worst type of stem (type of stem 2 + 4) are visible with *Diphysa americana, Dalbergia retusa* and *Tabebuia impetiginosa*.

The portion of **browsing and peeling damage** was with the examined tree species between 0 and 19 %. The most frequent damages appear with *Tabebuia rosea* (19 %) and *Diphysa americana*. The tree species *Enterolobium cyclocarpum, Simarouba glauca* and *Swietenia macrophylla* show no damages. For the remaining tree species the portion is between 2 and 5 %.

3 Explanations

3.1 Physical soil characteristics

After the weighing of the soil samples in the wet and dry condition, it was possible to determine the three soil characteristics air, water and soil solid substance. Then the following physical soil characteristics could be ascertained:

- dry matter density (DMD) : $\frac{\text{soil solid substance}}{\text{total volume}}$

- gravimetric water content (WC_g): $\frac{\text{water mass}}{\text{substance mass}} \cdot 100$

- volumetric water content (WC_v): $\frac{\text{water volume}}{\text{total volume}} \cdot 100$

- available field capacity: estimation with help of table values and the soil indices soil type and dry matter density

3.2 Vitality

The vitality of each examined tree was classified in regard of the development of the crown. According to *Fedlmeier* (1996) the following criteria was utilized:

0: dead

1: stunted

2: normal

3: luxuriant

3.3 Stem form

The stem form was differentiated between four groups:

1: straight-stemmed

2: crooked-stemmed

3: inclined straight-stemmed

4: inclined crooked-stemmed

3.4 Crown form

According to *Dawkins* (1959, quoted after *Blaser*, 198) the crown form was classed with one of the following categories:

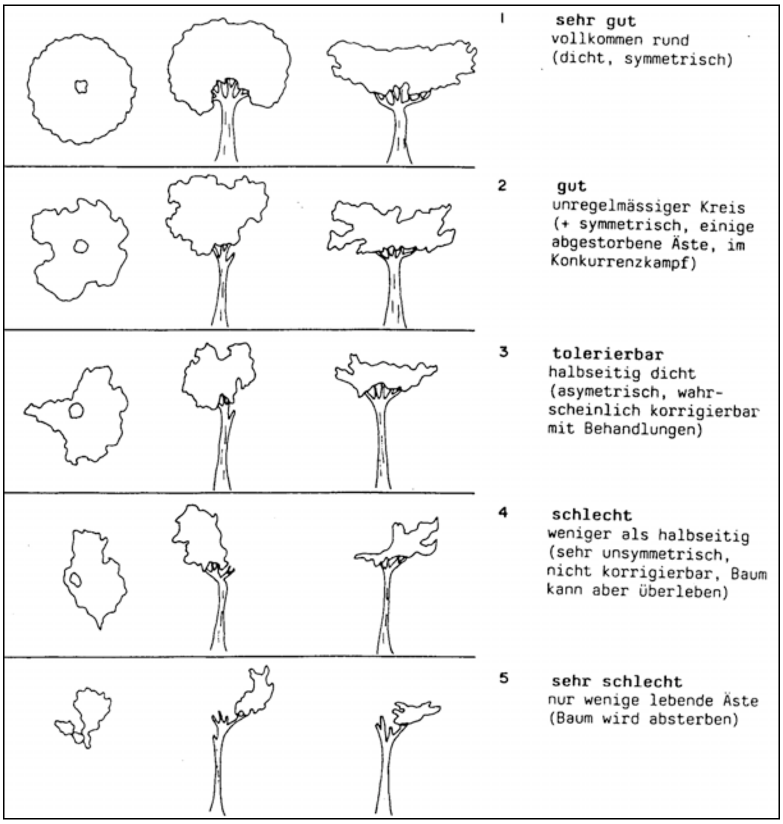

Figure 3-1: Five categories of the crown form (according to Dawkins*, 1959, quoted after* Blaser*, 1987).*

category 1: very good (total round)

category 2: good (irregular circle)

category 3: tolerable (on one side thick)

category 4: bad (less than on one side thick)

category 5: very bad (only a few living branches)

3.5 Crown ratio :

The crown ratio shows the relative portion of the crown to the tree height:

$$\frac{\text{crown length}}{\text{tree height}} \cdot 100$$

3.6 Crown index:

The crown index describes the relation of the crown length to the crown width:

$$\frac{\text{crown length}}{\text{crown width}}$$

3.7 Crown diameter ratio I:

The crown diameter ratio I gives the relation of the crown width to the DBH: $\frac{\text{crown width}}{\text{DBH}}$

3.8 Crown diameter ratio II:

This index presents the relation between crown width and tree height: $\frac{\text{crown width}}{\text{tree height}}$

3.9 Slenderness

The slenderness is an additional measure for the vitality and the stability of the single trees. It demonstrates the relation of the DBH to the tree height (synonym: H/D-value).

4 Discussion

In this examination, the soil conditions prove to be the most important factor for the tree growth. Except from *Tabebuia rosea*, all species show better growth with increasing clay content in the soil. The available field capacity decreases with increasing clay content. One reason for this is the high content of fine pores in the clay minerals. In this way, clay soils have more bound moisture and the available water is essentially smaller than in sandy soils. Stress caused by dryness during the dry season for about five months seems to be no problem for the tested tree species. Otherwise, the tree growth on sandy substrates would be better. Usually sandy soils in dry zones are better for providing water than heavy soils with many clay minerals. These soils present by the coarsely texture higher infiltration capacities and higher moisture depths, as well as a smaller surface flow.

The abundance of water during the rainy period has in the examination area a bigger influence on the tree growth than the low water available during the dry season. Because of the large pores the sandy soils can accumulate a lot of water in the rainy season. The examinations resulted in a higher water content of the soil where there was a higher content of sand of the soil. As was to be expected, there is a visible low reduction of the resistance to penetration with the increasing content of sand. But due to the influence of cattle tracks there exist only weak relations.

The bigger the part of clay in the soil is, the bigger the part of nutrients. The clay substrates are also more fertile which perhaps causes a higher growth on these soils. Optimal are loamy soils. According to *Gutiérrez* (2001c) loamy soils are better suited for the growth of trees than pure clay soils. Consequently, the growth only increases until a certain degree. Bad growth is especially visible on the forest plantation of 1993. There are mainly heavy clay soils. Whereas the forest plantations of 1991 and 1992 present a higher part of loamy substrates.

The examined tree species prefer fertile and good drained soils. Statements to the pH value are not possible because these values occur in a relatively small range (6,3 - 6,8).

During the climatic phenomenon *La Niña*, in some parts of the forest plantation backwater occurs. In these areas there can not be established a connection to the part of sand or clay of the soil. With help of the soil profiles, there were no ascertainable *Vertisols*. Externally there were no visible differences in the topography of the flooded sites. Causes of the backwater can be small sinkings in the micro relief. Clay layers of the soil can prevent the water flowing off. There was a noticeable high negative effect of the backwater to the growth relating to three tree species (*Dalbergia retusa, Diphysa americana* and *Enterolobium cyclocarpum*). Two tree species (*Samanea saman* and *Swietenia macrophylla*) showed no reaction in the growth to the occurrence of backwater.

Moreover in this examination, it was tried to produce relations between the combination of tree species and the type of stem. There was only a small influence detectable of the type of mixture to the growth of a tree. Many tree species show independent of the combination strong ramifications. On the one hand, this phenomenon could perhaps be improved by the application of a smaller planting space. On the other hand, possibly the quality of stems can be raised by the improvement of the plant material. The harvest of seed trees and the construction of seed plantations is not practiced in the examination area for a long time. In this matter the genetic potential of the native tree species can be improved.

5 Summary

The investigation took place in the tropical dry forest in the northwest of Costa Rica. The province *Guanacaste* is mainly determined by pasture farming. For a long period, huge dry forest areas were destroyed in order to attain new pastures. Only at about the end of 1980, projects were carried out with national and international help to manage the national forest reservats. In the future the reforestation, the silviculture and the construction of tree-breeding plantations will be more and more important. There are often long experiences with plantations of exotic tree species. However the experiences with the cultivation of native valuable tree species are very incomplete. The investigation on these native tree species took place in the area of the Forest Research Station *Horizontes (Estación Experimental Forestal Horizontes)*. The station represents a part of the *Conservation Area Guanacaste* (*Área de Conservación Guanacaste*) and is occupied with the forest tree breeding of typical tree species of the dry forest. There is a forest plantation on the area, which was built in 1991 and belongs to the oldest experimental plots of the station. Growing there are ten native tree species in different combinations. The plantation is distinguished by different micro sites. Within the scope of this work there were carried out examinations on the area in August and September of 2001. On the occasion, the influence of the soil or the combination with another tree species on the growth was tested. With help of small samples was there a realized forest-inventory. Apart from diameter and height there were determined the parameters of the crown and other qualitative characteristics. Besides there took place a detailed examination of the soil. Measurements were carried out with a penetrometer and with a soil sampling cylinder in order to determine the resistance to penetration of the soil, the water content and the dry matter density. Besides soil profiles were established. In the following analysis at first the soil values one another and then the relations between soil characteristics and growth were examined. Relating to the values of nutrients and the distribution of particle sizes the results of a former soil analysis could be used.

One of the results is that most of the tree species show a better growth with increasing clay content of the soil. There is a relatively high dependence on the content of nutrients of the soil. Despite of the five month during dry period, the little water availability seems to have no negative influence to the growth of the trees. The tree species show better thriftiness on soils with low available field capacity. Whereas an oversupply of water which occurs in rainy years (climate phenomenon *La Niña)* is a greater problem for some tree species and causes a higher mortality rate on the areas influenced by backwater.

An influence of the combination of different tree species to the type of stem and the frequency of twin stems was not detectable. The tree species show an indifferent growth relating to the crown density.

Concluding, the tree parameter with their arithmetic means for each species are shortly represented. On the occasion there are identifiable differences between the tree species relating to height growth, volume and crown parameters. Also the qualitative characteristics give information about the general condition of a tree species. Because of the frequent occurrence of crotches and bad stem forms more investigation in the forest tree breeding can be recognized.

The native tree species of the dry forest represent a good alternative to the exotic tree species. Of course they show minor height growth, but there is an optimal adaptation to the climatic conditions and valuable woods can be produced.

6 Literature

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7 Annex

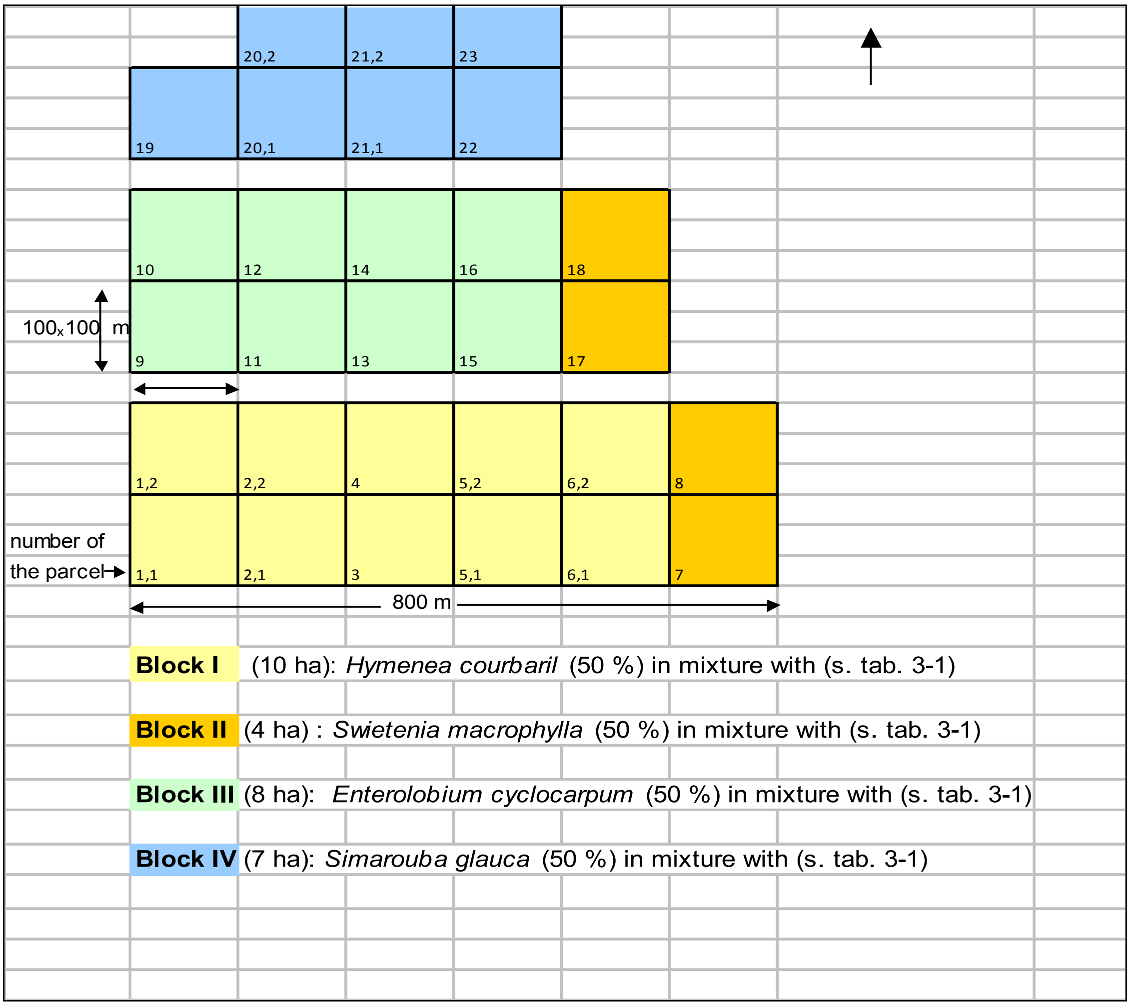

Figure 7-1: Forest plantation of 1991 with the blocks and the main tree species.

Table 7-1: Distribution of the tree species per block and parcel on the forest plantation of 1991.

block	parcel	tree species	portion (%)	distribution model
I	1	*Hymenea courbaril*	50	type A
		Dalbergia retusa	50	
I	2	*Hymenea courbaril*	50	type A
		Tabebuia rosea	50	
I	3	*Hymenea courbaril*	50	type A
		Swietenia macropylla	50	
I	4	*Hymenea courbaril*	50	type A
		Tabebuia impetiginosa	50	
I	5	*Hymenea courbaril*	50	type A
		Samanea saman	50	
I	6	*Hymenea courbaril*	50	type A
		Diphysa americana	50	
II	7	*Swietenia macrophylla*	50	type A
		Samanea saman	50	
II	8	*Swietenia macrophylla*	50	type C
		Enterolobium cyclocarpum	25	
		Hymenea courbaril	25	
II	17	*Swietenia macrophylla*	50	type A
		Dalbergia retusa	50	
II	18	*Swietenia macrophylla*	50	type B
		Dalbergia retusa	25	
		Simarouba glauca	25	
III	9	*Enterolobium cyclocarpum*	50	type A
		Hymenea courbaril		
III	10	*Enterolobium cyclocarpum*	50	type B
		Samanea saman	25	
		Swietenia macrophylla	25	
III	11	*Enterolobium cyclocarpum*	50	type A
		Dalbergia retusa	50	
III	12	*Enterolobium cyclocarpum*	50	type A
		Samanea saman	50	
III	13	*Enterolobium cyclocarpum*	50	type A
		Tabebuia rosea	50	
III	14	*Enterolobium cyclocarpum*	50	type A
		Diphysa americana	50	
III	15	*Enterolobium cyclocarpum*	50	type A
		Tabebuia impetiginosa	50	
III	16	*Enterolobium cyclocarpum*	50	type B
		Albizia adinocephala	25	
		Swietenia macrophylla	25	
IV	19	*Simarouba glauca*	50	type A
		Swietenia macrophylla	50	
IV	20	*Simarouba glauca*	50	type A
		Dalbergia retusa	50	
IV	21	*Simarouba glauca*	50	type A
		Samanea saman	50	
IV	22	*Simarouba glauca*	50	type A
		Enterolobium cyclocarpum	50	
IV	23	*Simarouba glauca*	50	type A
		Tabebuia rosea	50	

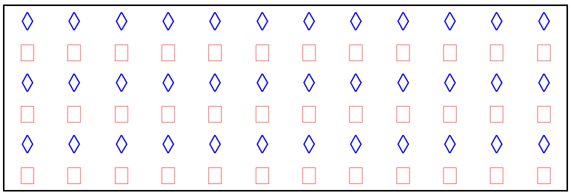

Figure 7-2: Distribution type A (□ main tree species, ◊ admixture tree species).

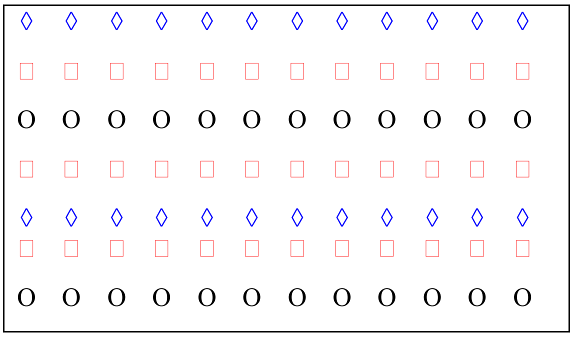

Figure 7-3: Distribution type B (□ main tree species, ◊ O: admixture tree species).

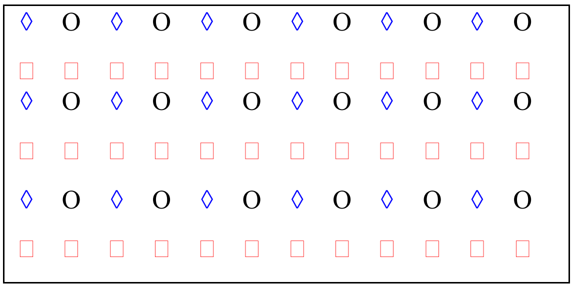

Figure 7-4: Distribution type C (□ main tree species with 50 %, ◊ O: admixture tree species, each with 25 %).

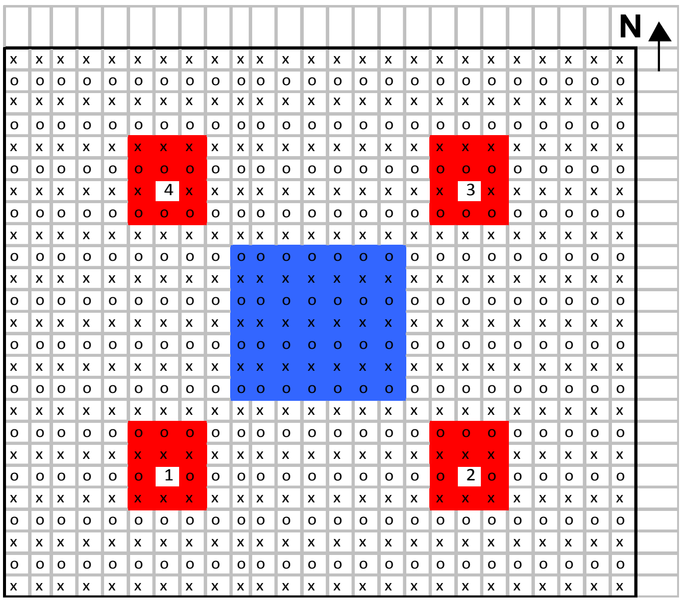

Figure 7-5: Distribution of the samples on each parcel unit with one ha size (x, o: distribution of the tree species in rows; blue marc: permanent sample of the Forest Research Station Horizontes, red marc: four new samples of this examination).

Figure 7-6: Sampling cylinder and implements of the sampling.

Figure 7-7: Penetrometer.

Typical stem forms of the examined tree species

Figure 7-8: Albizia adinocephala (stem form 4).

Figure 7-9: Dalbergia retusa (stem form 2).

Figure 7-10: Diphysa americana (stem form 2).

Figure 7-11: Enterolobium cyclocarpum (stem form 3).

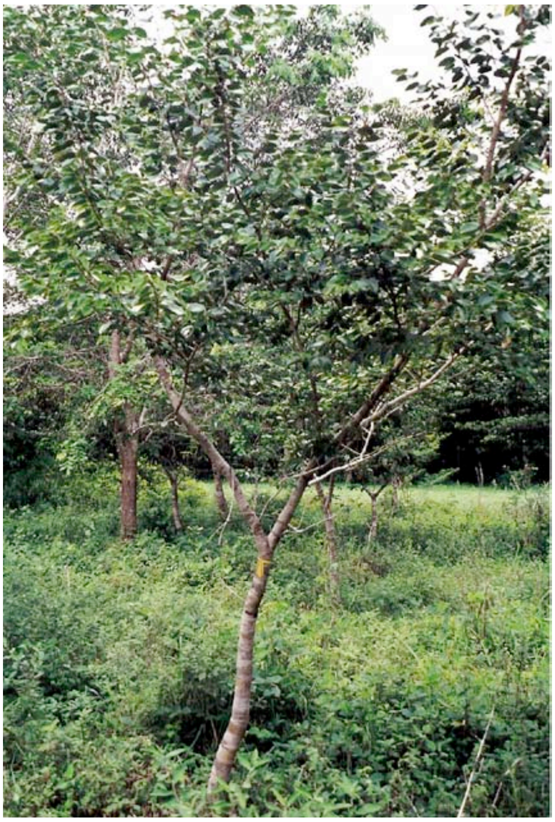

Figure 7-12: Hymenea courbaril (stem form 2).

Figure 7-13: Samanea saman (stem form 3).


Figure 7-14: Simarouba glauca (stem form 1).


Figure 7-15: Swietenia macrophylla (stem form 2).

Figure 7-16: Tabebuia impetiginosa (stem form 2).

Figure 7-17: Tabebuia rosea (stem form 1).

(the fruits in the upper crown area belong to *Hymenea courbaril*)