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MASTERARBEIT / MASTER'S THESIS

Titel der Masterarbeit / Title of the Master's Thesis

„The effect of reforestation on the carbon sequestration capacity of a degraded dryland in Binh Thuan, Vietnam"

verfasst von / submitted by

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angestrebter akademischer Grad / in partial fulfilment of the requirements for the degree of

Master of Science (MSc)

Wien, 2017 / Vienna 2017

Studienkennzahl lt. Studienblatt / degree programme code as it appears on the student record sheet:	A 066 855
Studienrichtung lt. Studienblatt / degree programme as it appears on the student record sheet:	Geographie / Geography
Betreut von / Supervisor:	Ass.-Prof. Mag. Dr. Robert Peticzka
Mitbetreut von / Co-Supervisor:	Mag. Dr. Erich Inselsbacher

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Wien, am 19.05.2017

Acknowledgements

I wish to express my appreciation of everyone who helped and supported me during the organization and research of my Master`s thesis.

Special thanks go to my supervisors: Erich Inselsbacher and Robert Peticzka, both from the Geoecology and Quaternary research group at the Department of Geography and Regional Research from the University of Vienna. They always had time for a meeting together and let me use the laboratory for the physical soil analyses.

In addition, a big thanks goes to Axel Mentler and Alena Rabitz from University of Natural Resources and Life Sciences (BOKU) in Vienna. My colleague Alena Rabitz was doing her thesis about organic farming in Binh Thuan at the same time and we supported each other in the organization and research for the theses. Axel Mentler from the Institute of Soil Research at BOKU helped me with the planning and the analyses of the soil sampling. He always gave good input and had great ideas for my research. In addition, he helped me with the analyses of the soil samples in the laboratory.

Without the support I received within Vietnam it wouldn't have been possible to conduct this thesis. I want to express my gratitude to the supervisors and staff of the Faculty of Chemistry of Vietnam National University – Hanoi University of Science. In particular, I would like to acknowledge the access to the laboratory in Hanoi and the strong support given by my supervisors Tien Duc Pham and Tu Binh Minh, the Dean of Faculty of Chemistry Le Thanh Son and Nguyen Manh Ha, who supported me in the laboratory in Hanoi.

I also would like to thank Chu Dinh Binh from Hanoi University of Science and Technology who was my first contact in Vietnam and who supported me with the organization of my research and continuously stayed in touch with me.

I would also like to thank my friend Le Thi Bich Phuong for her assistance and for translating Vietnamese to English during the field trip in Binh Thuan for a whole month. She always did her best to support me while writing this thesis.

Finally, I want to thank the officials in Vietnam, particularly in Binh Thuan, for giving me permission to do research and to share information for this Master´s thesis.

Alexander Hollaus, University of Vienna, May 2017

Abstract

Land degradation in drylands, also called desertification, caused by human impacts and climatic factors, results in a decline of ecological functionality as well as socioeconomic problems. Moreover, land degradation releases carbon (C) from soil and vegetation into the atmosphere in the form of carbon dioxide where it acts as a greenhouse gas, contributing to global warming. Thus, action is required to reduce dryland degradation in order to mitigate climate change. A key measure used for C sequestration and ecosystem restoration is reforestation. Understanding the potential of reforestation for the storage of C in vegetation and soil is essential if this action is to be applied to combat desertification. The purpose of this Master's thesis is to examine the interactions between reforestation and C sequestration during the restoration of a dryland area in Binh Thuan, Vietnam. The study area, Hoa Thang commune, is prone to land degradation because of its semiarid/sub-humid climate and geology. Especially the coastal plains are dominated by degraded consolidated and unconsolidated sandy soils. Thus, a comparison between the C content in the soil and vegetation of degraded, reforested as well as natural forest areas can show the sequestration potential of C through reforestation. Soil samples were taken in the study area and analyzed in the laboratory for total C content as well as other soil characteristics to determine soil fertility. Additionally, a remote sensing analysis of the research area was carried out to create a potential C sequestration map. The results indicate high C sequestration potential in *Acacia mangium* plantations compared to *Azadirachta indica* plantations and barren land during the first 10 years. Tree species used for plantations are, along with the age of the forest, a major factor determining the C storage capacity. Nonetheless, natural forests store a higher proportion of C in soil and contribute to higher biodiversity. Human impact on the C storage potential in plantations and natural forests is very high since logging for timber or charcoal production was observed to cause a decrease in biomass and soil C. In conclusion, reforestation in the research area could potentially help in sequestering C and mitigating dryland degradation, provided that human impact is reduced.

Zusammenfassung

Landdegradierung in Trockengebieten, auch Desertifikation genannt, wird durch menschliche Aktivitäten und klimatische Faktoren verursacht und führt zu einem Rückgang der ökologischen Funktionalität und zu sozioökonomischen Problemen. Darüber hinaus wird durch die Landdegradierung Kohlenstoff (C) aus Boden und Vegetation in die Atmosphäre in Form von Kohlendioxid freigesetzt, wo es als Treibhausgas wirkt und die Klimaerwärmung verstärkt. Daher müssen Maßnahmen in den Trockengebieten getroffen werden, um die Auswirkungen der Degradierung auf den globalen Klimawandeln abzuschwächen. Eine Schlüsselmaßnahme für die Sequestrierung von C und die Wiederherstellung des Ökosystems ist die Wiederaufforstung. Es ist daher wesentlich ein Verständnis für die Zuverlässigkeit und das Potenzial dieser

Schlüsselmaßnahme für die Speicherung von C in Vegetation und Boden zu entwickeln. Das Ziel dieser Masterarbeit ist es, diese Wechselwirkungen zwischen Wiederaufforstung und C-Sequestrierung bei der Restauration eines Trockengebiets in Binh Thuan, Vietnam, zu untersuchen. Das Untersuchungsgebiet, welches die Gemeinde Hoa Thang umfasst, ist wegen seines semiariden/sub-humiden Klimas und der Geologie anfällig für Landdegradierung. Vor allem die Küstenebenen werden von degradierten konsolidierten und unkonsolidierten sandigen Böden dominiert. Ein Vergleich zwischen dem C-Gehalt in Boden und Vegetation von degradierten Flächen und aufgeforsteten sowie natürlichen Waldgebieten soll die Speicherkapazität von C durch Wiederaufforstung zeigen. Im Untersuchungsgebiet wurden Bodenproben genommen und im Labor auf den Gesamt-C-Gehalt sowie andere Bodenmerkmale analysiert, um die Bodenfruchtbarkeit zu bestimmen. Zusätzlich wurde eine Fernerkundungsanalyse des Forschungsgebiets durchgeführt, um eine C-Sequestrierungskarte zu erstellen. Die Ergebnisse zeigen ein hohes C-Sequestrierungspotential in Acacia mangium Plantagen im Vergleich zu Azadirachta indica Plantagen und degradierten Flächen in den ersten 10 Jahren nach der Wiederaufforstung. Baumarten, die für die Wiederaufforstung verwendet werden, sind neben dem Alter des Waldes ein wichtiger Faktor in der C-Speicherkapazität. Die natürlichen Wälder speichern einen höheren Anteil an C im Boden und tragen zu einer höheren Biodiversität bei. Die Auswirkung der menschlichen Aktivitäten auf den C-Speicher in Plantagen und natürlichen Wäldern ist aufgrund der Holz- und Holzkohleproduktion sehr hoch, was zu einer Abnahme der Biomasse und des C-Gehalts im Boden führt. Zusammenfassend sieht man, dass die Wiederaufforstung im Forschungsgebiet dazu beitragen kann, die Degradierung von Trockengebieten zu verringern und die Sequestrierung von C zu verbessern, wenn die menschlichen Einwirkungen reduziert werden.

Bản tóm tắt

Suy thoái đất ở các vùng đất khô cằn, còn được gọi là sa mạc hóa, gây ra bởi các tác động của con người và các yếu tố khí hậu, dẫn đến sự suy giảm chức năng sinh thái cũng như các vấn đề kinh tế xã hội. Hơn nữa, sự thoái hoá đất thải carbon (C) khỏi đất và thực vật vào khí quyển dưới dạng carbon dioxide, nơi nó hoạt động như một khí nhà kính và góp phần làm nóng toàn cầu. Vì vậy, cần thiết hành động để giảm sự xuống cấp của vùng đất khô hạn nhằm giảm nhẹ sự thay đổi khí hậu. Một biện pháp quan trọng được sử dụng để củng cố và phục hồi hệ sinh thái C là tái trồng rừng.

Hiểu được tiềm năng tái trồng rừng đối với việc cô lập C trong thực vật và đất đai là rất cần thiết nếu hành động này được sử dụng để chống hoang mạc hóa. Sự hiểu biết này cũng có thể được sử dụng để dự đoán kịch bản biến đổi khí hậu trong tương lai. Mục đích của luận án Thạc sỹ này là xem xét các tương tác giữa trồng rừng và giữ đất trong quá trình khôi phục vùng đất khô ở

Bình Thuận, Việt Nam. Khu vực nghiên cứu, xã Hòa Thắng, có xu hướng bị thoái hoá đất do khí hậu khô cằn, thiếu nước và địa chất.

Các vùng đồng bằng ven biển đặc biệt bị chi phối bởi đất cát củng cố và chưa được củng cố. Như vậy, việc so sánh hàm lượng C trong đất và thực vật của các khu vực rừng bị suy thoái, tái trồng rừng cũng như rừng tự nhiên có thể cho thấy tiềm năng cô lập C thông qua việc trồng lại rừng. Các mẫu đất được lấy ở khu vực nghiên cứu và phân tích trong phòng thí nghiệm với tổng hàm lượng C cũng như các đặc tính đất khác để xác định độ màu mỡ của đất. Ngoài ra, một phân tích từ vệ tinh không gian của 10 năm trước cho khu vực nghiên cứu đã được thực hiện để tạo ra một bản đồ C tích lũy tiềm năng. Kết quả cho thấy tiềm năng cô lập C cao ở đồn điền Acacia mangium so với rừng trồng Azadirachta indica và đất trống trong 10 năm đầu. Các loài cây trồng được sử dụng cho trồng rừng, cùng với độ tuổi của rừng, là yếu tố chính xác định khả năng lưu trữ C. Tuy nhiên, rừng tự nhiên có tỷ lệ C trong đất cao hơn và góp phần vào sự đa dạng sinh học cao hơn. Tác động của con người lên tiềm năng lưu trữ C trong các đồn điền và rừng tự nhiên rất cao do việc khai thác gỗ hoặc sản xuất than đã làm giảm sinh khối và đất C.

Kết luận rằng trồng rừng ở khu vực nghiên cứu có thể giúp giảm thiểu sự thoái hóa đất khô và cải thiện hấp thu của C, với điều kiện con người giảm tác động không tốt tới đất, rừng và các điều kiện tự nhiên khác ở khu vực này.

Abbreviations

ABG	Aboveground Biomass
AEC	Acid Extractable Cations
Am	*Acacia mangium*
Ai	*Azadirachta indica*
APSL	Above Present Sea-Level
Barren	Barren Land
BD	Bulk Density
BGB	Belowground Biomass
B_{litter}	Litter Biomass
C	Carbon
DBH	Diameter at Breast Height
DOC	Dissolved Organic Carbon
BL	Barren Land Class (Barren)
EC	Electrical Conductivity
E_4/E_6	Fulvic Acid/Humic Acid Ratio
FAO	Food and Agriculture Organization of the United Nations
NF	Natural forest Class (nForest)
MARD	Ministry of Agriculture and Rural Development, Vietnam
NDVI	Normalized Density Vegetation Index
nForest	Natural forest
N_{tot}	Total Nitrogen
P	Plantation Class
SIC	Soil Inorganic Carbon
TC	Total Carbon
UNFCCC	United Nations Framework Convention on Climate Change
UNCCD	United Nations Framework Convention to Combat Desertification
WEA	Water Extractable Anions
yr	Year

Table of Content

1. Introduction

Drylands, occupying approximately one third of the total land area of the globe, are very sensitive terrestrial ecosystems and prone to land degradation. In drylands one major limiting factor which affects soil fertility and biomass production is the lack of water because of frequently high evapotranspiration due to high temperature and low rainfall. (Loik, et al., 2004; FAO, 2004b) Generally, there is a lower biomass productivity, which results in low soil organic matter (SOM) and nutrient concentration in soil (Lal, 2001a). SOM in drylands usually reaches a content of 0.5-1.6% (SOC ~0.2-0.8%) (Lal, 2003; Lal, 2002).
The degradation of drylands through human and climatic impacts, also known as desertification, influences local ecosystem functionality and thus decreases the quality of soil and vegetation. (D'Odorico, et al., 2013; Lal, 2011) All drylands, especially semiarid types, are prone to desertification which could lead to a loss of soil aggregation (Lavee, et al., 1998; Taghizadeh-Mehrjardi & Akbarzadeh, 2013), disruption of the biogeochemical cycles of for example carbon, nitrogen and phosphorus (Graaff, et al., 2014; D'Odorico, et al., 2013; Schlesinger, et al., 1990), a change in water and energy balance (Houérou, 2002; Nicholson, et al., 1998; D'Odorico, et al., 2013) and a decrease in agricultural productivity (Kassas, 1995). Furthermore, carbon (C) stored in biomass and soil is released through different maladjusted land use practices into the atmosphere in the form of CO_2 (Lal, 2001a; FAO, 2004b). The impacts of human activities consist mainly in the reduction of vegetation cover, leading to an increase in soil erosion by wind and water resulting in a displacement of material and to CO_2 emissions (Houerou, 1996; Mensching, 1990; D'Odorico, et al., 2013). The rate of C released from soil respiration and biomass decay depends on the activity of microbiological decomposition as well as on erosion processes. These factors are strongly influenced by desertification. (FAO, 2004b; Batjes & Sombroek, 1997)
However, degraded drylands have the potential to store C by way of adapted land use practices (Lal, 2001a) because of a long residence time of SOM due to the slow turnover time of organic matter (Lal, 2004) and the huge land area, occupied by drylands (FAO, 2004b; Lal, 2001b; Keller & Goldstein, 1998). Thus drylands can be used to sequester C from the atmosphere by biomass production and uptake of organic substances from soil. Soil can store three times more carbon than plant biomass (Batjes & Sombroek, 1997). Therefore, increasing the capacity of dryland ecosystems to sequester C is a key measure to reduce greenhouse gas emissions and thereby mitigate global climate change (FAO, 2004b).

Possible actions to improve and retain C storage in dryland areas is to maintain forests or to reforest degraded land (Li, et al., 2013). The starting point for international reforestation and deforestation reduction programmes were in the 1970s when the degradation of drylands appeared on the agenda of the UN and in the public consciousness for the first time. (Kassas, 1995; Thomas, 1993; Hermann & Hutchinson, 2005; Houérou, 2002; Thomas, 1997) Programmes, such as the United Nations Collaborative Programme on Reducing Emissions from

Deforestation and Forest Degradation (UN-REDD) – established in 2008 – were implemented to reduce C emission from deforestation by supporting national governments to conserve forest areas. Furthermore, the application of reforestation or afforestation measures to combat desertification and support C sequestration are well funded by international organizations and development agencies, such as the UNFCCC and UNCCD. Based on the international cooperation, conservation and sustainable management of forests as well as the enhancement of the C forest stock are aims in the REDD+ concept. Therefore, extensive national action plans are created and are financially supported in Vietnam and other countries to determine and to restore the C stock in biomass and soil. Vietnam is one of the pioneer countries participating in such programmes. (UN-REDD; UNEP, 2014) The country has to cope with strong erosion and leaching after deforestation due to its monsoonal and tropical/subtropical climate and loses a huge amount of productive soil every year (Global Mechanism of the UNCCD, 2008). Thus, Vietnam already implemented, after years of severe deforestation, national reforestation actions in the 1990ties, such as the Five Million Hectares Rehabilitation Program (5MHRP) (McNamara, et al., 2006).

The southeastern coastal area of Vietnam is a particularly semiarid/sub-humid region with a long lasting dry season in winter due to the orographic situation. Furthermore, the geological genesis and the sandy soils make the area prone to land degradation. This region is affected by desertification owing to the massive deforestation in the 1970s and subsequent extensive agricultural cultivation as well as increasing soil erosion through aeolian processes and massive rainfall events during the summer season. (Gobin, et al., 2012) Reforestation programmes in the region have already been carried out since Vietnam ratified the UN Convention to Combat Desertification in 1998 and are intended to reduce the spread of sand dunes, as well as to increase the quality of the soil and to maintain ecosystem functionality (UNCCD, 2002; Nguyen & Catacutan, 2012). An additional aim of these programs is to increase C storage in the forest areas and reducing C emissions to the atmosphere (UNEP, 2014; UN-REDD).

However, it remains unclear how effective such reforestation measures for C storage in soil and vegetation in degraded drylands are (Dang & Do, 2014). This Master's thesis aims to obtain data on C content in this ecosystem and investigate the question: How do reforestation measures for combating land degradation affect total C content in soils and vegetation during the first years of forest growth in the communal area of Hoa Thang (Binh Thuan, Vietnam)? The hypotheses for the study are that

(i) after reforestation, C content in soils increases, but remains at a lower level than other degraded and non-degraded areas in Vietnam with ecosystems other than drylands,
(ii) in the first ten years following reforestation C is mainly stored in the tree biomass,
(iii) the C content in degraded soils is lower compared to soils under plantation and natural forest.

To answer the research question, soil samples were taken in a field mission and above- and belowground biomass estimations were conducted in six different classes to create a C storage change timeline from barren land (BL) to plantation (P) to continuously forest covered land (natural forest, NF). The research design is built on a model that claims that natural forest, because of its climax state of forest succession, has the highest and degraded barren land the lowest potential of C storage. Thus, the C pool of biomass grows after the establishment of a forest by increasing tree density and tree growth (Figure 1). Furthermore, higher biomass production contributes more C to the soil pool. Additionally to the enhanced C production in biomass, increased soil fertility and vegetation cover will reduce the loss of C from soils through leaching and erosion. These conditions are also true for plantations which are artificially planted. Therefore, the further the forest succession, the higher the biomass on a site and the higher the C storage in the biomass and soil pools.

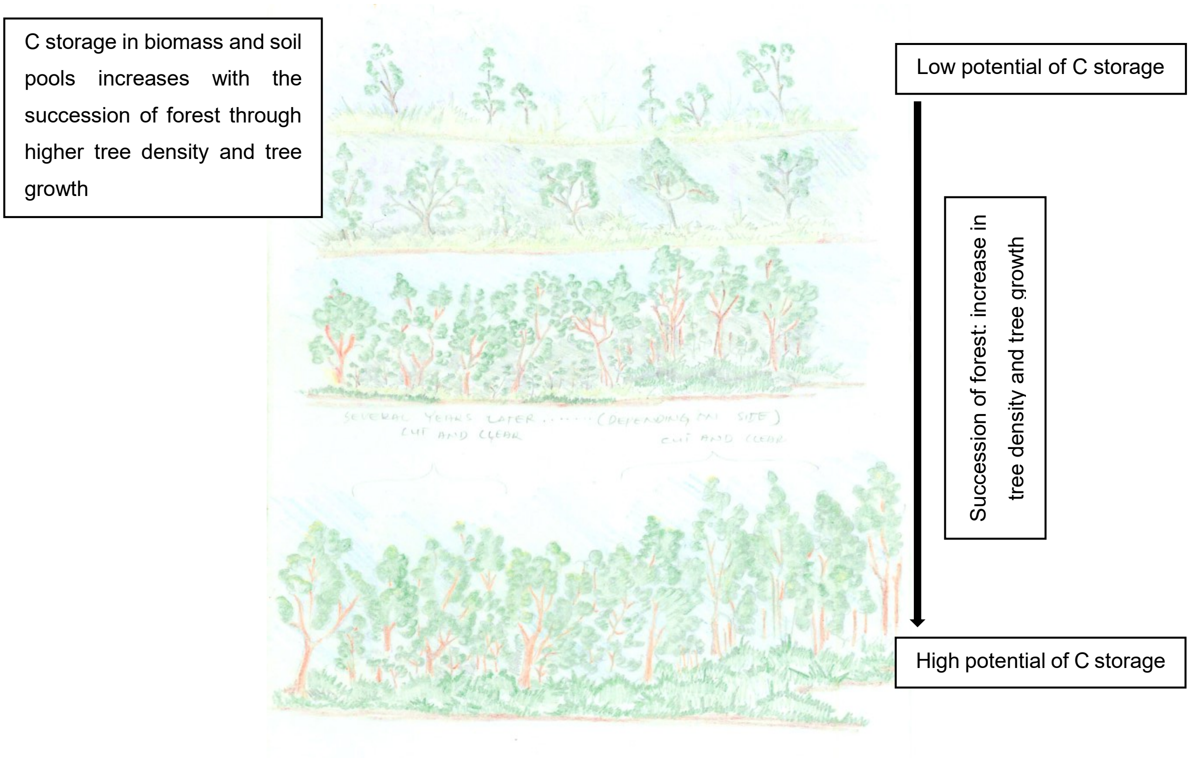

Figure 1: Model of forest succession with higher biomass in older forest stands and thus increased C in biomass and soil (drawing by Affendi Belawan 2016).

2. Study Area

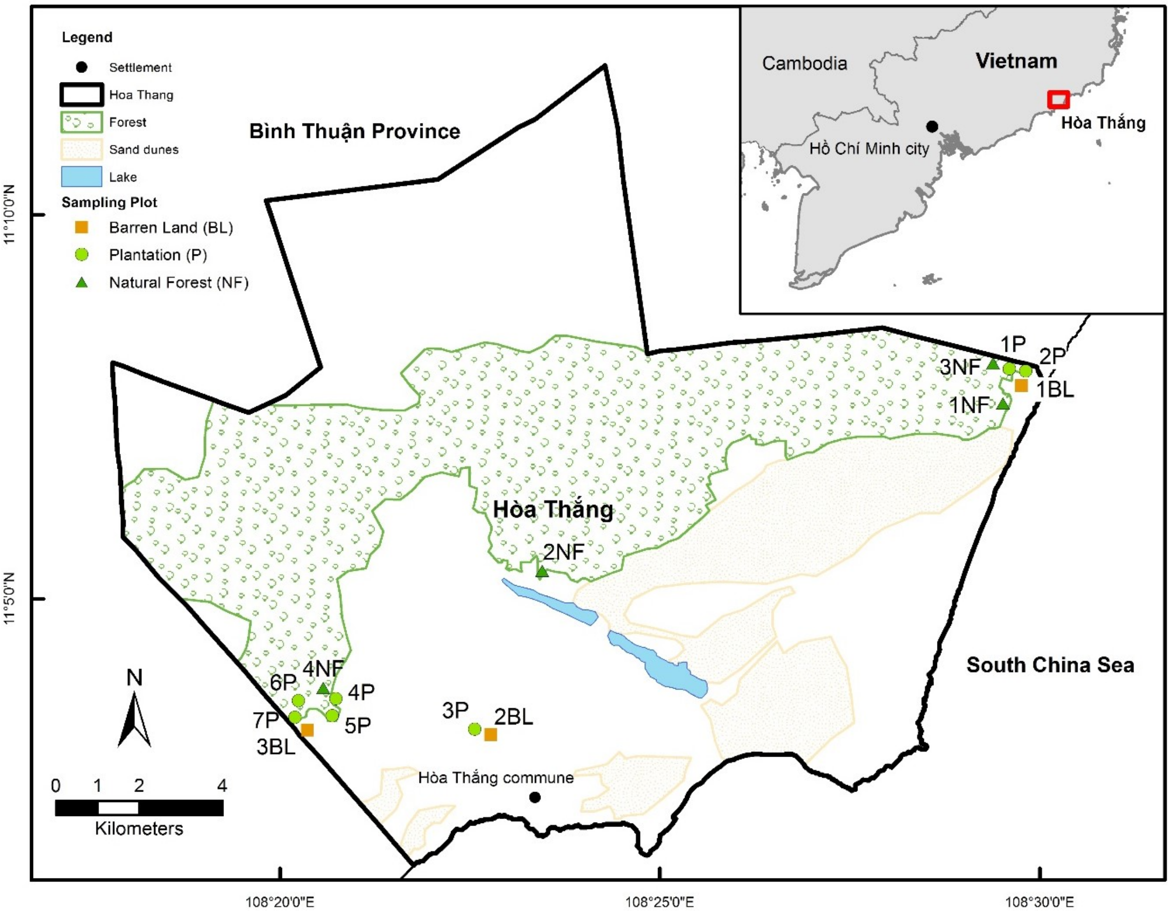

Figure 2: Schematic map of the study area Hoa Thang in Binh Thuan Province, Vietnam, with location of sampling plots: NF - Natural forest, P - Plantation, BL - Barren land.

The study area is located in Bac Binh district, Binh Thuan province, in southern central Vietnam and encompasses the coastal commune of Hoa Thang between 108°17’50’’ – 108°30’10’’E and 11°01’30’’ – 11°11’50’’N (Figure 2). Hoa Thang is one of the driest regions in Vietnam. The climate is semiarid to dry-subhumid due to tropical monsoonal and orographic conditions. (Pham, et al., 2012) It is characterized by two main seasons with a wet period (May – October) in summer and a long dry period (November – April) in winter (Annex: Figure 29). The dry period lasts in average 4-6 months and is influenced by ENSO-Phenomena (Annex: Figure 30) (Hang, et al., 2014, p. 372; Kuo, et al., 2004). Precipitation varies around an average annual of 1,142 mm for Phan Thiet city weather station (Annex: Table 19) but can also decrease to 550 mm or even less in the region (Hountondji, et al., 2012). Rainfall is mainly concentrated in the summer period with heavy rainfall events. In the dry season, northeast monsoonal winds are blowing parallel to the coast line and are blocked by a mountain range close to the sea which prevents moist air masses reaching the area. Furthermore, the upwelling of cold water in the coastal zone hinders the building of clouds. Therefore, precipitation can be less than 1 mm per month. On the other hand, potential evapotranspiration (ET0) is high at around 1,400 mm because of long sunshine hours and persistent high temperatures with an average of 27 °C (Annex: Table 19). Thus, the region is prone to droughts in the dry season. (Pham, et al., 2012) The geology of the greater region is formed by Cretaceous dacitic and rhyolitic hard basement rocks, which emerge at some places on the surface in the form of inselbergs. The basement rock is overlaid by marine and reworked aeolian sand accumulations. (Quy, et al., 2001; Nguyen, et al., 2009) The sand was mainly deposited as a coastal barrier succession in the late Pleistocene in the last interglacial maximum (Oxygen Isotope Substage 5) and in Holocene times at the last sea level peak (7 ka ago) as a result of the marine transgression. Further aeolian reworking with overlying processing of the sand deposits occurred in the Last Glacial Maximum (28 – 19 ka). In Hoa Thang three main sand types of red, white and yellow colour appear at the surface, where the former was deposited in the Pleistocene with underlying white marine sand which can be seen at the surface in deep erosion valleys. This sequence forms the inner barrier and extends over most of the area. The yellow sand was deposited in the Holocene and forms the outer barrier succession mostly along the coast line. At some places the inner barrier shapes the coast line because of coastal erosion. The barrier systems reach a height of around 160 m APSL with consolidated sand to active dune fields. (Murray-Wallace, et al., 2002) Thus, the geomorphology of the area shows gently slopes, deep cut in valleys and gullies as well as sand dunes and aeolian sand accumulation. Groundwater can be found in two aquifers with different depths ranging from 20-40 m and 60-90 m (Nguyen, et al., 2009). In depressions, close to the dune field groundwater fed lakes, such as Bau Trang (lake), emerge at the surface. River systems are very short and are mostly close to the coast line. The main soil types in this area are haplic and rhodic Arenosols. Arenosols can be divided according to the Vietnamese soil classification into three sandy soil units: white and yellow sand dunes soils; red sand dunes soils; and sandy marine soils. (MARD, 2002) Arenosols are characterized by sandy texture and a weak development of layers. Permeability of these soils is mostly high and water holding capacity as well as the nutrient storage potential is very low. Thus, nutrients are generally stored in the biomass of vegetation and in the soil organic matter. (IUSS Working Group WRB, 2015) The land use/cover in the research area ranges from active dune fields to pasture, agriculture for annual and perennial crops as well as forestry for timber and charcoal production (Gobin, et al., 2012). Thus, forest cover in the area is fluctuating very fast because of the clear cut after a plantation rotation. In Vietnam natural forest and plantations with timber and non-timber products are classified as production forest. The dry tropical natural secondary forest in the study area, called Rung Nhu, is used as protection forest in the core parts and as production forest in the outer parts. (Mant, et al., 2013) During the time of the Vietnam war, the forest was used as hiding place for soldiers. After the war a massive clearing of the forest started. Thus, forest cover decreased after 1975 until the end of the 1990s, since then reforestation programmes have been implemented (UNESCO, 2012). Nonetheless, signs of tree cutting and charcoal production can be found in many localities. Reforestation occurs mainly in the form of monoculture production forest with tree species adapted to the semiarid climate, such as *Acacia mangium* and *Azadirachta indica*. On abandoned sites natural vegetation succession can establish.

3. Methods

For the examination of the C storage in biomass and soil in the research area a remote sensing analysis, a field trip for forest inventory and soil sampling as well as soil analyses in the laboratory were conducted. For the analyses of C sequestration capacity C content in soil was examined in 3 classes – barren land (BL), plantation (P) and natural forest (NF) – to detect a change of the C content over time, with the class barren land as initial and natural forest as climax stage of vegetative succession. In the class plantation, subclasses of different forest ages – 2, 5, 7 and 10 year-old – were selected during the remote sensing analysis. At the 12 examined plots – 3 in BL, 4 in NF and 7 in P (1 plot in the subclass 2-year-old P; 2 in the others) – 2 to 3 soil profiles were taken with a core drill (Pürckhauer) (Table 1). At 10 of the 14 plots a forest inventory was conducted. The distribution of the sample sites was organized so that the BL and NF plots were directly adjacent to the P plots selected in the remote sensing analysis (Figure 2).

Table 1: Overview of plots for soil sampling and forest inventory with coordinates, forest vegetation, soil type and soil colour. x marks plots with conducted forest inventory; DD: Decimal Degrees.

Plot ID	Coordinates (DD, °)		Class (years)	Soil Profile	Forest Inventory	Forest Vegetation	Soil	
	N	E					Type	Colour (Munsell)
1NF	11.12331	108.49327	Natural forest	2	x			light brown
2NF	11.08811	108.39150	Natural forest	2	x	see species list in Annex: Table 20	Haplic Arenosol	strong brown
3NF	11.13101	108.49252	Natural forest	3	x			strong brown
4NF	11.06050	108.34384	Natural forest	3	-			yellowish red
1P	11.13021	108.49358	Plantation Ai (7yr)	3	x	*Azadirachta indica*	Haplic Arenosol	reddish yellow
2P	11.13045	108.49687	Plantation Ai (7yr)	3	x			reddish yellow
3P	11.05348	108.37736	Plantation Am (2yr)	3	x		Rhotic Arenosol	red
4P	11.06012	108.34447	Plantation Am (5yr)	3	x	*Acacia mangium*	Haplic Arenosol	yellowish red
5P	11.05967	108.34451	Plantation Am (5yr)	3	x			yellowish red
6P	11.05947	108.33802	Plantation Ai (10yr)	3	x	*Azadirachta indica*	Haplic Arenosol	yellowish red
7P	11.05652	108.33646	Plantation Ai (10yr)	3	x			yellowish red
1BL	11.1296759	108.49660	Barren Land	2	-	-	Haplic Arenosols	reddish yellow
2BL	11.0534163	108.37768	Barren Land	2	-	-	Rhotic Arenosol	red
3BL	11.0561562	108.33637	Barren Land	2	-	-	Haplic Arenosol	yellowish red

3.1. Field Sites

During the field trip in April 2016 – at the end of the extended dry season influenced by recent El Niño phenomena (FAO, 2016) – the field sites (Figure 3) chosen in the remote sensing analysis were tested. The examination plots in every class were selected randomly. The natural forest and barren land class act as reference sites for the plantation plots assuming that the environmental conditions (e.g. soil properties) of nearby plots are similar. Thus, plantation plots 1P and 2P are related to 3NF (natural forest) and 1BL (barren land) – cluster east – as well as 4P, 5P, 6P, 7P are clustered with 4NF and 3NF – cluster west. For 3P only the barren land class 2BL – cluster central – acts as reference site, because of no natural forest in the proximity.

Figure 3: Top: Natural forest plots (Rung Nhu) 4NF (left) and 2NF (right); Bottom: Plantation (2P) of 7-years-old A. indica *trees (left) and barren land (2BL) with plantation (3P) of 2-years-old* A. mangium *trees in the background.*

3.1.1. Natural Forest

The natural forest (NF) class is represented by a secondary tropical dryland forest with trees and shrubby vegetation called Rung Nhu (Figure 3). Rung Nhu is an open dipterocarp forest, where endemic and Red List species can be found; among others *Dimocarpus longan, Manilkara hexandra, Albizia attopeuensis* and *Dalbergia spinosa* (see species list in Annex: Table 20) (Tran, et al., 2012). The plots are continuously covered with trees and shrub vegetation, but forest degradation occurs due to logging for firewood and other timber products. Consequently, the human impact on the examined sites is high because of its proximity to the reforested plots and its accessibility. Due to the forest definition of FAO (Annex: Chap. 3) the investigated plots are not reaching the requirements of trees higher than 5 m and more than 10% crown cover to be classified as forest. Thus, the plots fall within the scope of the FAO definition of "other wooded land". Nonetheless, the definition of UNFCC – tree height >2-5 m and crown cover of >10-30% - is more appropriate because of trees reaching over 3 m at the plots. Furthermore, higher tree cover would be possible without forest degradation at the plots. Thus, if the potential to reach the requirements of the forest definition is given but not reached in the moment – because of human impact or natural causes – the area is even so classified as forest. (Chazdon, et al., 2016; FAO, 2012; FAO, 2002) In addition, tree cover will increase to the core parts of the forest. However, Plot 1NF is slightly different from the other locations as this site was cut down before 2000 and natural vegetation was reestablished. Hence, vegetation cover is not as dense as it is at other places. The NF class represents the climax succession of natural vegetation.

3.1.2. Barren Land

The class barren land (BL) is characterized by scattered grass and shrub cover and is either used for pasture or has no particular use (Figure 3). Gully and aeolian erosion as well as sand accumulations and soil compaction are visible and indicate land degradation in the research area.

3.1.3. Plantation

Plantations are planted monocultural forests – also in terms of the FAO forest definition – with fast growing tree species (Figure 3) classified as production forest in Vietnam (MARD, 2010). The examined plantations were classified in four subclasses of different plantation ages where tree species of *Acacia mangium* (2 and 5-years-old) and *Azadirachta indica* (7 and 10-years-old) are planted in rows. For the remote sensing analysis classes are labeled as "plantation + age" since not all identified plantations in the research area are planted with the same tree species. In the plot analysis classes are labeled with "(plantation +) tree species + age". Generally, plantations of *A. mangium* are cleared after a rotation of 7-15 years in Vietnam (MARD, 2010). At the 10-year-old plantation, trees were thinned out and new trees were growing. This indicates that the forest is used continuously and protection forests are in a steady transition without reaching a climax situation.

3.1.4. Agricultural Land

In the research area agricultural land is cultivated with perennial crops such as dragon fruit, mango, cassava and cashew as well as annual crops like peanuts and sweet potatoes. For this study agricultural areas were integrated in the remote sensing analysis for the estimation of the C storage capacity. Data about Total Carbon (TC) content are not further investigated.

3.2. Remote Sensing Analysis

For the remote sensing analysis Landsat 5 and 8 as well as Aster images were collected over the research area for the month of April for the last 11 years. In the case of unavailability of a particular year's image for April, images from January to March were selected. Aster data were used for the selection of the sampling site, because of their higher resolution and thus improved identification of forest or non-forest areas. Sample site selection was done by calculating the normalized difference vegetation index (NDVI) following Equation 1 from ASTER data in the time from 2005 until 2016 - where images were available. (Nguyen, et al., 2012; Lu, 2006)

Equation 1:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

NDVI *Normalized Difference Vegetation Index*
NIR *Near-infrared Band*
RED *Visible Red Band*

Through a change analysis of NDVI between years the development of the forest cover could be estimated and chronologically categorized (Equation 2). Since for the research qualified ASTER images were not available for every year, additional high resolutions images from Google Earth were visually analysed for the establishment of forest vegetation at a plot.

Equation 2:

$$\Delta\, NDVI = NDVI_i - NDVI_{i+j}$$

Δ *NDVI* *Change in Normalized Difference Vegetation Index*
$NDVI_i$ *Normalized Difference Vegetation Index in the base year i*
$NDVI_{i+j}$ *Normalized Difference Vegetation Index j years after the base year i*

This method allowed the age of a plantation to be identified, ± 2-3 years. The data time series of Landsat 5 and 8 enabled further analyses to be conducted and interpreted for forest or non-forest areas based on these images. Thus, the year that the forest was established could be calculated with an uncertainty of one year (Annex: Chap. 4). The next step included a transformation of the NDVI to forest or non-forest land. For each image NDVI values for forest and non-forest were selected individually since NDVI values are dependent on satellite and environmental conditions. The histogram of the NDVI distribution was visually interpreted and natural breaks were used as a first classification method between forest and non-forest area. Additionally, known forest area with low NDVI were taken as the lowest NDVI value of forest land. Every area with higher values was classified as forest and with lower values as non-forest. Agricultural areas, settlement areas, lakes and natural forest areas – for a further step to distinguishing natural forests from plantations – were manually excluded from the NDVI analyses for plantation by simply leaving out the main areas of their distribution based on field experience. Furthermore, it was also a requirement that the established forest still existed during the field trip in April 2016. Thus, the resulting map from the change analyses represents the establishment year contrasted to the reference year (April 2016) image. The change analyses for the C sequestration map included time ranges for every class. Thus, 10-year-old plantations represent established forests in 2006 till 2004, 7-year-old from 2006 till 2009, 5-year-old from 2009 till 2013 and 2-year-old from 2013 to 2016. Therefore, the area of established forest in a previous year could be smaller in 2016 because deforestation may have occurred in the interim. During the field trip the classes were validated and the plots were randomly selected from the different classes. After ground data collection, C data from soil sampling and biomass estimation (Chap. 3.3, 3.4) from the plots were integrated with the GIS data and extended over the research area to estimate the total C sequestration capacity. In the resulting map land cover can be differentiated into natural forest (e.g.Rung Nhu), plantations with the age of 2, 5, 7, and 10 years, barren land, lakes and agriculture. All analyses were done with ArcGIS 10.4 and with Python 2.7.10.

3.3. Biomass Estimation

Biomass was estimated through forest inventory and allometric equations for the tree species and forest type following the description of FAO (2004a). Total biomass for one plot (i) was calculated by adding aboveground biomass ($AGB_{(i)}$), belowground biomass ($BGB_{(i)}$) and litter biomass ($B_{Litter(i)}$) (Equation 3):

Equation 3:

$$B_{tot(i)} = AGB_{(i)} + BGB_{(i)} + B_{Litter(i)}$$

$B_{tot(i)}$ *Biomass total for plot i*
$AGB_{(i)}$ *Aboveground Biomass for plot i*
$BGB_{(i)}$ *Belowground Biomass for plot i*
$B_{Litter(i)}$ *Litter Biomass for plot i*

For the calculation of AGB tree diameter at breast height (DBH) and tree height was measured for every tree and shrub at the randomly selected 10x10 m plot in the 5 forest stands. DBH were taken at 1.30 m (breast height) by determining the perimeter with a measuring tapeline and calculating the diameter. Tree height was measured with a laser distance meter or – if not possible – with an inclinometer from eye level (1.70 m) up to the top of the crown. For inclinometer assessment, additional tree-to-measurement position distance was measured to calculate the tree height by trigonometry (Equation 4). For the laser distance meter method only 1.70 m were added to the measured distance to the crown because the distance between the observer and the tree was small and deviations from the real tree height negligible.

Equation 4:

$$Ht = \tan\alpha * d + hm$$

Ht *Tree height*
d *Distance to tree*
α *Angle to top of the crown*
hm *Measuring height*

Tree species were identified in the field, corroborated by literature and expert communication. With the information about the vegetation and climate data, natural forest was classified into sub-evergreen, dense dryland forest (Tran, et al., 2012) for the selection of the allometric equation, although the term semi-dense shrub land can be used for the transition area to the adjacent barren land - where sampling plots are located (see also remarks in methods: Chap. 3.1.1.) In a further step, appropriate allometric equations were collected for all different forest types from literature based on DBH, height, species, ecoregion and rainfall. The equations for the natural forest were derived from comparing different allometric formula. One equation is provided from a study by UN-REDD which developed biomass allometric equations for deciduous forests close to the research area (Hung, et al., 2012). In addition, two generally accepted equations from FAO (2004) and two equations from Chave et al. (2005) were tested. The equation which was closest to the mean value between all equations was chosen for the further analyses. Thus, the equation from Chave et al. (2005) was selected to calculate AGB for the natural forest class (Equation 5). The equation was developed for dryland forests with rainfall below 1,500 mm/year and a long lasting dry season. The equation includes diameter (D), height (H) and wood density (p). (Chave, et al., 2005) For wood density 0.57 g/cm^3 was applied as an average value for tropical forests (FAO, 1997).

Equation 5 (Chave, et al., 2005):

$$AGB_{FN} = \exp(-2.187 + 0.9160\ x\ ln(pD^2H))$$

AGB_{NF} *Aboveground Biomass for the Natural forest class (kg)*
p *Wood density (g/cm^3)*
D *Diameter (cm)*
H *Height (m)*

Since primary biometric variables (e.g. DBH, height, wood density) play an important role in the biomass calculation species-specific allometric equations were chosen from literature for the different plantations (Ali, et al., 2015). Thus, for the *Acacia mangium* plantations in the age of 2 and 5 years an allometric equation from Miyakuni et al. (2004) was applied and includes diameter at breast height (DBH) as a variable (Miyakuni, et al., 2004) (Equation 6).

Equation 6 (Miyakuni, et al., 2004):

$$AGB_{Am} = 0.0472 \text{ x } \mathrm{DBH}^{2.75055}$$

AGB_{Am} *Aboveground Biomass for* Acacia mangium *plantation (kg)*
DBH *Diameter at Breast Height (cm)*

For the *Azadirachta indica* plantations AGB was derived from a biomass expansion factor (BEF) provided by Bohre and Caubey (2016) for an *A. indica* plantation in India (Equation 8). Therefore, the tree volume was calculated and multiplied by wood density and the BEF (Bohre & Chaubey, 2016). A wood density of 0.69 g/cm^3 was applied following FAO species-specific wood density values (FAO, 1997). Stem volume was also calculated following the approach of Bohre and Chaubey (2016) (Equation 7) by:

Equation 7 (Bohre & Chaubey, 2016):

$$AGB_{Ai} = \text{stem wood volume x WD x BEF}$$

AGB_{Ai} *Aboveground Biomass of* Azadirachta indica *(kg)*
WD *Wood Density (g/cm^3)*
BEF *Biomass Extension Factor*

Equation 8 (Bohre & Chaubey, 2016):

$$V_{Ai} = -0.068 + 0.008D + 4.191\,x\,10-5D^2 2H - 1.038\,x\,10-9$$

V_{Ai} *Volume of* Azadirachta indica
D *Diameter Breast Height (cm)*
WD *Height (m)*

After AGB calculation BGB was estimated by applying shoot to root ratio from the literature (Equation 9). For natural forest sites a factor of 0.40 was selected because of the high amount of shrub vegetation at the plot (IPCC, 2006). For the *A. mangium* plantations a ratio of 0.23 was used following a study in a degraded *A. mangium* stand in Indonesia (Syahrinudin, 2005). For the *A. indica* site the ratio was set to 0.27 derived from a study about root biomass at a research farm in India (Das & Chaturvedi, 2008).

Equation 9:

$$BGB = AGB \ x \ SR$$

BGB *Belowground Biomass (kg)*
AGB *Aboveground Biomass (kg)*
SR *Shoot-to-Root Ratio*

AGB and BGB for each tree in kg was summed up for every plot of 100 m^2 and divided by 10 to obtain tonnes per hectare (t/ha).

Litter biomass was estimated at one plot in every class by taking litter from randomly selected subplots of an area of 0.25 m^2 (0.5x0.5 m). The samples were air dried and weighed. Additionally, during the field survey litter cover in percent was estimated for the plots. Litter biomass was calculated by multiplying the weight with the litter cover in percent (Equation 10).

Equation 10:

$$B_{litter} = Lw \ x \ Lc$$

B_{litter} *Litter Biomass (kg/ha)*
Lw *Weight of Litter per plot (kg)*
Lc *Litter cover of the plot (%)*

Total biomass was calculated by adding the three compartments of biomass, AGB, BGB and B_{litter}, together.

Equation 11:

$$B_{tot} = AGB + BGB + B_{litter}$$

B_{tot} *Total Biomass (t/ha)*
AGB *Aboveground Biomass (t/ha)*
BGB *Belowground Biomass (t/ha)*
B_{litter} *Litter Biomass (t/ha)*

3.4. Soil Sampling

Soil samples were taken at every plot. Sampling spots in the plots were chosen at three places under different impact factors of (i) close to tree/non-tree, (ii) low/medium/high litter cover and (iii) low/medium/high occurrence of roots to get a range of conditions which can influence soil properties. The soil was taken with a one-meter drill (Pürckhauer) with a core diameter of 2 cm. Sampling depth was 1 m from soil surface. Since the soil had a low coherence and was falling out of the drill during extraction from the ground the drill was inserted into the soil at an angle of between 70° to 90° into the soil surface. Furthermore, to mitigate the loss of soil from the drill during extraction, the soil falling out from the top 0 to 15 cm was captured using a shovel. The sampling depth was at an interval of 5 cm until a depth of 30 cm and after this in 10 cm steps. Additionally, because of the soil loss from the drill from the top layers, bulk samples were collected with a shovel from the top 30 cm in intervals of 5, 10, 15 and 30 cm. Therefore, a hole approximately 30 cm deep was dug and samples were taken with the shovel on the side wall of the hole. Soil samples from the drill method and the bulk samples were collected in plastic bags, marked with a sample ID, air dried for 48 hours, sieved using an analytical sieve of a 2 mm mesh size according to the Austrian Standard (ÖNORM) L-1060 (2004) and finally transported to the laboratory. For the analyses representative composite samples for the soil depth of 0-5, 5-10, 10-20, 20-40, 40-60, 60-100 cm were combined from the taken samples.

3.5. Soil Chemical and Physical Analysis

Soil analyses were carried out at the Faculty of Chemistry of the Vietnam National University - Hanoi University of Science (VNU-HUS) in Hanoi, Vietnam, the Department of Soil Science at the University of Natural Resources and Life Sciences (BOKU) in Vienna, Austria and the Department of Geography at the University of Vienna, Austria.

One part of the Total Carbon (TC) analyses was conducted at VNU-HUS. Air dried soil samples were first homogenized and manually grounded. The TC content in the solid soil samples was examined by the catalytically aided combustion oxidation at 900°C with the Shimadzu TOC-V_{CPH} and the Shimadzu Solid Sample Module SSM-5000A.

Further analyses for TC, dissolved organic carbon (DOC), total nitrogen (N_{tot}), p*H*, electrical conductivity (EC), water extractable anions (WEA), acid extractable cations (AEC) and soil colour were carried out at BOKU. Previous to TC analyses, soil samples were first tested for inorganic C (SIC) components with 10% HCl. Samples were grounded and homogenized with a ball mill (Retsch MM 2000) for 5 minutes. TC and N_{tot} were examined following the Austrian Standard L-1080 (1989) and Austrian Standard L-1095 (2002), respectively, with a Carlo Erba Elementary-Analyser CNS NA1500. The applied method was dry combustion at 1800 °C with a sample weight of 1.5-1.8 mg. Analysis of the pyrolysis gases was done with a GC-TCD system and recorded with Agilent Chemstation 32.

There was no reaction of the soil on the applied 10% HCl test, thus SIC content was negligible which means that TC is equal to OC (Equation 12).

Equation 12:

$$C_{org} = TC - SIC$$

TC *Total Carbon*
SIC *Soil Inorganic Carbon*
C_{org} *Organic Carbon*

For the DOC, pH, EC and WEA analyses a water extract in the ratio of 1:10 was produced by filling up the weighted soil sample (3 g) with deionized water to 30 ml and leaving it overnight before shaking with an end-over-end tumbler (GFL 3015 shaker) for one hour. After shaking, samples were gravimetrically filtered through a folded filter paper (Whatmann TM, #40). The suspension was centrifuged and decanted.

DOC in the water extract was determined with a PerkinElmer 2300 EnSpire Multimode Plate Reader by UV absorbance at a wavelength of 245 nm in accordance with Brandstetter et al. (1996). Furthermore, the spectral adsorption coefficient at 400 nm (E_4) and 600 nm (E_6) was analyzed to characterize the origin of DOC and the degree of humification as the ratio of humic to fulvic acid. A low ratio indicates higher content of humic acid and a higher ratio a higher content of fulvic acid (Canellas & Façanha, 2004; Martin-Neto, et al., 1998). The applied method and calculation of the ratio of the extinction (E_4/E_6) followed the described approach of Schinner et al. (1993).

The soil acidity (pH) as well as electrical conductivity (EC) was determined in the water extract at 25°C with a pH-meter (Mettler Toledo and SevenGo DuoTM SG23) by following Austrian Standard Procedure L-1083 (1989) and with a conductometer (WTW LF 191) by applying Austrian Standard Procedure L-1092 (1993), respectively.

Water extractable anions (Cl, NO_3, PO_4, and SO_4) were analyzed by a liquid ion chromatic system from Metrohm 881 Compact IC pro according to Austrian Standard L-1092 (1993).

Acid extractable cations were analyzed with aqua regia acid digest for nutrients. Using atomic absorption spectroscopy (AAS Perkin Elmer PinAAkle 800T) element (Ca, Mg, K and Na) concentrations were measured. Water extractable anions and acid extractable cations were only spot-checked in this study.

Soil colour was determined with the air dried soil in the laboratory with a standard Munsell soil colour chart according to Austrian Standard L-1071 (2005).

Soil physical analyses were carried out at the University of Vienna. Bulk density for three representative combined soil samples from the first 0-30 cm were simulated in the laboratory by filling up a cylinder (volume: 20 cm^3) with the soil and weighing it. After subtracting the weight of the cylinder bulk density was calculated (Equation 13) by:

Equation 13:

$$BD = \frac{m}{V}$$

BD	*Bulk Density of the soil sample ($g.cm^3$)*
m	*Mass of the soil sample (g)*
V	*Volume of the cylinder (cm^3)*

In addition, for the three composite samples particle size distribution was analyzed by wet sieving and sedimentation following the approach of Austrian Standard L-1061-2 (2001).

3.6. Estimation of Carbon Sequestration

The determination of the C sequestration capacity of the six classes was done by calculating C storage in biomass and soil for each plot. C in biomass was simply calculated (Equation 14) by applying a factor of 0.475 (FAO, 2015), since Schlesinger observed that C content in oven dried biomass is between 45 to 50% (Schlesinger, 1991).

Equation 14:

$$C_B = 0.475 \ x \ B$$

C_B	*Carbon (t/ha)*
B	*Biomass (t/ha)*

C storage in soil was calculated for each layer by multiplying the TC content of the layer with the representative bulk density of the class, layer height as well as area (Equation 15) and summed up for one profile (Baldock, 2009; Justine, et al., 2015).

Equation 15:

$$C_{Storage \ i} = C_{h \ i} \ x \ BD_{class} \ x \ D_h \ x \ A$$

$C_{Storage \ i}$	*Carbon storage in layer i (t/ha)*
$C_{h \ i}$	*Carbon Content of layer i (%)*
BD_{class}	*Bulk Density of the class (g/cm^3)*
D_h	*Depth of Layer i (m)*
A	*Area 1ha (m^2)*

C storage at class level was calculated by adding the mean values of soil C and biomass C together and expressed in tonnes C per hectare (tC/ha). Furthermore, for plantation classes a simple linear regression analysis was conducted between C storage and age of the plantations to apply correction of species-specific influences on the C storage of a certain age since every age is only represented by one species. Results from the regression were used for the total C stock calculation and map. The C stock for one class was calculated by multiplying C storage values derived from the regression with the extent of the class area derived from the satellite analysis (Equation 16).

Equation 16:

$$C_{stock \ i} = (C_{S \ i} + C_{B \ i}) \ x \ A_i$$

$C_{stock \ i}$	*Carbon stock in Class i (t)*
$C_{S \ i}$	*Total Carbon in Soil in Class i(t/ha)*
$C_{B \ i}$	*Total Carbon in Biomass in Class i (t/ha)*
Ai	*Area of Class i (ha)*

Summing up all C stocks of the classes results in the estimated overall C stock capacity of Hoa Thang.

3.7. Statistical Analyses

Statistical methods were applied to the data set using SPSS 24 as well as MS Excel. Significance threshold for all tests was at $p < 0.05$. Besides descriptive analyses of variables, the data were tested whether certain conditions for statistical tests are complied with. To test for normal distribution a Kolmogorov-Smirnov and a Shapiro-Wilk test were both applied. A Levene test was used to test variables for homogeneity of variances across groups. Since data violated normal distribution or couldn't reach homogeneity of variance comparison between groups (classes) were analysed with a non-parametric Kruskal-Wallis test. After differences between groups were significant by analyses of variance, alterations between specific groups were examined with a Post-hoc test of pairwise comparison. For pairwise comparison variances between groups had to reach an adjusted significant level to be meaningful.

Correlation and linear regression models were applied for the relationship between the variables. For regression, outliers were eliminated by hierarchical cluster analyses or by the SPSS unusual cases tool. If the non-normal distribution of data or the assumption of homoscedasticity was not reached data were transformed with square root function to reach conditions for regression analyses. Correlation was applied with a non-parametric Spearmen's rho for non-normal distributed data.

Applied statistical tests and raw data are presented in the Annex. Boxplots show with the box weight the 1st and 3rd quartile and with the thick middle line the median. Whiskers indicate 1.5 times the interquartile. Error bars in bar plots show the standard error (SE). Values in brackets after results represent the standard error.

4. Results

4.1. Remote Sensing Analyses

Based on the NDVI calculation of the satellite data analysis of Landsat 5 and 8 images the net forest area (gain and loss) increased by 2,230.92 ha from a total of 8,112.06 ha to 10,342.98 ha in Hoa Thang in the time from 2005 to 2016 (Table 2). Thus, in the 11 years of observation the loss of forest by conversion to non-forest land was 779.59 ha and the gain of forest land was 3,010.52 ha. Overall the forest area increased by 202.81 ha/a.

Table 2: Extent of land use areas in Hoa Thang in ha during the examined time range. Plantation extent indicates the change of plantation areas from the previous examined year to the given.

Year	Barren Land (ha)	Forest (ha)	Plantation extent (ha)	Agriculture (ha)	Lake (ha)
2016	12,810.14	10,342.98	685.37	738.72	
2014	13,151.87	10,303.83	360.29	436.23	
2011	13,429.88	10,130.94	360.55	330.84	156.52
2009	14,115.68	9,534.42	1,187.15	241.92	
2005	15,557.75	8,112.06	-	222.3	

Thus, in 2016 43.01% (10,342 ha) of Hoa Thang commune (total 24,048 ha) was covered with forest and 53.27% (12,810 ha) with barren land. The remaining area was used for agriculture with the extent of 738.72 ha (3.07%) or was occupied by lakes with 156.52 ha (0.65%). For the further analyses, the newly established forest in the time period of 2005 to 2009, 2009 to 2011, 2011 to 2014 and 2014 to 2016 had to remain without clear cutting till 2016. The time periods were placed on the examined classes of 2, 5, 7 and 10-year-old plantations. Thus, in the time range of 2005/09 1,325.48 ha forest established in the research area. In the period form 2009/11 forest area increased by 503.75 ha. In the 2011/14 and 2014/16 periods additional forest area covered 409.80 ha and 771.48 ha, respectively. The growth was mainly through plantations. The reforestation was conducted mostly within one year in the time periods. Thus, in the first time period (2005/09) new forest stock increased rapidly because of reforestation of plantations in 2006 where most of the reforested area was in the west of Hoa Thang. In 2009 a huge project was conducted in the east of Hoa Thang but only a small part in the administrative area of interest, with the main part of the project located in the neighboring commune. In 2015 new forest areas developed mainly in the central part of the research area. Because of the different lengths of the time periods the growth rates for these areas were from 2005/09 onwards 331.37, 251.87, 136.60 and 385.74 ha/a; showing that in the recent period the forest growth rate was highest followed by the earliest period (2005 to 2009). Looking only at plantations by excluding areas of natural forest succession plantation extended by 1,187.15 (05/09, plantation 10yr), 360.55 (09/11, plantation 7yr), 360.25 (11/14, plantation 5yr) and 685.37 ha (14/16, plantation 2yr) for the 4 periods. Plantations represent 88% of the total forest area which established since 2005. In the period 2009-2011 71% of the newly developed forest were plantations, the period with the lowest contribution from plantations. The extent of the plantation areas is used here as a multiplier for the calculation of the C stock in the plantation class (Figure 5). For the natural forest class the forest area excluding plantations is used for C stock calculation. The natural forest area covered 7,749.61 ha in 2016, mainly represented by Rung Nhu and woody shrub land close to the coast and sand dune area.

4.1. Biomass Estimation

4.1.1. Natural Forest

Total biomass for the natural forest class is on average 36.74 t/ha (±9.14) including three plots of conducted forest inventories, whereby one plot in the class has more than double (61.22 t/ha) of the biomass compared to the others (23.67 and 25.13 t/ha). Biomass distribution in the three compartments is 2.45 t/ha (7%) in the litter, 9.78 t/ha (27%) in the belowground and 24.44 t/ha (66%) in the aboveground biomass (Figure 4; Annex: Figure 32). Stem density varies in the plots from 11,000 stem/ha for 1NF to 7,800 stems/ha for 2NF and 4,700 stems/ha for 3NF. Thus, the average stem density is 7,833 stems/ha. The average height is 270 cm and the mean diameter is 4.92 cm. The tree height and diameter do not vary strongly from the average.

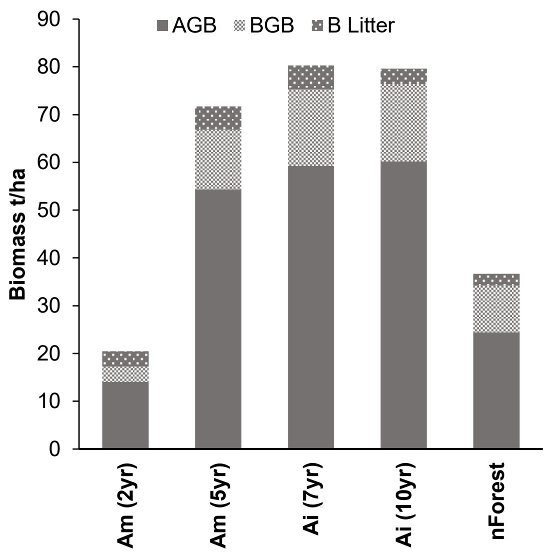

Figure 4: Biomass distribution in the tree compartments AGB, BGB and B_{litter}. Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest.*

4.1.2. Plantation A. mangium 2yr

In the 2-year-old plantation class – planted with *A. mangium* trees - total biomass at the single investigated plot is 20.48 t/ha with 3.22 t/ha (16%) of B_{litter}, 3.30 t/ha (16%) of belowground and 14.03 t/ha (68%) of aboveground biomass (Figure 4, Annex: Figure 33). Stem density is 1,700 stems/ha and average height and diameter are 403 cm and 6.41 cm, respectively.

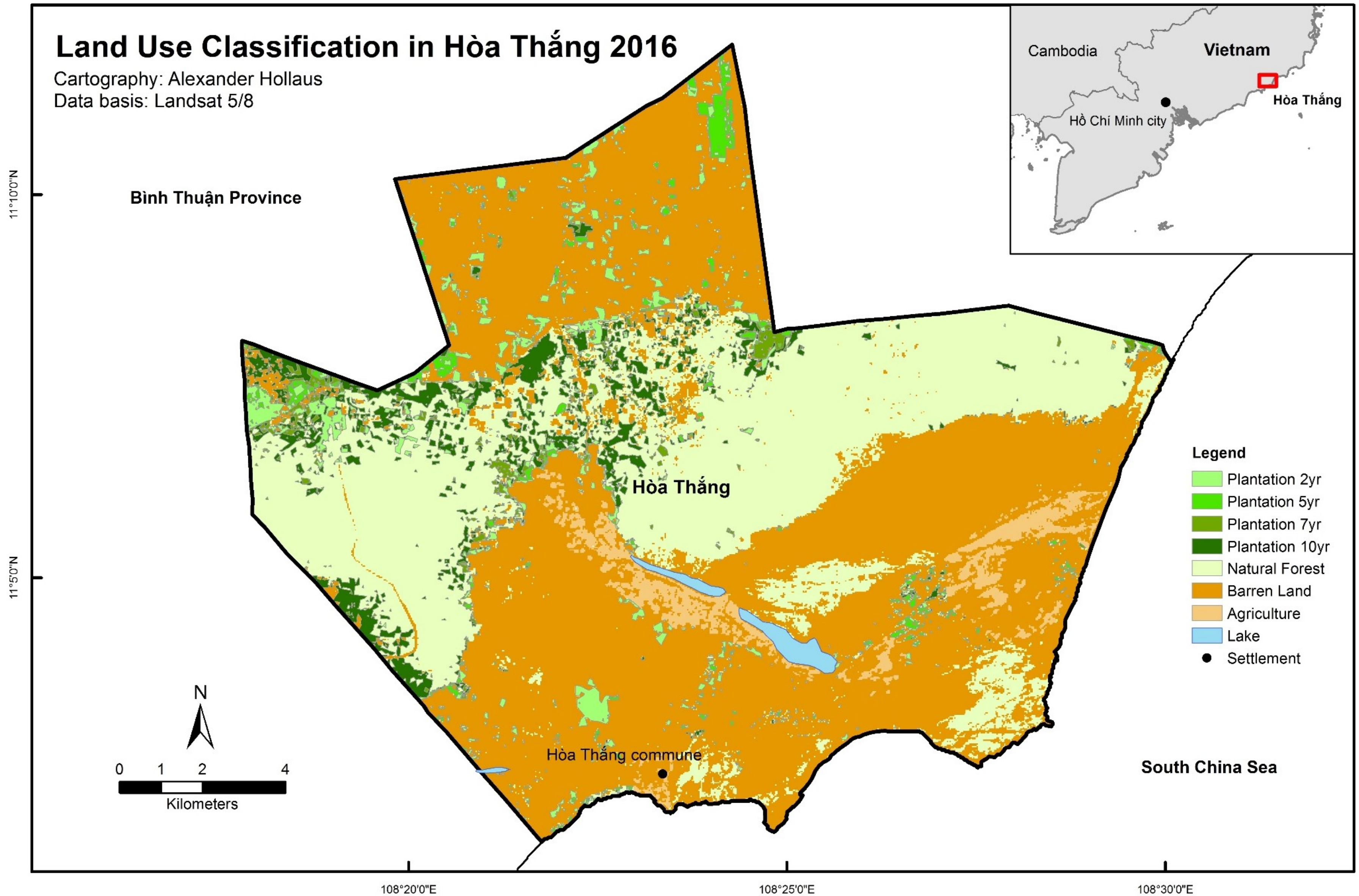

Figure 5: Map of the distribution and extent of the examined classes in Hoa Thang commune.

4.1.3. Plantation A. mangium 5yr

The 5-year-old plantation class with *A. mangium trees* has a mean total biomass of 71.72 t/ha (±9.13). The biomass is distributed to 4.85 t/ha (6%) in B_{litter}, 12.50 t/ha (20%) in belowground and 54.35 t/ha (74%) in aboveground biomass (Figure 4, Annex: Figure 34). Average values of height and diameter are 727 cm and 12.85 cm, respectively. Stem density is 1,100 stems/ha.

4.1.4. Plantation A. indica 7yr

Biomass in the plantation 7yr class with *A. indica* trees is distributed to 5.04 t/ha (6%) to B_{litter}, 16.05 t/ha (20%) to belowground and 59.28 t/ha (74%) to aboveground biomass (Figure 4, Annex: Figure 35). Thus, mean total biomass is 80.32 t/ha (±18.65) for this class. Trees in the plantations have an average height and diameter of 540.51 cm and 12.99 cm, respectively by a stem density of 1,100 stem/ha.

4.1.5. Plantation A. indica 10yr

In the plantation 10yr class – planted with *A. indica* trees – stem density is 800 stem/ha with a mean height and diameter of 496 cm and 14.89 cm, respectively. B_{litter} had 3.24 t/ha (4%), belowground has 16.24 t/ha (20%) and aboveground biomass has 60.17 t/ha (76%) (Annex: Figure 36). This is a mean total biomass of 79.65 t/ha (±27.47) for the 10-year-old plantation class (Figure 4).

4.2. Soil Analyses

4.2.1. Soil Colour

The appearance of the soil colour in the research area can be separated into three main colour types: red, white and yellow (MARD, 2002). The soil colours for the examined plots are all situated in the principal hue of yellow red (YR). The soil colour at the eastern cluster of plots and the 2NF plot is in the range of 7.5YR 5/4, 5/6, 6/4, 6/6 and 7/6 for the top layers which correspond to light brown, brown, strong brown to reddish yellow colour. At all soil profiles in that cluster soil colour changes with depth into the reddish yellow range and in most cases end up with a value of 7.5YR 7/6 in 60-100 cm horizon. The western cluster of plots appears in a principal hue of 5YR and a value and chroma of 3/4, 4/6 and 5/8. This is equal to a dark reddish brown to yellowish red colour. Also, a shift to the yellowish red colour range with soil depth is present for these plots. At the central cluster in the research area plots are in the 2.5YR 4/6, 4/8 and 5/8 range which correspond to a red soil colour. At these plots value and chroma change with depth and end with the 2.5YR 4/6 value in 60-100 cm depth. The only exception was barren land which has no change in chroma and value with soil depth. Soil colour is influenced by iron oxides and their properties (e.g. crystal size). The iron minerals originate from the parent material. Red soil colour indicates the dominant presence of hematite and yellowish colour goethite. (Schwertmann, 1993)

4.2.2. Particle Size Distribution

Particle size analyses reveal a sand fraction of 93.76, 94.94 and 95.71% for barren land, plantation and natural forest, respectively, with the highest amount in the medium sand section

(Table 3; Figure 6). The silt fraction accounts for 4.41% in Barren Land, 3.63% in plantation and 2.88% in natural forest of the particle size distribution. The medium and coarse sand fraction increase from barren land (93.75%), to plantation (94.94%) to natural forest (95.71%).

Table 3: Particle size distribution of barren land, plantation and natural forest classes following WRB classification scheme (IUSS Working Group WRB, 2015).

Particle Size (WRB Class.)	Barren Land (%, n=1)	Plantation (%, n=1)	Natural Forest (%, n=1)	Notation
>2 mm	0.02	0.01	0.01	>2mm
0.63-2 mm	1.50	3.41	3.23	Coarse Sand
0.2-0.63 mm	67.16	81.49	83.70	Medium Sand
0.063-0.2 mm	25.09	10.03	8.78	Fine Sand
20-63 цm	3.15	2.14	1.91	Coarse Silt
6.3-20 цm	0.59	0.93	0.56	Medium Silt
2-6.3 цm	0.68	0.56	0.42	Fine Silt
<2 цm	1.82	1.43	1.40	Clay

On the contrary, the fine sand, coarse and fine silt as well as clay portion decreases in this sequence. Especially between barren land to plantation and natural forest differences occur in the size distribution. In barren land a higher fine sand fraction (25.09%) is present, which is more than the double of the other classes (plantations 10.03%; natural forest 8.78%). Thus, barren land has the finer soil texture compared to the other two, but still has the characteristics of a sandy soil (Arenosol).

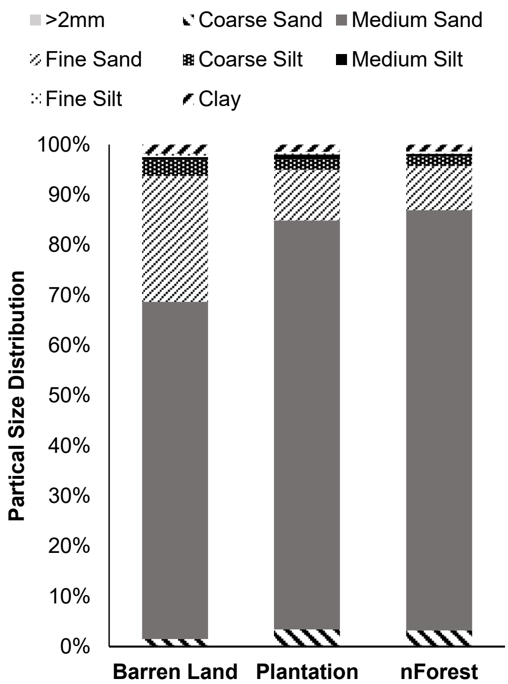

Figure 6: Proportion of particle size distribution in the classes barren land, plantation and natural forest following WRB Classification scheme. nForest: Natural forest

4.2.3. Bulk Density

Bulk density is an important variable for the further calculation of C storage. Mean bulk density in the research area is 1.60 g/cm^3 (Table 4).

Table 4: Bulk density in the three classes barren land, plantation and natural forest.

Class	Bulk Density (g/cm^3)
Barren Land	1.72 (n=1)
Plantation	1.65 (n=1)
Natural forest	1.51 (n=1)
Mean	1.60

With growing age of the forest cover bulk density drops from 1.72 g/cm^3 to 1.65 g/cm^3 to 1.51 g/cm^3 (Figure 7) for barren land, plantation and natural forest, respectively. Thus, bulk density correlates negatively with the increase of the sand fraction.

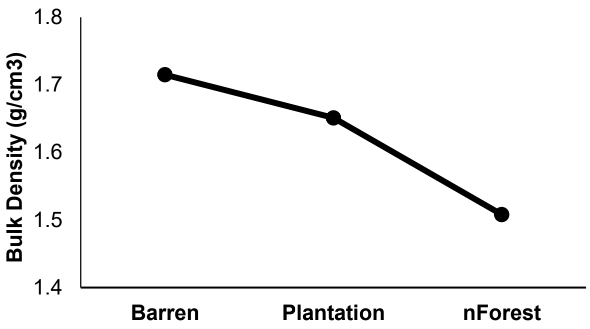

Figure 7: Bulk density in the three classes: Barren land, plantation and natural forest.

4.2.4. Soil pH_{H2O}

Soil pH_{H2O} is in the range from neutral to moderately acid. Mean soil pH_{H2O} is 6.39 over all classes and depth. Lowest mean values are found in the plantation Am 2yr class with a mean of 5.95 and highest in the plantation Ai 7yr class with 6.49 (Table 5, Figure 8).

Table 5: Soil pH_{H2O} min., max. and mean values, standard deviation (SD) and cases (n); Barren: Barren land; Am: A. mangium; Ai: A. indica; nForest: Natural forest.

pH_{H2O}	Class					
	Barren	Am (2yr)	Am (5yr)	Ai (7yr)	Ai (10yr)	nForest
Minimum	5.18	5.20	5.46	5.11	5.63	5.64
Mean	6.38	5.95	6.24	6.49	6.40	6.40
Maximum	8.80	6.47	6.84	7.30	7.11	7.24
SD	0.53	0.37	0.35	0.42	0.36	0.38
n	45	18	36	36	36	54

Basically, the pH_{H2O} decreases in deeper soil layers in every class. If comparing the profiles with the same soil colour samples in the eastern and western cluster have almost the same pH_{H2O} value of 6.47 and 6.31, respectively. The red soil cluster in the central part of the research area has a lower mean value of 6.07 (Annex: Figure 36).

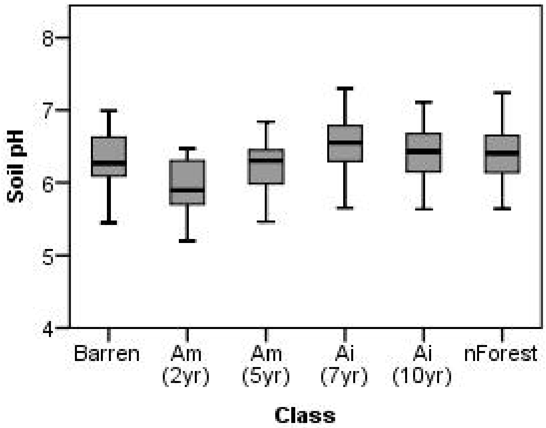

Figure 8: Boxplot of soil pH_{H2O} *in the classes: Barren: Barren land; Am: A. mangium; Ai: A. indica; nForest: Natural forest.*

4.2.5. Electrical Conductivity

In general, EC is on a low level with mean values of 10.9 µS/cm in plantation Am 2yr to 27.6 µS/cm in the plantation Ai 7yr class (Table 6; Figure 9).

Table 6: Electrical conductivity (EC) min., max. and mean values; standard deviation (SD); cases (n); Barren: Barren land; Am: A. mangium; Ai: A. indica; nForest: Natural forest

EC (µS/cm)	Class					
	Barren	Am (2yr)	Am (5yr)	Ai (7yr)	Ai (10yr)	nForest
Minimum	5.6	7.3	6.6	7.7	8.2	6.6
Mean	20.2	10.9	17.3	27.6	20.3	25.9
Maximum	102.3	17.2	62.3	134.9	66.5	109.6
SD	20.8	2.7	10.8	23.8	12.6	24.6
n	45	18	36	36	36	54

EC values decrease with depth of the soil profile whereby in the classes barren land and plantation Am 2yr as well as Am 5yr the declination is very low (Annex: Figure 38). The pattern of the EC values between classes follow that of the pH. pH and EC correlate over all classes by a correlation coefficient of 0.566 (Annex: Table 23).

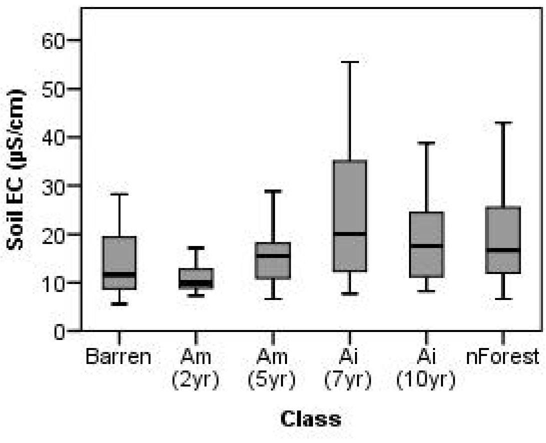

Figure 9: Boxplot of electrical conductivity (EC) in the classes: Barren: Barren land; Am: A. mangium; Ai: A. indica; nForest: Natural forest

4.2.6. Anions

Water extractable anions (Cl, PO_4, NO_3) were spot-checked over some randomly selected samples. Anion concentration is very low in all tested samples (Table 7; Figure 10). Cl shows a peak in the depth of 40-60 cm in barren land and plantation Ai 7yr class with 56.89 and 61.95 mg/kg, respectively. The highest peak for the natural forest class is in 5-10 cm depth with 39.40 mg/kg. In the surface layer values start at a similar level in all classes between 15.7 and 18.5 mg/kg and increase (barren land and natural forest) with depth or do not change (plantation Ai 7yr). After the peaks, Cl concentration drops to the lowest values in natural forest and plantation 7yr class with 13.10 (60-100 cm) and 9.80 mg/kg (40-60 cm), respectively. Also, in barren land Cl decreases again but remains at a higher level in 60-100 cm as in 0-5 cm.

Table 7: Water extractable anions (WEA: Cl, NO_3, PO_4, SO_4) with mean, standard error (SE) and cases (n) in the classes of barren land (Barren), plantation 7-year-old (Ai (7yr)) and natural forest (nForest).

WEA (mg/kg)		Cl			NO3			PO4			SO4		
Class	Depth (cm)	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Barren	0-5	15.70	(5.55)	6	5.28	(1.24)	6	3.63	(0.56)	6	4.56	(1.07)	6
	5-10	23.16	(12.84)	6	7.08	(1.56)	6	3.15	(0.27)	6	4.15	(0.76)	6
	10-20	31.83	(15.39)	6	7.25	(1.59)	6	3.59	(0.75)	6	4.31	(0.76)	6
	20-40	26.26	(21.82)	5	5.27	(0.90)	5	2.81	(0.26)	5	3.25	(0.77)	5
	40-60	56.89	(40.18)	6	5.18	(1.29)	6	2.46	(0.45)	3	5.66	(0.78)	6
	60-100	36.47	(29.77)	6	3.88	(0.59)	6	2.37	(0.39)	5	5.92	(1.58)	6
Ai (7yr)	0-5	17.95	(8.15)	2	7.90	(1.70)	2	3.15	(0.15)	2	4.25	(0.35)	2
	5-10	16.87	(3.20)	3	5.87	(0.97)	3	4.50	(0.46)	3	6.00	(0.85)	3
	10-20	14.85	(3.55)	2	7.85	(3.55)	2	2.80	(0.10)	2	4.60	(1.00)	2
	20-40	17.05	(1.55)	2	4.60	(0.70)	2	.	(.)	0	3.10	(0.10)	2
	40-60	61.95	(54.95)	2	6.30	(2.20)	2	2.90	(0.30)	2	4.65	(0.45)	2
	60-100	13.10	(2.40)	2	3.35	(0.15)	2	.	(.)	0	2.85	(0.05)	2
nForest	0-5	18.50	(11.00)	2	21.70	(6.80)	2	4.80	(0.60)	2	6.20	(0.10)	2
	5-10	39.40	(5.80)	2	24.10	(6.70)	2	3.00	(0.40)	2	5.55	(0.25)	2
	10-20	26.80	(6.80)	2	42.10	(34.90)	2	3.15	(0.65)	2	6.85	(1.85)	2
	20-40	18.00	(10.70)	2	5.05	(0.35)	2	2.50	(0.00)	2	4.05	(0.35)	2
	40-60	9.80	(.)	1	6.90	(.)	1	.	(.)	0	3.10	(.)	1

Phosphate (PO_4) values are in the range of 2.37 and 4.50 mg/kg. In general, PO_4 concentration decreases with depth in all classes. There are fluctuations in the top 0-10 cm with PO_4 concentration in barren land and natural forest in the 5-10 cm layer dropping before slightly rising in the 10-20 cm layer and dropping again in the deeper horizons. Plantation Ai 7yr class acts differently by rising in the 5-10 cm layer and decreasing after the peak to the 10-20 cm layer and do not change anymore.

Nitrate concentration in the class barren land and plantation Ai 7yr is on a low level between 7.90 to 3.35 mg/kg. In these classes the concentration does not change between 5.28 to 7.90 mg/kg till the 20-40 cm layer and decreases afterwards to 3.88 (barren land) and 3.35 mg/kg (Ai 7a), respectively. Natural forest NO_3 concentration in the 0-5 cm layer has 21.70 mg/kg and rises to the 10-20 cm layer to 42.10 mg/kg. In the 20-40 cm layer nitrate concentration decreases (5.05

mg/kg) to the values of the other classes in this depth (~5.10 mg/kg). Because of the small sample size (mostly 2 cases in each variable) standard error is very high in some cases, e.g. nitrate in the natural forest class 10-20 cm layer with 34.90 mg/kg.

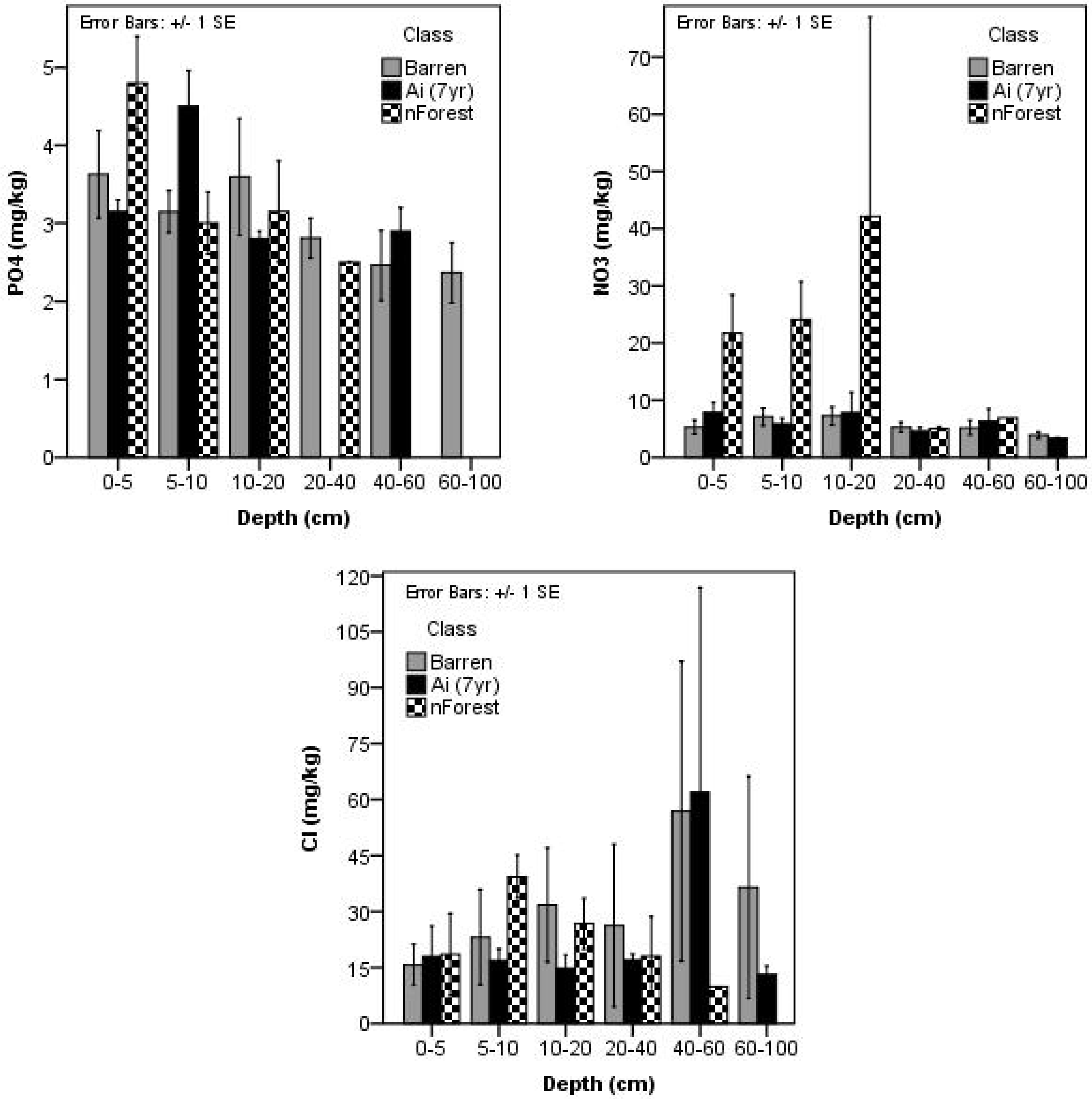

Figure 10: Water extractable anions in the three classes of barren land (Barren), plantation 7yr (Ai (7yr)) and natural forest (nForest) in the soil depth of 0-100 cm. Error bars show ±1 times standard error.

4.2.7. Cations

Aqua regia extracted cations (Ca, Mg, K, Na) were also spot-checked for certain samples of barren land and natural forest class. Higher concentrations are found over all examined cations in the natural forest class (Table 8; Figure 11). Calcium (Ca) values are in the range of 3.09 and 23.73 mg/kg in 0-5 cm to 2.43 and 10.57 mg/kg in 10-20 cm for barren land and natural forest class, respectively. In barren land class Ca concentration drops further in 10-20 cm to 2.03 mg/kg. Magnesium (Mg) shows similar patterns with values of 24.93 and 116.76 mg/kg in 0-5 cm and decreases to 19.87 and 62.23 mg/kg in 5-10 cm in barren land and natural forest class, respectively. In 10-20 cm soil depth Mg drops to 1.60 mg/kg in barren land.

Table 8: Aqua regia extracted cations (AEC: Ca, Mg, K, Na) with mean, standard error (SE) and cases (n) in the two examined classes of barren land (Barren, 0-20 cm) and natural forest (nForest, 0-10 cm).

AEC (mg/kg)		Ca			Mg			K			Na		
Class	Depth (cm)	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Barren	0-5	3.09	(0.28)	2	24.93	(17.53)	2	64.38	(5.88)	2	6.45	(0.46)	2
	5-10	2.43	(0.24)	2	19.87	(13.30)	2	69.61	(16.44)	2	5.57	(0.22)	2
	10-20	2.03	(.)	1	1.60	(.)	1	51.42	(.)	1	4.51	(.)	1
nForest	0-5	23.73	(.)	1	116.76	(.)	1	105.74	(.)	1	8.86	(.)	1
	5-10	10.57	(.)	1	62.23	(.)	1	113.42	(.)	1	9.95	(.)	1

Sodium (Na) values decrease with soil depth from 6.45 mg/kg in 0-5 cm to 4.51 mg/kg in 10-20 cm in the barren land class. In the natural forest class Na concentration increases slightly from 8.85 to 9.95 mg/kg in 0-5cm to 5-10 cm depth.

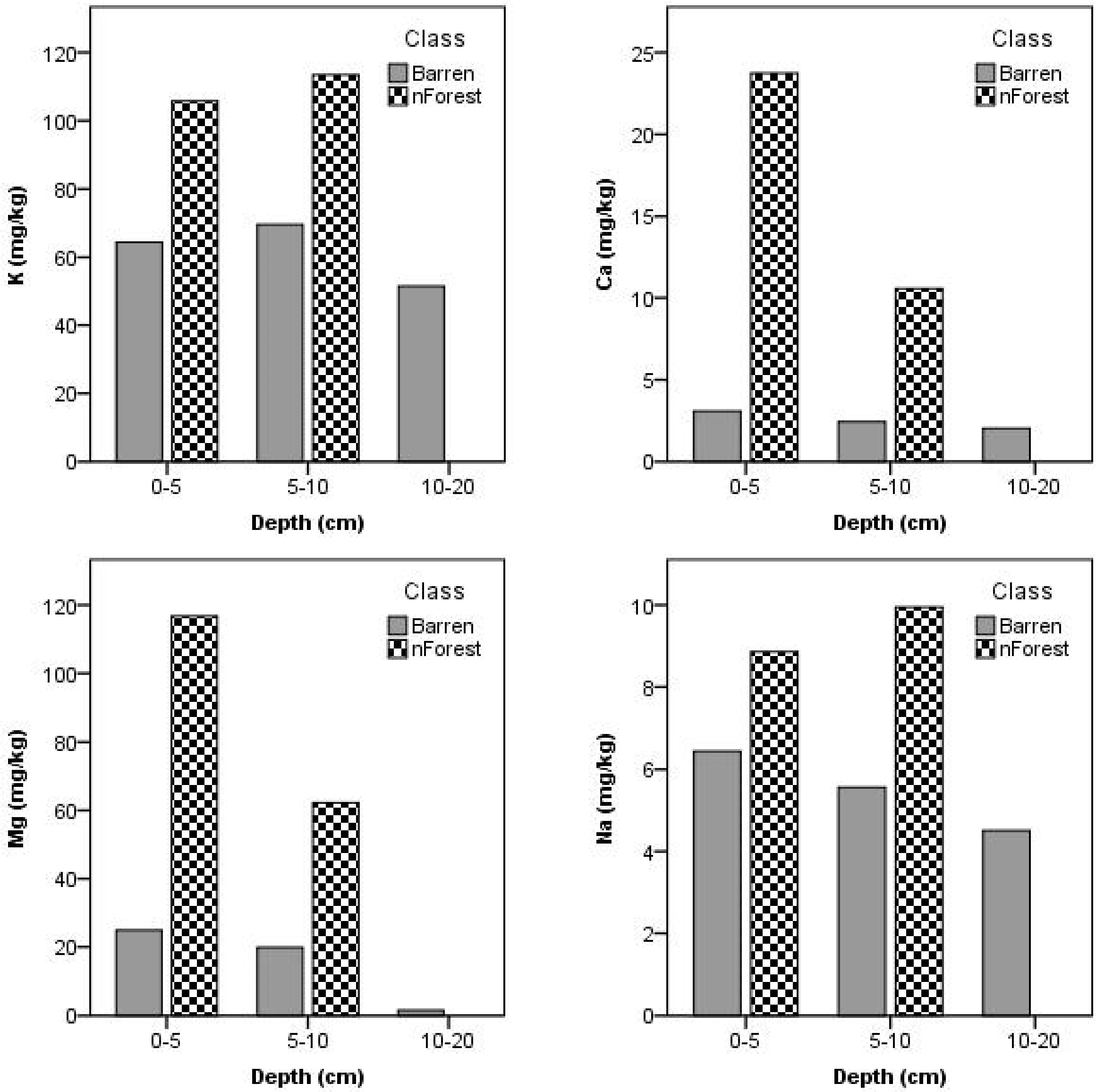

Figure 11: Aqua regia extracted cations (Ca, Mg, Na, K,) in the two examined classes of barren land (Barren, 0-20 cm) and natural forest (nForest, 0-10 cm).

This pattern is also visible in the potassium (K) values where the concentration rises within the first 0-10 cm from 64.38 to 69.61 mg/kg for barren land and 105.74 to 113.42 mg/kg in natural forest. In barren land concentration decreases in the third layer to 51.42 mg/kg.

4.2.8. Total Nitrogen

Mean total nitrogen (N_{tot}) content in the soil ranges between 0.01% in deeper soil layers to 0.09% in the surface layer. Highest mean N_{tot} content can be found in the plantation Am 5yr class (Table 9, Figure 12). Barren land N_{tot} content differs significantly from plantation Am 5yr and Ai 7yr in the surface layer (0-5 cm). This significant difference between barren land and plantation Am 5yr is also visible in the 5-10 cm layer where additionally natural forest differs significantly from barren land (Annex: Table 25). In 10-20 cm, only the plantation Am 5yr class varies from barren land and plantation Am 2yr at a significant level. At soil depth deeper than 20 cm no significant difference between groups occurs.

Table 9: N_{tot} content (%) with mean, standard error (SE) and cases (n) in the classes and with depth. Barren: Barren land; Am: Acacia mangium; Ai: Azadirachta indica*; nForest: Natural forest.*

N_{tot} (%)	Barren			Am (2yr)			Am (5yr)			Ai (7yr)			Ai (10yr)			nForest		
Depth (cm)	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
0-5	0.02	(0.00)	6	0.02	(0.01)	3	0.09	(0.01)	6	0.07	(0.01)	6	0.04	(0.00)	6	0.09	(0.04)	9
5-10	0.02	(0.00)	6	0.02	(0.01)	3	0.08	(0.02)	6	0.06	(0.01)	6	0.03	(0.01)	6	0.13	(0.06)	9
10-20	0.02	(0.00)	6	0.02	(0.00)	3	0.07	(0.01)	6	0.04	(0.00)	6	0.04	(0.01)	6	0.09	(0.04)	9
20-40	0.02	(0.00)	6	0.02	(0.00)	3	0.03	(0.00)	6	0.02	(0.00)	6	0.02	(0.00)	6	0.07	(0.04)	9
40-60	0.01	(0.00)	6	0.01	(0.00)	3	0.02	(0.00)	6	0.02	(0.00)	6	0.02	(0.00)	6	0.02	(0.00)	9
60-100	0.02	(0.01)	6	0.02	(0.01)	3	0.01	(0.00)	6	0.01	(0.00)	6	0.02	(0.00)	6	0.02	(0.01)	7

Comparing mean N_{tot} content in the same class at different depths reveals that significant differences can be found between the depths in the older plantation classes Am 5yr, Ai 7yr and Ai 10yr as well as the natural forest class (Annex: Table 26).

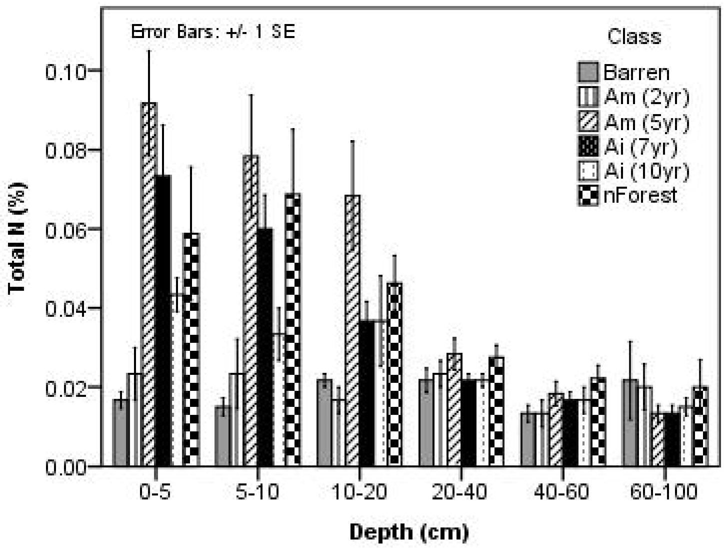

Figure 12: N_{tot} content (%) in the classes and with depth. Error bars show ±1 times standard error. Barren: Barren land; Am: A. mangium*; Ai:* A. indica*; nForest: Natural forest.*

The significant differences in plantation Am 5yr occur in a depth of 20-40 cm to the top layers from 0-10 cm and in plantation Ai 7yr in 10-20 cm to the top layer. In plantation Ai 10yr the top layer significantly differs from the deepest layer of 60-100 cm. In the natural forest class the 5-10 cm layer is significantly different from the layer below 40 cm. In the barren land and plantation Ai 2yr no significant changes are found with depth.

4.2.9. Total Carbon

The mean TC content ranges between low values of 0.16% in the deepest layer in the plantation Ai 7yr class and 2.52% in the natural forest class in 5-10 cm depth (Table 10, Figure 13).

Table 10: TC content with mean, standard error (SE) and cases (n) in the class with depth. Barren: Barren land; Am: Acacia mangium *stand; Ai:* Azadirachta indica*; nForest: Natural forest*

TC (%)	Barren			Am (2yr)			Am (5yr)			Ai (7yr)			Ai (10yr)			nForest		
Depth (cm)	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
0-5	0.32	(0.04)	6	0.46	(0.10)	3	2.05	(0.39)	6	1.23	(0.30)	6	0.94	(0.13)	6	2.12	(0.91)	9
5-10	0.29	(0.05)	6	0.39	(0.15)	3	1.99	(0.43)	6	1.25	(0.26)	6	0.84	(0.13)	6	2.52	(1.06)	9
10-20	0.44	(0.07)	6	0.33	(0.05)	3	1.57	(0.31)	6	0.61	(0.10)	6	0.84	(0.30)	6	1.83	(0.76)	9
20-40	0.34	(0.07)	6	0.46	(0.04)	3	0.68	(0.08)	6	0.30	(0.03)	6	0.43	(0.05)	6	1.49	(0.84)	9
40-60	0.34	(0.08)	6	0.51	(0.20)	3	0.41	(0.06)	6	0.23	(0.02)	6	0.26	(0.03)	6	0.44	(0.10)	9
60-100	0.21	(0.03)	6	0.56	(0.19)	3	0.34	(0.14)	6	0.16	(0.00)	6	0.30	(0.09)	6	0.38	(0.10)	7

TC significantly decreases with depth in the plantation Am 5yr, Ai 7yr, Ai 10yr and natural forest class (Annex: Chap. 14). In barren land and plantation Ai 2yr the TC content stays in the profile at a low level and rather increases in the depth of 10-60 cm. In case of the natural forest, before TC content drops with depth the value increases from 2.12% to 2.52% in the 5-10 cm depth range.

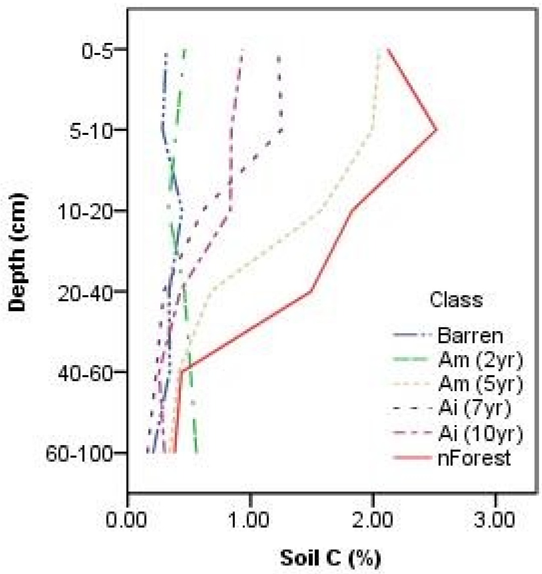

Figure 13: Profile of TC content in the examined classes. Barren: Barren land; Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest.*

The boxplots (Figure 14) show an increase in TC content from barren land to the 5 years-old Am plantation, before dropping down to lower values in the 7 and 10-year-old Ai plantation classes. However, in the natural forest class the TC content rises again to the level of the 5-year-old plantation. This pattern can be seen until depth of 40 cm. Below 40 cm the TC content varies on a similar level in all classes, except the plantation Am 2yr class which increases in the 60-100 cm range to 0.51%. However, variance of TC content is especially high in plantation 5yr and natural forest class.

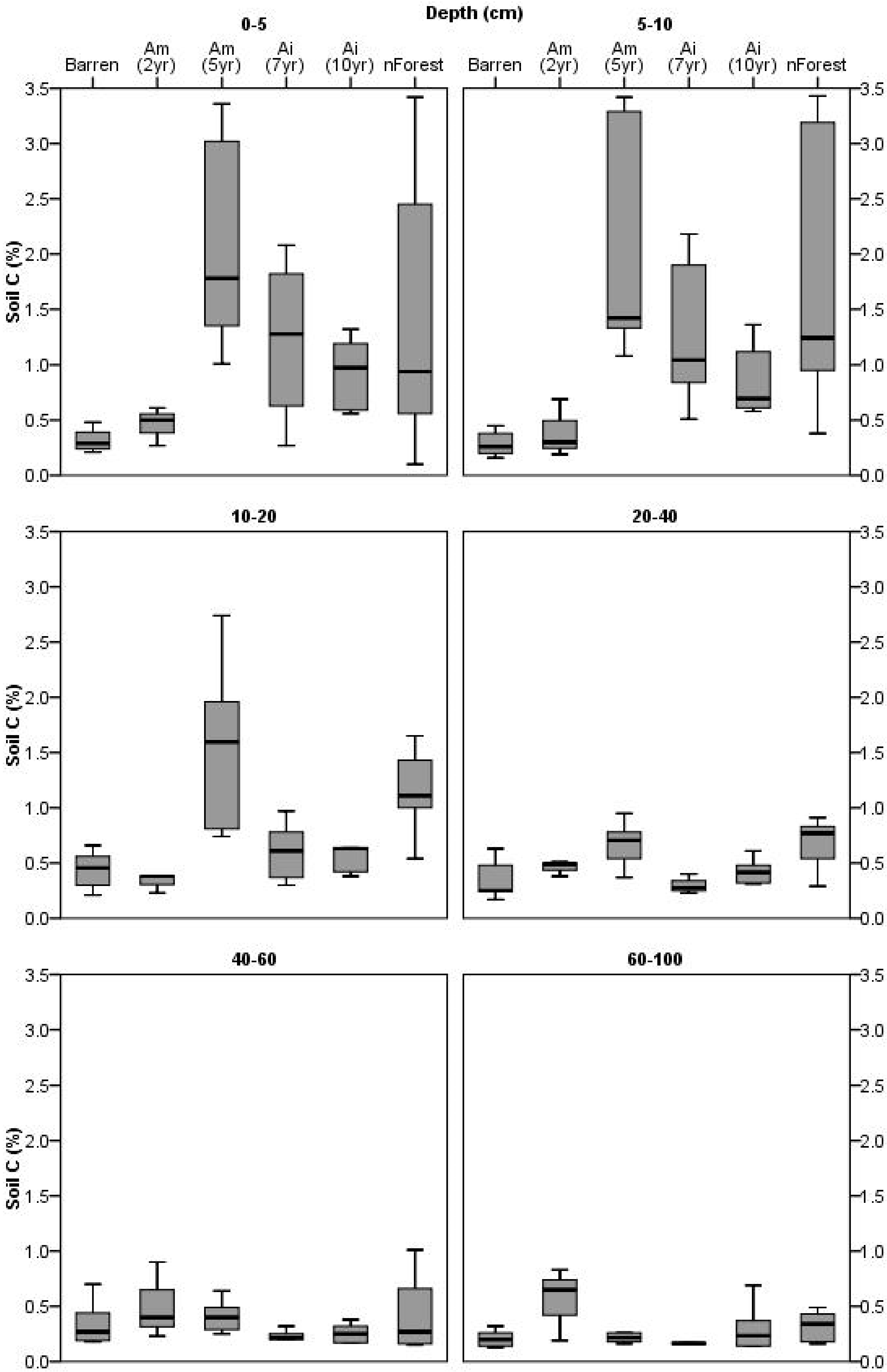

Figure 14: Boxplot of soil TC content (%) in the classes and with depth. Barren: Barren land; Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest.*

4.2.10. C:N Ratio

The C:N ratio varies between 11.53 in the 60-100 cm layer in the plantation Ai 7yr to 41.23 in the plantation Am 2yr class in the 40.60 cm depth range (Table 11, Figure 15). Generally, the C:N ratio stays stable with depth and class, although the standard error increases in deeper layers.

Table 11: C:N ratio with mean, standard error (SE) and cases (n) in the classes and with depth. Barren: Barren land; Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest*

C:N	Barren			Am (2yr)			Am (5yr)			Ai (7yr)			Ai (10yr)			nForest		
Depth(cm)	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
0-5	19.71	(1.46)	6	18.82	(1.74)	3	21.74	(1.79)	6	16.09	(1.91)	6	22.41	(1.80)	6	20.23	(1.18)	9
5-10	18.59	(2.24)	6	18.41	(1.38)	3	25.02	(0.79)	6	20.22	(2.60)	6	23.42	(1.65)	6	20.82	(1.11)	9
10-20	20.09	(2.25)	6	21.26	(1.80)	3	22.67	(1.34)	6	17.80	(1.74)	6	22.15	(2.50)	6	24.43	(1.56)	9
20-40	16.97	(2.24)	6	20.37	(2.32)	3	24.60	(1.18)	6	13.44	(1.51)	6	21.89	(1.98)	6	25.65	(3.98)	9
40-60	25.71	(5.00)	6	41.23	(21.05)	3	24.28	(3.68)	6	14.85	(2.71)	6	16.98	(2.86)	6	22.74	(4.21)	9
60-100	14.34	(2.82)	6	27.37	(7.50)	3	26.21	(8.63)	6	11.53	(1.29)	6	24.65	(9.24)	6	23.44	(3.04)	7

The lowest total mean C:N ratio at all depths occurs in the plantation Ai 7yr class with 15.65 followed by barren land with 19.23. Highest values appear in the plantation Am 2yr and Am 5yr classes with 24.58 and 24.09, respectively.

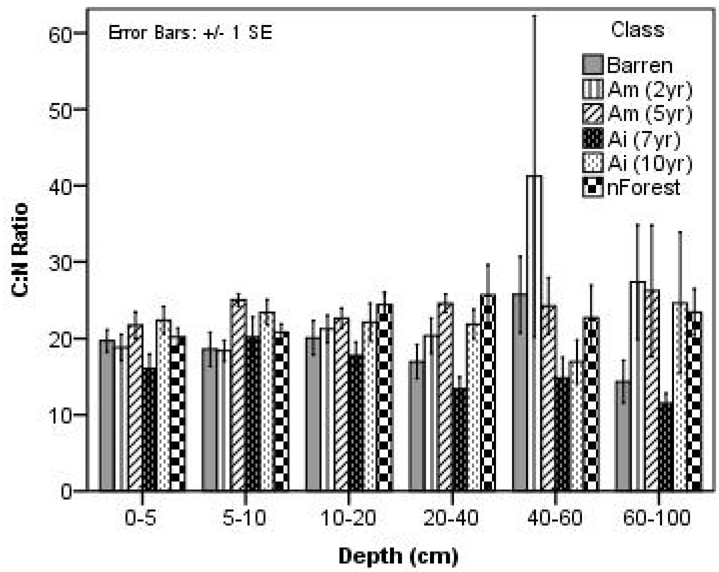

Figure 15: C:N ratio in the classes and with depth. Error bars show ±1 times standard error. Barren: Barren land; Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest*

4.2.11. Dissolved Organic Carbon (DOC)

Concentrations of DOC in the soil water solution range from 8.80 mg/l to 35.35 mg/l in plantation Am 2yr and natural forest class, respectively, in the 0-5 cm soil depth range. With forest age DOC concentration increases, but the standard error also rises (Table 12, Figure 16). Significant differences in DOC concentration can be found only between barren land (8.36 mg/l) and plantation Ai 7yr (18.50 mg/l) classes in 5-10 cm depth by a pairwise comparison. In all classes

DOC concentration decreases until 40 cm soil depth, significantly so in the planation Am 5yr, Ai 7yr and Ai 10yr class (Annex: Table 27).

Table 12: DOC concentration with mean, pairwise comparison between classes (p <0.05), standard error (SE) and cases (n) in the classes and with depth. Barren: Barren land; Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest*

DOC (mg/l)	Barren Mean	SE	n	Am (2yr) Mean	SE	n	Am (5yr) Mean	SE	n	Ai (7yr) Mean	SE	n	Ai (10yr) Mean	SE	n	nForest Mean	SE	n
0-5	9.30_a	(1.94)	6	8.88_a	(2.51)	3	16.48_a	(2.71)	6	21.87_a	(4.20)	6	15.72_a	(1.12)	6	35.35_a	(14.89)	9
5-10	7.09_a	(1.03)	6	10.66_a	(1.64)	3	15.59_a	(3.04)	6	18.50_a	(2.00)	6	14.65_a	(2.48)	6	31.39_a	(13.54)	9
10-20	8.36_a	(1.50)	6	5.07_a	(0.98)	3	10.74_a	(1.11)	6	15.93_a	(3.54)	6	10.72_a	(1.81)	6	34.73_a	(17.12)	9
20-40	$5.27_{a,b}$	(1.64)	5	$4.02_{a,b}$	(0.94)	3	$6.25_{a,b}$	(0.58)	6	$6.21_{a,b}$	(0.26)	6	4.67_a	(0.39)	6	11.04_b	(1.88)	9

Note: Values in the same row and subtable not sharing the same subscript are significantly different at p< 0.05 in the two-sided test of equality for column means. Cells with no subscript are not included in the test. Tests assume equal variances.[1]
1. Tests are adjusted for all pairwise comparisons within a row of each innermost subtable using the Bonferroni correction.

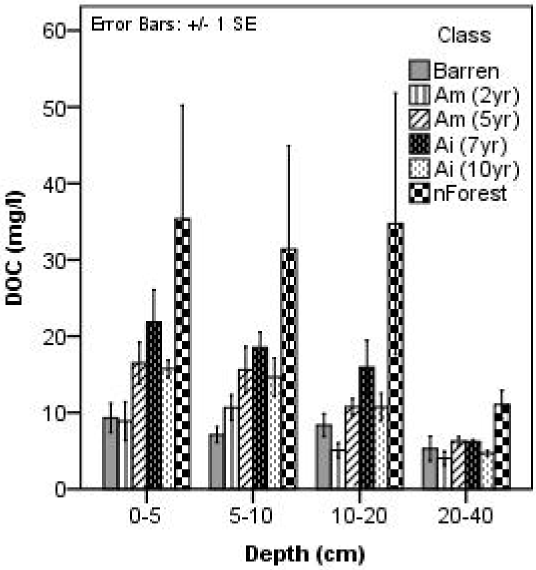

Figure 16: DOC concentration in the classes and at different soil depths. Error bars indicate range of ± 1 times standard error. Barren: Barren land; Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest*

4.2.12. Humic Acid to Fulvic Acid Ratio (E4/E6)

The E4/E6 ratio indicates the degree of humification by comparing the proportion of humic to fulvic acid. The mean E4/E6 ratio is in the range of 3.83 to 8.25. There are no significant differences between groups (Table 13, Figure 17). A rise in the E4/E6 ratio in either the 5-10 cm range or (as in most cases) in the 10-40 cm range exists in all classes. Higher ratios of E4/E6 indicate higher content of aliphatic chains and are related to fulvic acid. Since fulvic acid is more mobile, distribution to deeper horizons is possible. Ratios higher than 5 suggest the presence of fulvic acid. (You, et al., 1999) Only in the plantation Ai 7yr in the 20-40 cm depth range occurs one value of 3.83 and therefore characterized as humic acid (Martin-Neto, et al., 1998). However, results indicate a translocation of fulvic acid into deeper layers.

Table 13: E4/E6 ratio (degree of humification) with mean, pairwise comparison between classes (p <0.05), standard error (SE) and cases (n) in classes and with depth. Barren: Barren land; Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest.*

E4/E6	Barren			Am (2yr)			Am (5yr)			Ai (7yr)			Ai (10yr)			nForest		
Depth (cm)	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
0-5	7.44_a	(2.67)	6	5.81_a	(0.22)	3	6.65_a	(0.51)	6	6.29_a	(0.70)	6	5.95_a	(0.77)	6	6.26_a	(1.02)	9
5-10	5.36_a	(1.13)	6	6.78_a	(0.19)	3	6.90_a	(0.83)	6	5.42_a	(0.29)	6	6.56_a	(0.50)	6	5.73_a	(0.89)	9
10-20	6.54_a	(2.11)	6	8.25_a	(1.86)	3	6.24_a	(0.48)	6	5.50_a	(0.61)	6	8.02_a	(1.41)	6	6.40_a	(0.95)	9
20-40	5.47_a	(2.73)	5	7.61_a	(0.65)	3	6.77_a	(1.83)	6	5.31_a	(0.68)	6	3.83_a	(0.46)	6	5.85_a	(0.84)	9

Note: Values in the same row and subtable not sharing the same subscript are significantly different at p< 0.05 in the two-sided test of equality for column means. Cells with no subscript are not included in the test. Tests assume equal variances.[1]
1. Tests are adjusted for all pairwise comparisons within a row of each innermost subtable using the Bonferroni correction.

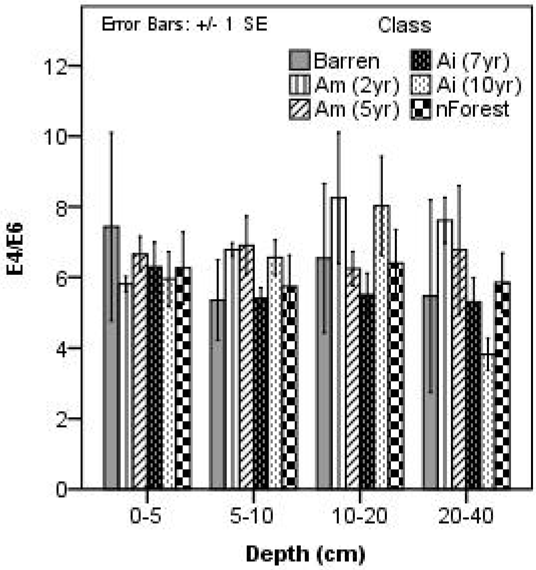

Figure 17: E4/E6 ratio (degree of humification) in the classes and with depth. Error bars indicate range of ± 1 times standard error. Barren: Barren land; Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest.*

4.2.13. C Storage

C storage consists of the two pools of biomass with C in AGB, BGB as well as B_{litter} and C in soil. Natural forest class stores the most C with 157.05 tC/ha in the C pools followed by the plantation Ai 5yr, Ai 10yr, Ai 7yr, Am 2yr and barren land with 153.61, 110.71, 98.81, 91.46 and 49.59 tC/ha, respectively (Table 14; Figure 18). Thus, C storage increases with forest age. However, the high amount of C in the plantation Ai 5yr indicates an influence of further parameters.

Table 14: C storage with mean, standard error (SE) and cases (n) in the class. Barren: Barren land; Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest.*

C-Storage	Barren			Am 2yr			Am 5yr			Ai 7yr			Ai 10yr			nForest		
(tC/ha)	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
C_{AGB}	.	(.)	0	7.01	(.)	1	27.18	(3.68)	2	29.64	(6.69)	2	30.08	(10.32)	2	12.22	(3.11)	4
C_{BGB}	.	(.)	0	1.61	(.)	1	6.25	(0.85)	2	8.00	(1.81)	2	8.12	(2.79)	2	4.89	(1.24)	4
C_{litter}	.	(.)	0	1.61	(.)	1	2.43	(0.19)	2	2.52	(0.36)	2	1.62	(0.06)	2	1.23	(0.18)	4
$\mathbf{C_{biomass}}$	.	(.)	0	10.24	(.)	1	35.86	(4.34)	2	40.16	(8.86)	2	39.83	(13.05)	2	18.34	(4.34)	4
Soil C	49.59	(7.95)	3	81.22	(.)	1	117.75	(9.69)	2	58.65	(8.88)	2	70.88	(9.75)	2	138.71	(51.44)	4
Total C	49.59	(7.95)	3	91.46	(.)	1	153.61	(14.02)	2	98.81	(17.74)	2	110.71	(3.30)	2	157.05	(55.75)	4

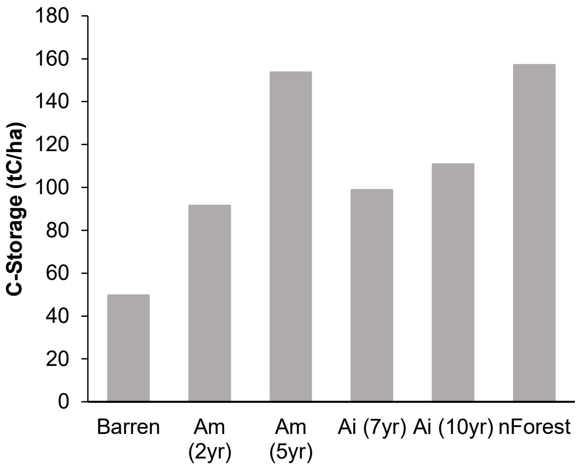

Figure 18: C storage in the classes: Barren: Barren land; Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest.*

Of the different C storage pools, the soil is the largest pool for all classes. For barren land 100% of C is stored in the soil since biomass estimation was only applied for woody shrubs and trees. In plantation Ai 2yr and natural forest class 88.81 and 88.32% of C are stored in the soil. A higher proportion of C stored in biomass is found in the older plantation classes, where plantation Ai 7yr stores 59.35%, Ai 10yr 64.03% and Am 5yr 76.66% in the soil (Figure 19).

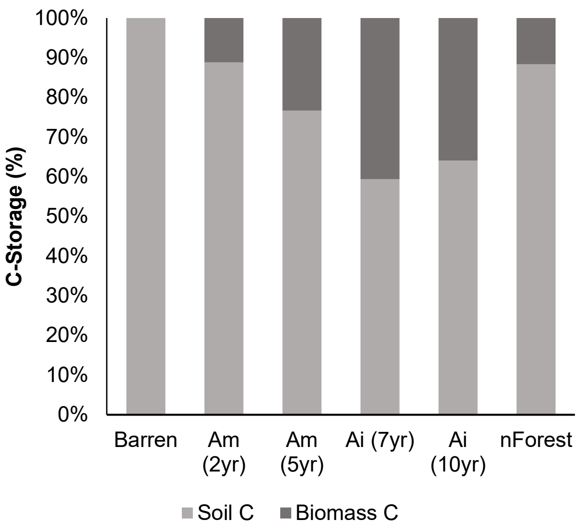

Figure 19: Proportional C storage soil C and biomass C in the classes: Barren: Barren land; Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest*

Comparing C storage above and below the soil surface more C is stored in soil and BGB than in B_{litter} and AGB. The belowground C pool accumulates 100.00, 90.57, 80.72, 67.45, 71.36, 91.85% in barren land, plantation Am 2yr, Am 5yr, Ai 7yr, Ai 10yr and natural forest, respectively (Figure 20). In the aboveground C pool the main factor is AGB which contributes to the storage with 0, 9.43, 19.28, 32.55, 28.64, 8.56% for barren land, plantation Am 2yr, Am 5yr, Ai 7yr, Ai 10yr and natural forest class, respectively.

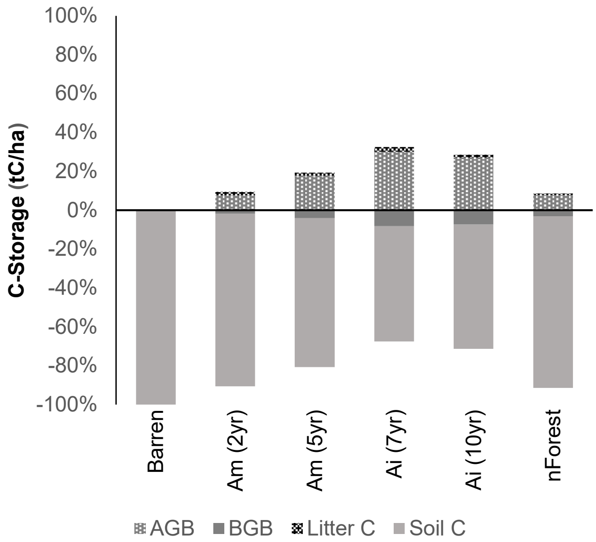

Figure 20: Proporation of C in the pools of AGB, BGB, B_{litter} and soil in the classes: Barren: Barren land; Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest*

4.2.14. Comparison of Soil TC Content Analyses of Hanoi and Vienna

Analyses for the TC content in soil were carried out in two different laboratories (Hanoi and Vienna) with slightly diverse approaches (see methods chap. 3.5). The comparison between the doubled measured samples for TC content from Hanoi and Vienna show a strong significant positive correlation coefficient of 0.811 ($p < 0.01$). For the regression 18 outliers of 94 double measured cases are excluded by a hierarchical cluster analyses (Annex: Chap. 12). The linear regression explains 65.7% (Figure 21) of the variation in the TC content values. The TC values of Hanoi slightly increase more by 1.06 points compared to the TC values of Vienna. This can be an underestimation of Vienna or an overestimation of Hanoi TC data.

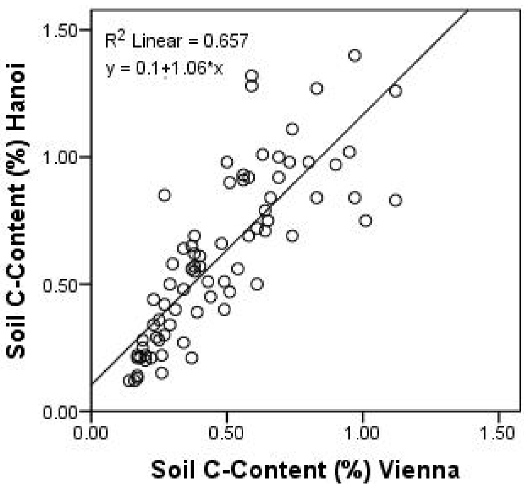

Figure 21: Linear regression between soil TC content analyses from Hanoi and Vienna.

5. Discussion

This thesis examines the effect of reforestation on C storage along a chronological line of forest growth in a dryland. Assuming that barren land has the lowest potential to store C and natural forest the highest the results show that with the aging of forest the C in biomass and soil increases. This is indicated by the situation that the natural forest has the highest C storage capacity. Furthermore, the study reveals that reforestation of degraded sandy soils can reload the C pools in soil and biomass. Similarly, other studies found an increase in C by afforestation (Shi & Cui, 2010; Dong, et al., 2014; Nosetto, et al., 2006; Li, et al., 2013). Lal (2003) noted the importance of afforestation for the restoration of degraded dryland ecosystems and pointed out that through the use of appropriate tree species such as *Acacia* or *Azadirachta* SOC, C stored in biomass and soil fertility all improve. Paul et al. (2002) reviewed world-wide data for C storage change following afforestation and noted a potential of N-fixing trees species (e.g. *Acacia*) to sequester C in tropical and subtropical regions. On the contrary, Turner and Lambert (2000) reported a decline in soil C after the first years of afforestation in subtropical Australia (Cowie, et al., 2006).

Generally, soil TC content in the research area is low compared to other ecosystems in Vietnam. Overall mean TC content is 0.86% (n=214) which corresponds with other studies of Arenosols (sandy soils) in Vietnam. For example, Ha (2010) and Ha et al. (2005) reported mean OC values with 0.68% (n=212) and 1.08% (n=300), respectively, for sandy soils. Nguyen (2005) reported C concentration for red sandy soil in Bac Binh district – close to the research area of this study – of 0.717% for the top 0-15 cm while C decreased with depth to 0.220% under 45 cm. For white sandy soils Nguyen (2005) found values of 0.40% in 0-18 cm to 0.29% in 50-100 cm depth.

Sang et al. (2013), who tested TC concentration in the first 0-10 cm of the soil in four different ecological zones with various soil types in Vietnam, reported average TC concentrations in plantations with *A. mangium* and pasture of 1.89% and 1.73%, respectively. The findings in the study presented here show that the TC content in the first 0-10 cm of the soil is lower in the comparable classes of plantation and barren land with 1.25% and 0.30%, respectively. A difference occurs in the natural forest class compared to the class secondary forest in the study of Sang et al. (2013) where higher TC content with 2.32% is found in the natural forest in contrast to lower values of 1.83% in the secondary forest. Sang et al. (2013) pointed out that soil type and land use type have no significant effect on the C content in the soil, although the study only considered the first 10 cm of the soil and young establishment age of the forest.

Contrary to the results of Sang et al. (2013), Hung et al. (2016b) show that there is a significant difference between land use types on the C concentration in soils. The study compared the discrepancy between *Acacia* plantation and adjacent fallow land from a part of a shifting cultivation system in northern Vietnam. Moreover, Hung et al. (2016a) related *Acacia* hybrid plantations on Acrisols in different ecoregions in Vietnam to generate a prediction of productivity. In the first 20 cm of the soil of *Acacia* hybrid plantations in southern and south central Vietnam C content shows concentrations in the range of 1.1% to 3.9% and 1.1% to 1.2%, respectively. For the northern region of Vietnam, the study indicates C concentrations between 1.4% and 2.7%. In the research presented here the two *Acacia mangium* plantations have a mean C content of 1.38% (n=27, SE=0.197) which is in the lower range of the results of Hung et al. (2016a). Furthermore, Dong et al. (2014) compared C storage (soil depth 0-20 cm) in different aged *Acacia* hybrid plantations and abandoned land in degraded Acrisols, where a significant increase in C storage between abandoned land and all age classes of the plantations exists. Nonetheless, there was no significant rise of C with the age of the plantations whereas an increasing trend is recognizable. The C storage in abandoned land (class: barren land) in Hoa Thang (results from this study) is slightly lower with 11.37 tC/ha to 12.99 tC/ha in the contrasted study. C storage values reported by Dong et al. (2014) for the 2-year-old and 5-year-old *Acacia* plantation were 20.72 tC/ha and 19.48 tC/ha, respectively. In the here present study TC values were 12.55 tC/ha for the Am 2yr plantation and 59.30 tC/ha for the Am 5yr plantation. The difference between *A. indica* plantations and the two younger plantations of *A. mangium* in the soil C content is not significant. Only in the 20-40 cm depth range was C content between plantation Am 5yr and Ai 7yr significantly different with higher C content in the 5-year-old *A. mangium* stand. Nonetheless, Am 5yr and Ai 10yr should have very similar environmental conditions because of the proximity to each other. However, the results offer vital evidence for a lower C storage potential of *A indica*.

5.1. Effect of Tree Species and Biomass on Soil C

For the verification of the better performance of *A. mangium* compared to the other classes the effect of tree species and biomass on the soil C was investigated. Therefore, a correction of the soil C storage in the 2-year-old *A. mangium* plantation was applied for this examination. In this class the layers below 40 cm of 2 profiles show an influence of charcoal buried in the soil which was visible during the field trip on the C content. Thus, C storage in 40-100 cm was adapted by comparison with the third profile of the class and with the adjacent barren land values to reduce this site effects. If comparing C storage of all forest classes with the class 2-year-old *A. mangium* plantation as reference, all older classes have higher C stored in soil and in biomass (Figure 22, left). The percentage increase of C storage was higher in biomass than in soil between 2-year-old *A. mangium* and all other plantation ages.

Table 15: C storage changes between Ai 2yr as reference class and the other forest classes and C storage increment of plantations per year. Am: A. mangium*; Ai:* A. indica*; nForest: Natural forest.*

C Storage Change	**C-Storage Change** compared to reference class: Plantation Am 2yr (%)		**C-Storage Increment of Plantation per Year** (tC/ha/a)	
Class	Soil C	Biomass C	Soil C	Biomass C
Am 2yr	-	-	9.41	6.83
Am 5yr	113.85	250.26	15.02	7.17
Ai 7yr	7.69	292.30	2.28	5.74
Ai 10yr	14.36	289.01	2.82	3.98
nForest	171.62	79.12	-	-

Biomass C increased by 250.26, 292.30, 289.01, 79.12% and soil C pool by 113.85, 7.69, 14.36, 171.62% in plantation Am 5yr, Ai 7yr, Ai 10yr and natural forest class, respectively (Table 15, Figure 22).

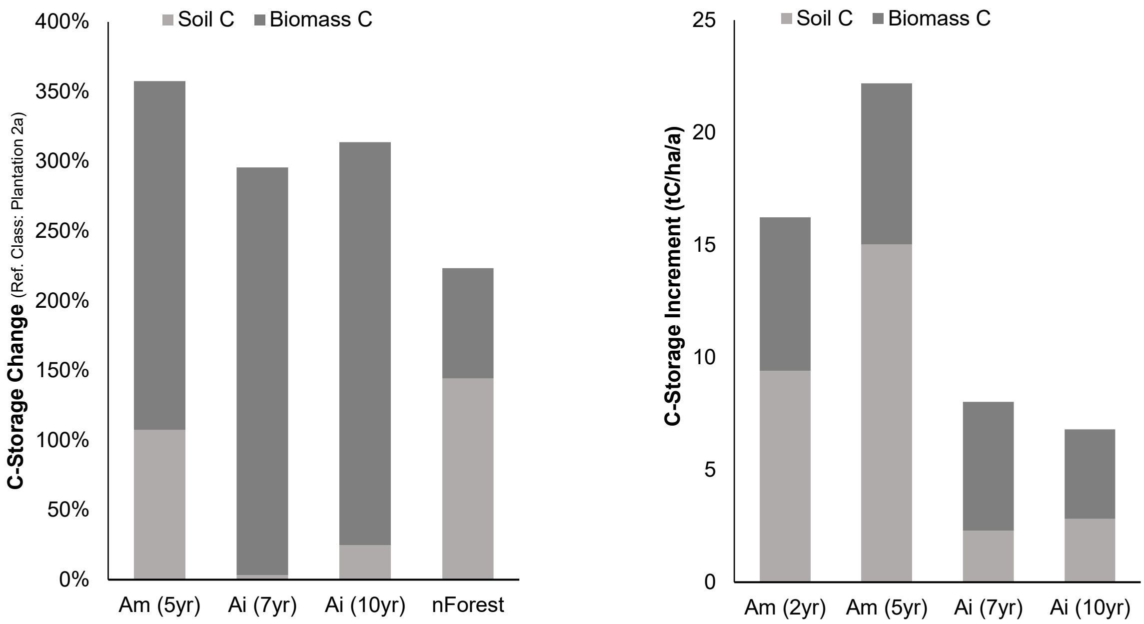

Figure 22: C storage changes in the classes: Am: A. mangium*; Ai:* A. indica*; nForest: Natural forest. Left: Comparison of Ai 2yr class as reference year to the other forest classes in %. Right: C storage increment per year of plantations in tC/ha/a.*

Biomass along the time sequence of forest age increases until plantation Ai 7yr followed by a low decrease to the Ai 10yr class. The soil C pool increased until Am 5yr before decreasing in the Ai 7yr plantation followed by an additional low increase in the Ai 10yr class. Stem density shows a low number of trees in the 10-year-old plantation because trees have been already cut down and the stand thinned out. This was evidenced by the presence of younger trees in the stand and from information from local people. Thus, also the average diameter is influenced and height is lower because of the occurrence of younger trees (Table 16). The thinning can also influence positively and negatively the soil C pool by either an increase in C through the residues left at the site or the decrease through free space and thus higher leaching and erosion through direct rainfall (Shi & Cui, 2010; Paul, et al., 2002). Human impact on the forest, such as by thinning/logging, can stop the growth of the biomass. This can be seen in the small difference in biomass growth between plantation Ai 7yr and Ai 10yr (Figure 4).

Table 16: Mean tree height, mean tree diameter and mean stem density in the classes: Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest*

Class	Tree height (cm)	Tree diameter (cm)	Stem density tree/100m^2
Am 2yr	403.52	6.41	17
Am 5yr	727.32	12.85	11
Ai 7yr	540.54	12.99	11
Ai 10yr	496.34	14.89	8
nForest	270.03	4.92	78

Thus, because of the thinning in Ai 10yr plantation AGB and BGB only increased from 75.33 t/ha in Ai 7yr to 76.41 t/ha in Ai 10yr class. However, litter biomass in plantation Ai 10yr is also low compared to the other classes. Natural forest has low biomass values because of the structure of the forest. Woody shrubs – characterized by a high stem density – are the main vegetation in the forest and thus stem density has a high mean value of 7,800 stems/ha. Contrarily, woody shrubs are small in diameter and height. Also, litter cover is very low because of open spaces between trees and shrubs.

C storage increment per year of the plantations show rates between 6.80 to 22.19 tC/ha/a (Table 15; Figure 22: right). The soil C pools have a higher yearly increment rate than biomass C in A. mangium plantations. Both biomass C and soil C increased more in the *A. mangium* stands than in *A. indica*. An increase in the increment rate occurs for the Am plantations between 2yr and 5yr, which indicates a faster growing after 2 years. The findings show a higher C storage capacity of *A. mangium sites* over the observed time period which could be related to the N-fixing ability and the growth rate of the species. However, the difference in the increment rate of C between tree species suggests that tree species have a clear effect on the C storage capacity.

Other studies about the effect of tree species and biomass on the soil C point out lower C content in soil under *A. indica* as compared to other species (Dagar, 2014; Singh, et al., 2008; Lawal, 2013). Singh et al. (2008) examined biomass production and soil amelioration of 10 tree species on sodic soil in India. All species improved soil C content after 10 years but *A. indica* was among the trees with lowest increase in biomass and soil C. On the opposite Bohre & Chaubey (2016) indicate a very good performance of *A. indica* in coal mine spoil heaps among 5 other tree species. *A. indica* could improve SOC content by 317.8% after 16 years of plantation by an initial C content of 0.73% in the 2-years-old plantation. After 7 and 10 years C content in soil was at 1.73% and 2.25%, respectively (Bohre & Chaubey, 2016). Other soil properties such as pH and water holding capacity also improved. The positive soil amelioration effect of *A. indica* is also found in more studies (Singh & Shuka, 2013; Radwanski, 1969). Tang and Li (2014) conducted research into the soil improvement of afforested degraded sites in a savanna in China and compared among other tree species *Acacia auriculiformis* and *A. indica* plantations. The results demonstrate a higher C concentration in soil by the *A. auriculiformis* stand. The three main factors that they could identify as influence on the soil amelioration by tree species are the decay of plant residues (e.g. litter and roots), the establishment of soil microflora and symbionts with roots (e.g. root nodules, soil microbes) and the alteration of microclimate (e.g. soil moisture, temperature in soil and atmosphere) (Tang & Li, 2014). Furthermore, Lawal (2013) suggests that the decomposing properties of the plant tissue play a very important role for the C concentration in the soil. Jha et al. (2014), who were focusing on the mineralization of root C and C stabilization, indicate that *A. indica* has a high potential of SOC stabilization. *A. indica* shows a low decomposition rate of fine roots and thus a higher potential to stabilize the biochemically fixed C pool (Jha, et al., 2014). Also, C input from litter fall is influenced by litter amount and litter decomposition rate which might be higher in *A. indica* compared to *A. mangium* plantations but is also influenced by precipitation (Hardiyanto, et al., 2004; Hasanuzzaman & Hossain , 2014; Leon & Osorio, 2014; Hossain , et al., 2011; Sreejesh, et al., 2011).

Therefore, in the study presented here the effects of biomass on soil C were examined. Profiles for soil testing were taken on three locations on every plot with different local conditions related to biomass. These conditions are subdivided in low, medium and high litter cover, tree and non-tree and low, medium or high root occurrence.

The local conditions of biomass are assumed to have a significant effect only in the first 40 cm of soil and thus, only this range is examined. The TC content of plantation Am 2yr in the depth range from 0-40 cm differs significantly from plantation Am 5yr as well as natural forest class. Plantation Am 5yr varies significantly from the Ai 7yr class. TC content correlates with increasing root occurrence, litter cover and with non-tree to tree sites significantly by coefficients of 0.470, 0.418 and 0.303, respectively. Roots and litter are input sources of C and nutrients for soil. Besides the amount of biomass the turnover rate - which is also dependent on climatic parameters (temperature and moisture) as well as on the quality of the material - is another important factor for the C input. (Leon & Osorio, 2014; Cowie, et al., 2006)

The variance between the TC content in the groups low, medium or high litter cover is significant ($p < 0.05$) between low litter cover and the two latter groups. Additionally, between low, medium and high root occurrence low root differ significantly from the two higher classifications. Like in the case of litter cover between medium and high amount of roots no significant change is given. Between non-tree and tree groups a significant difference is identifiable.

When comparing TC content visually with the influence conditions of biomass in Figure 41 - Figure 43 with depth (Annex: Chap. 16), especially in 0-5, 5-10, 10-20, 20-40 cm the plantation Am 5yr and natural forest show obvious influences of the litter amount on the TC content. Roots affect mainly the natural forest class from the surface to 40 cm depth. In addition, a difference of TC content between medium and high root occurrence can be seen in plantation Ai 7yr and Ai 10yr in the two top layers. Between tree and non-tree groups the greatest effect is in the natural forest class in the top layers. However, also the classes plantation Am 5yr and Ai 10yr show variances at 5-10 cm and 10-20 cm depth, respectively. Plantation Am 2yr shows no influence from root, litter and tree on the TC content. Paul et al. (2002) noted that in the first year after reforestation C from litter input is low and soil C may decrease because of ongoing decomposition of residues in deeper layers. Therefore, the growth rate of trees is important to increase root and litter biomass and to control the microclimate (Paul, et al., 2002). This is in turn dependent on species and environmental conditions (i.e. sunlight). Additionally, the planting space between trees determines the stem density and thus the total biomass per plot, too.

Investigating the correlation between the age of the forest cover and the soil TC content a significant and positive relation by a coefficient of 0.256 including the soil depth from 0-100 cm exists (Annex: Table 46). Moreover, analyses of variance show a variation between the TC content in soil between the forest age classes (0-100 cm, Annex: Table 48), but the difference is only statistically significant between barren land and plantation Am 5yr class. Comparing similar depths between different classes together changes are significant between barren land and natural forest as well as plantation Am 5yr class for 5-10 and 10-20 cm. In 20-40 cm, significant variances occur between plantation Ai 7yr and Am 5yr as well as natural forest class which is also distinctive to barren land. Deeper than 40 cm no significant difference between classes can be found. This confirms the assumption that the effects of influencing conditions of biomass and forest age on the TC content in the soil disappear with depths greater than 40 cm. These results are also reflected if comparing TC content in each single class with the different depths. Significant variations between different depths mostly can be found between the layers of 0-40 cm to 40-60 cm.

The results indicate that tree species and the influence of biomass are important factors besides forest age on the C concentration in soil. Furthermore, human impact is a major disruptive factor on plantations as well as natural forest in the research area. Conversion of barren land to plantation or natural forest succession would have a positive effect on the C content and other soil properties.

5.2. Effect of Soil Properties on Soil C

The results show that the soil stores a higher proportion of C compared to biomass in the research area. Besides the effect of living and dead biomass on the soil TC content, soil properties are also imperative for the C sequestration potential. Figure 23 shows the importance of variables on the TC content in soil.

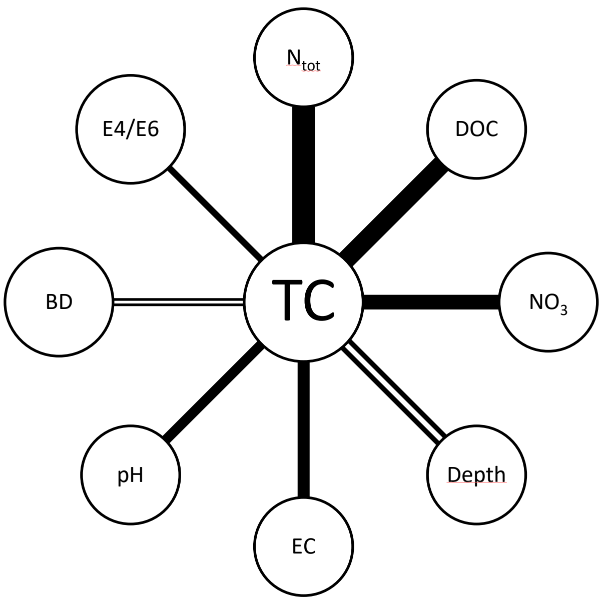

Figure 23: Most important factors that significantly correlate with the TC content in soil. Line width indicates strength of correlation. Single lines demonstrate positve and double lines negative correlation between the soil properties and the TC content.

TC content correlates significantly and positively with N_{tot} content with a coefficient of 0.839. Thus, N_{tot} is the most important factor which correlates with the TC content in the soil. The regression between N_{tot} and TC content explains significantly 70.5% of the square root of the N_{tot} content (Figure 24). This indicates a close relation between TC content and N_{tot} content in the soil. As shown in Figure 39 (Annex) TC and N_{tot} content follow the same pattern in the classes and with depth since C:N ratio doesn't vary a lot.

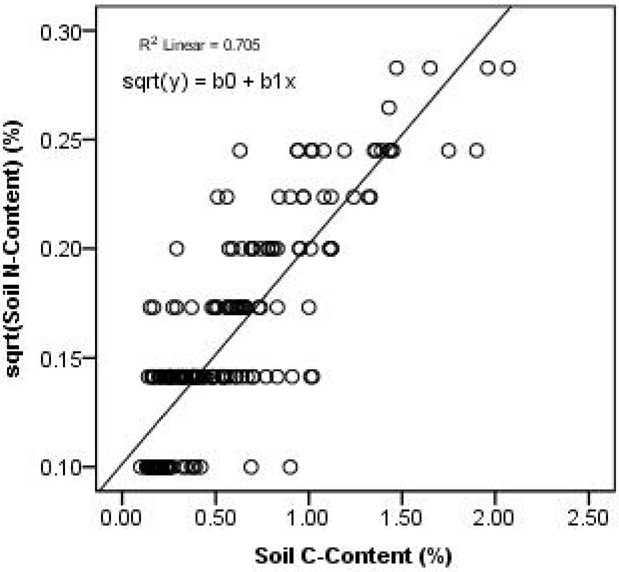

Figure 24: Regression between soil TC content and square root of the N_{tot} content.

Furthermore, DOC (0.682), NO_3 (0.537), pH (0.327) and E4/E6 ratio (0.240) have a positive significant correlation with the TC content. A negative correlation exists between TC content and soil depth (-0.537) as well as bulk density (BD; -0.320). As stated in the results soil nutrient content is very low. Ca, Mg, Na and K correlate positively with TC content but not on a significant level. Ca shows the highest correlation coefficient with 0.536. Ha (2010) also reports a strong significant correlation between C and N in fluvisols in Vietnam. As indicated by Tang and Li (2014), who compared several reforested plantations with different tree species in China for soil physical and chemical properties, nutrient content and C increased in all tested plantations during the study but vary strongly between species. Soil pH hasn't changed over the research period.

In Hoa Thang sand content and bulk density is high because of the sandy soils and soil compaction. From barren land through plantation to natural forest the soil changes from a finer to a coarse texture by an increasing of medium sand fraction. Bulk density decreased from barren land to natural forest. These findings are also in accordance with Tang and Li (2014). They presented that bulk density decreased after 22 years significantly by 4.7% and that the particle size distribution shows a significant rise in the sand fraction in the different tested reforested plantations. Anh (2014) reported a significantly and negatively correlation between bulk density and SOC for North Vietnam.

5.3. Carbon Stock in Hoa Thang

In Hoa Thang mean C sequestration is 91.72 tC/ha overall classes whereby approximately 3/4 of C is stored in the soil. For barren land and agriculture class biomass C has not been calculated. In both classes, C in biomass from crops and grass is existent but is not considered in this study. The natural forest class has the highest C storage potential. The high soil C storage value with 138.71 tC/ha in the natural forest class results from two profiles (1NF1 and 4NF1) close to a tree with high content of C in the layers from 5-40 cm (5-10 cm: 10.48%, 10-20 cm: 7.85%, 20-40 cm: 8.18%) in the profile 1NF1 and 0-5 cm (8.75%) in 4NF1 (Annex: Figure 44). Since these high values can be found in two profiles and are also in line with previous findings of Tran et al. (2012), who detected a C content of 8.0% in the top layer (0-5 cm) at a nearby site in Rung Nhu, this profile's C values remain in the C storage calculation. Sang et al. (2013) found that in the southern region in Vietnam *A. mangium* (7-15yr) stores 80.4 tC/ha and secondary regrowth forest 66.7 tC/ha in biomass and soil from 0-30 cm. This thesis here found out that in Hoa Thang the 5-year-old *A. mangium* plantation and natural forest have a C storage capacity in biomass and soil (0-30 cm) of 105.86 tC/ha and 98.34 tC/ha (Table 17), respectively which is higher than in the comparative study of Sang et al. (2013). Nguyen (2012) analyzed biomass in Yok Don National Park in the Central Highland of Vietnam by satellite analyses and presented for poor forest and shrub, and for dry forest 33.56 and 153.49 t/ha biomass which is equal to 15.77 and 72.14 tC/ha, respectively. This is in the range of the findings of this thesis where C in biomass is between 10.24 to 40.16 tC/ha. Dong et al. (2014) reported for Me Linh Biodiversity Station in North Vietnam for biomass and soil in two types of natural forest succession of 7-15 years a C storage of 122.41 and 165.14 tC/ha. In Me Linh Biodiversity Station soil is the larger C pool with storing approximately 2/3 of C. This is relatively less C storage in soil than in the Arenosols in Hoa Thang. For South Vietnam Tran et al. (2015) found a C storage potential of *Melaleuca* peat swamp on clay soil of 246.96 to 784.68 tC/ha. They indicate that programmes (such as the 5 Million Hectare Reforestation Programme) for reforestation are implemented mainly in the upland region but should also try to promote the potential of other ecosystems because of a higher C storage capacity (Tran, et al., 2015). Compared to the results here, where forest areas store between 67.68 and 157.05 tC/ha in biomass and soil, the *Melaleuca* peat swamp can store 2 to 6 times more and thus has a higher value for the C storage.

However, in the research area *A. mangium* plantations have a high potential to sequester C, seeming to perform best under the environmental conditions in Hoa Thang. *A mangium* is a leguminous tree and thus has the ability to fix N in soil (Leon & Osorio, 2014; Chaer, et al., 2010). Soil C correlates significantly and positively with N_{tot} in soil. This can be a main reason in the proportionally higher C concentration in the *A. mangium* (Am 2yr and Am 5yr) compared to *A. indica* (Ai 7yr and Ai 10yr) plantations.

Table 17: Summary of C storage potential of biomass and soil C pools and total C storage capacity for the classes: Barren: Barren land; Am: Acacia mangium*; Ai:* Azadirachta indica*; nForest: Natural forest.*

Class	Biomass C (tC/ha)	Soil C (tC/ha)	Total C (tC/ha)
Barren Land	-	49.59	49.59
Am 2yr	10.24	57.44	67.68
Am 5r	35.86	117.75	153.61
Ai 7yr	40.16	58.65	98.81
Ai 10yr	39.83	70.88	110.71
Natural forest	18.34	138.71	157.05
Agriculture	-	64.57	64.57
Mean	18.05	73.67	91.72

For the C stock calculation in Hoa Thang in 2016 a regression between C storage and age of the plantation and barren land data was conducted (Figure 25). This leads to a correction of the C storage to mitigate the tree species' influence on the plantation classes since in every plantation class only one species is represented. With the formula from the regression C storage for every plantation age class was recalculated and used for the C stock estimation as well as for the C storage capacity map (Figure 25; Figure 26). The map shows the special distribution of the C storage capacity. The huge area occupied by low (49.59 tC/ha) and high (157.05 tC/ha) C storage values is clearly visible because of the spatial extent of the corresponding class of barren land and natural forest.

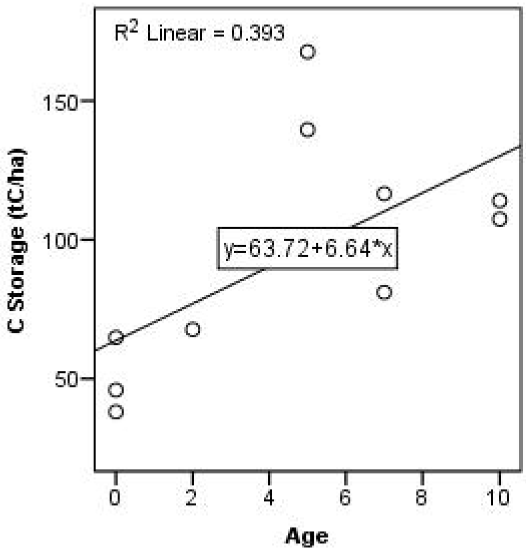

Figure 25: Regression between age and C storage for the correction of tree species influence on the plantation age class.

In 2016 total C stock in Hoa Thang was 2.182 Mt on 24,048.35 ha (Table 18). The largest C stock was stored in the natural forest class occupying an area of 7,749.61 ha (32.23%) with an estimated storage of 1.217 Mt and 55.78% of the total C stock of Hoa Thang. The second largest C pool was barren land with 12,810 ha (53.27%) and stored 0.635 Mt of C or 29.11% of the total stock. Together, both classes store 84.89% of the C stock in Hoa Thang.

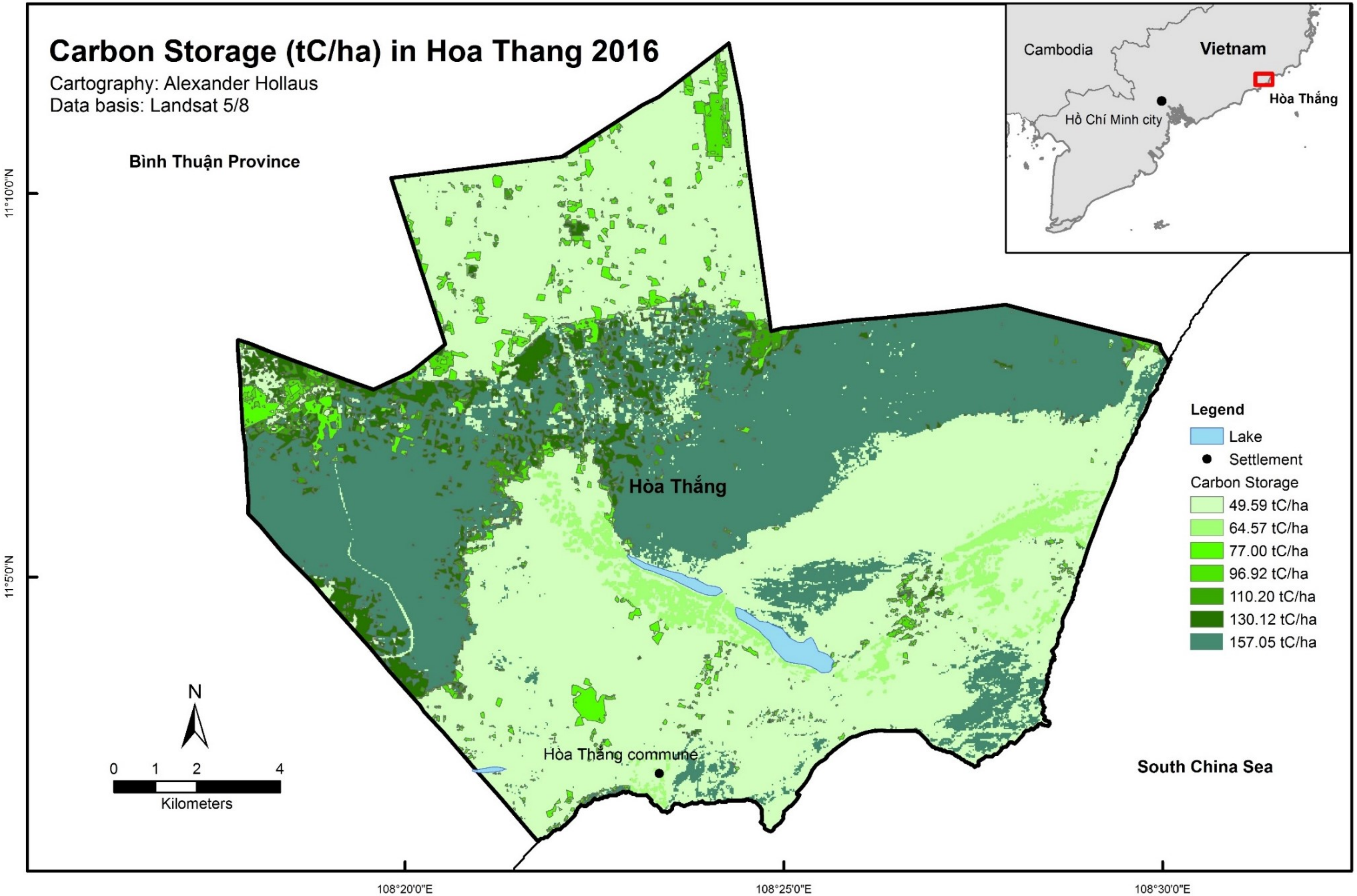

Figure 26: Map of C storage capacity (tC/ha) in Hoa Thang 2016.

Table 18: Total C storage, area occupied by class and C stock in the examined classes in Hoa Thang 2016.

Land Use Class	C Storage (tC/ha)	Area (ha)	C Stock (Mt)
Plantation 5yr	96.92	360.29	0.035
Plantation 7yr	110.20	360.55	0.040
Agriculture	64.57	738.72	0.048
Plantation 2yr	77.00	685.37	0.053
Plantation 10yr	130.12	1,187.15	0.154
Barren Land	49.59	12,810.14	0.635
Natural Forest	157.05	7,749.61	1.217
Total	**-**	**24,048.35**	**2.182**

The remaining C stock (15.11%) is spread over the other classes, whereby plantation 10yr stored 0.154 Mt (7.08%; 1,187.61 ha), plantation 2yr 0.053 Mt (2.42%, 685.37 ha), agriculture class 0.048 Mt (2.19%, 738.72 ha), 7yr 0.040 Mt (1.82%. 360.55 ha) and plantation 5yr 0.035 Mt (1.60%, 360.29 ha), respectively (Figure 27; Figure 28).

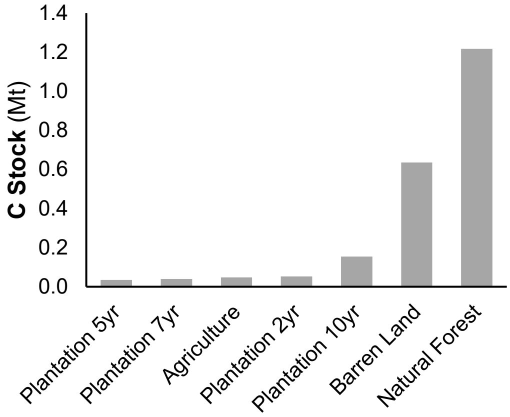

Figure 27: C stock in the examined classes in Hoa Thang in 2016.

Thus, the area occupied by natural forests sequesters the highest amount of C, despite the forest in this area being very degraded because of a strong impact of humans through logging. Barren land is the second largest pool of C because of the area (12,810.14 ha) occupied by this class (Figure 28). Barren land has a high potential to sequester C if it is converted to plantation or by supporting regeneration of a natural forest by protection measures.

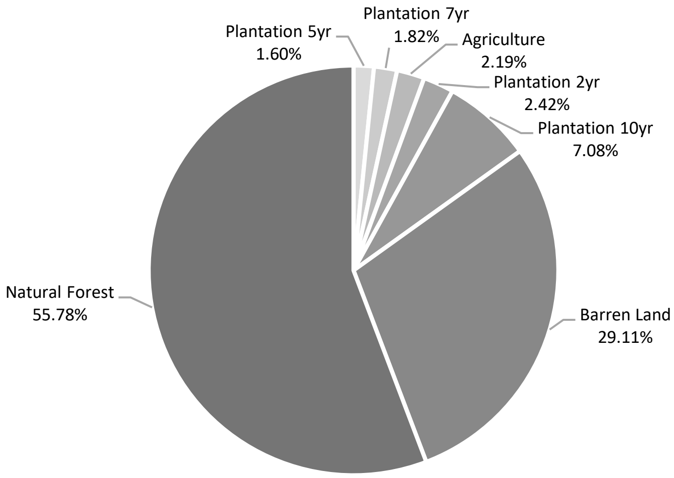

Figure 28: Proportional distribution of the total C stock in the examined classes in Hoa Thang 2016.

6. Conclusion

This thesis examined the effect of reforestation on the C sequestration capacity of a degraded dryland in Binh Thuan, Vietnam. The dryland, represented here by Hoa Thang commune, is prone to land degradation which affects the C storage of this ecosystem. Thus, a comparison of C content and storage between barren land, plantations and natural forest was conducted to investigate the interaction between reforestation and C sequestration and to estimate the C stock in Hoa Thang in 2016.

The study has shown that soil fertility and C storage (tC/ha) of degraded barren land is lower than in the natural forest. In all plantation classes C storage is higher in biomass and soil than in barren land. The biomass C pool increased in percentage more than the soil C pool in all plantations. The yearly increment rate of C was higher in soil than in biomass for the *A. mangium* plantations but lower in *A. indica* stands. After the age of the forest, the tree species used for reforestation and human impacts are a main determinant of the C storage potential. The impact of species is reflected in the higher C storage capacity under *A. mangium* than under *A. indica* plantations. *A. mangium* has the advantage of being able to fix nitrogen. As indicated soil TC and N_{tot} correlate significantly. N_{tot} is the main soil factor correlating with TC content. Human impact is detectable by the fact that the 10-year-old *A. indica* plantation actually has slightly less biomass C than the 7-year-old plantation, due to the thinning of trees and thereby reduction of tree density. Furthermore, in the natural forest mostly woody shrub vegetation dominates the forest because of logging of single trees. As shown for Hoa Thang, the commune has a high potential to sequester C by reforestation or by natural forest succession because it has a large area of barren land. However, linked to other areas in Vietnam C storage capacity on sandy soil is low.

In conclusion, reforestation of degraded drylands has the potential to increase C storage. Nonetheless, this potential for C sequestration may be greater in other ecosystems and thus consideration is needed when deciding on where, in terms of C storage, it would be most effective for hypothetical reforestation programmes to be located. On the other hand, drylands occupy a large area globally and it is important to maintain and to protect the dryland forest. Forest also has economic and social values beyond acting as a carbon sink, such as being a food and income source for timber and non-timber products for humans. Natural forest also supports a high biodiversity, which cannot be offered by monocultural plantations or degraded areas. Plantations may also persist only for a limited time until the trees are cut down and if left uncovered the area will be degraded with a loss of the sequestered soil C.

Further research is recommended in order to understand the potential of different tree species as well as the influence of other factors - such as age, root turnover or litter decomposition – to store C in drylands. Furthermore, the benefits of a natural forest compared to plantations and the potential of agroforestry systems should be analyzed.

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Annex

1. Climate Data

Table 19: Average monthly precipitation and temperature over the climate period from 1979 to 2006 (data: World Bank; Berkeley Earth).

Climate Period 1979-2006. Phan Thiet Weather Station	Temp. Ø (°C)	Precip. Ø (mm)
Jan	25.46	0.38
Feb	25.95	0.18
Mar	27.22	8.39
Apr	28.65	24.06
May	28.86	158.34
Jun	28.01	153.02
Jul	27.35	180.78
Aug	27.32	179.48
Sep	27.28	193.53
Oct	27.21	159.19
Nov	26.81	63.23
Dec	25.91	22.01
Annual Average	27.17	1142.58

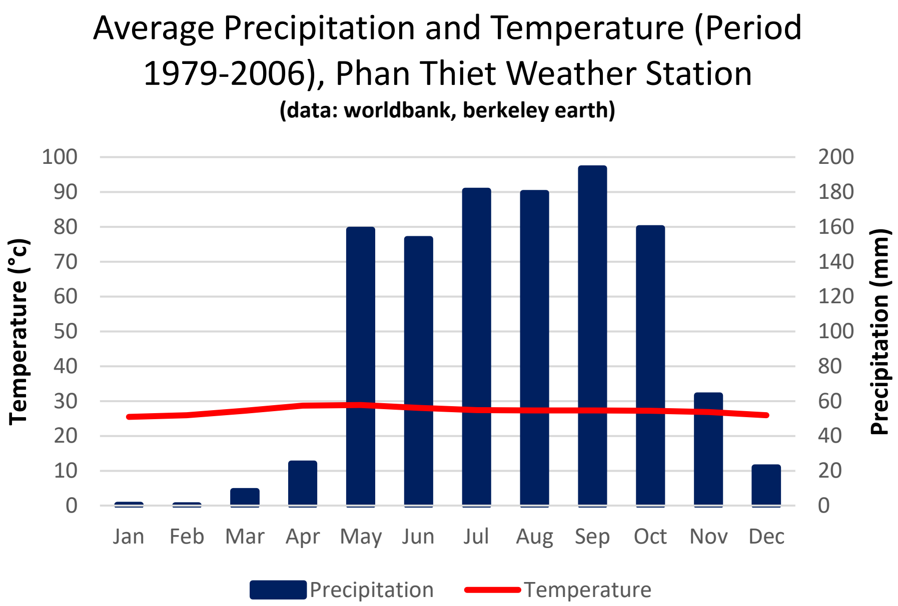


Figure 29: Average precipitation and temperature (Period 1979-2006). Phan Thiet Weather Station (data: World Bank; Berkeley Earth).

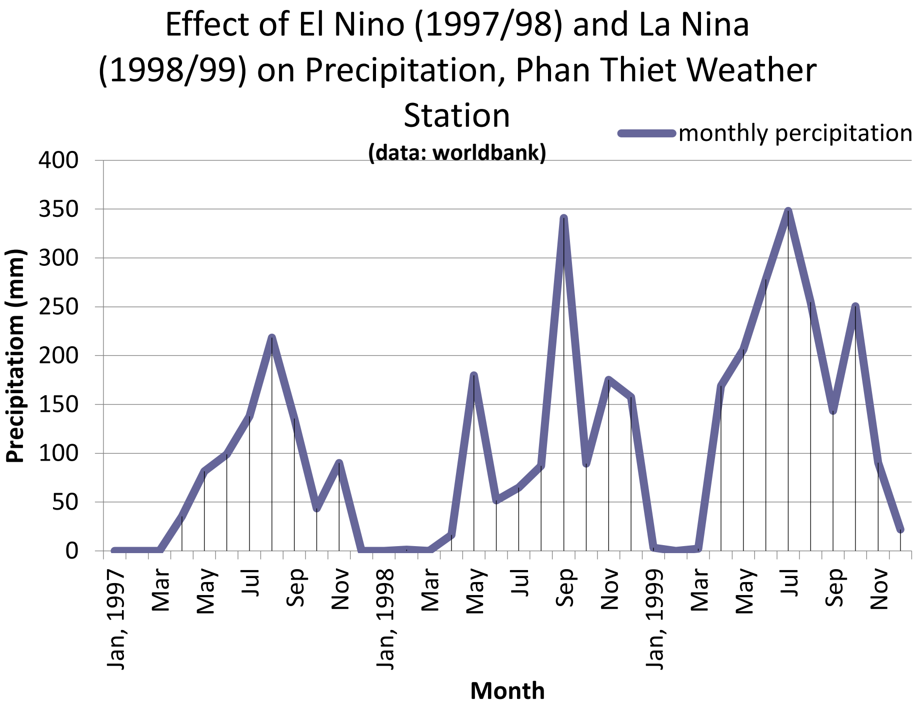


Figure 30: Effect of El Nino and La Nina on precipitation and extent of the dry period at Phan Thiet Weather Station. Dry period lasts in the El Nino year (1997/98) at least for 5 months. In the La Nina year (1998/99) the dry period covers only 3 months of the year. Furthermore. annual precipitation changed between the different ENSO years from 840 mm in 1997 to 1768 mm in 1999 (data: World Bank; Berkeley Earth).

2. Natural Forest (NF, Rung Nhu) Species List

Table 20: Species list of Rung Nhu representing the natural forest class. List communicated with Ministry of Agriculture and Rural Development. Binh Thuan (December 2016).

Family	Species	Vietnamese name
Bignoniaceae	Fernandoa serrata (Dop) Steen.	Sò đo
Fabaceae	Alysicarpus vaginalis (L.) DC.	Vảy ốc
Fabaceae	Dalbergia spinosa Roxb.	Trắc gai
Ochnaceae	Gomphia serrata (Gaertner) Kanis	Mai cánh lõm
Randia spinosa	Randia spinosa Bl.	Găng gai
Lythraceae	Lagerstroemia calyculata Kurz.	Săng lẻ
Sapindaceae	Dimocarpus longan Lour.	Nhãn rừng
Lythraceae	Lagerstroemia speciosa (L.) Pers.	Bằng lăng nước
Tiliaceae	Grewia eriocarpa Juss	Cò ke
Fabaceae	Pterocarpus macrocarpus Kurz	Giáng hương
Fabaceae	Dialium cochinchinensis Pierre	Xoay
Fabaceae	Sindora siamensis Teysm. ex Miq	Gõ mật
Fabaceae	Afzelia xylocarpa (Kurz.) Craib	Gõ đỏ
Hypericaceae	Cratoxylon formosum (Kurz.) Gagnep.	Thành ngạnh
Dipterocarpaceae	Shorea siamensis Miq.	Cẩm liên
Dipterocarpaceae	Dipterocarpus obtusifolius Teusm ex Miq.	Dầu trà beng
Chrysobalanaceae	Parinari Annamensis Hance	Cám
Burseraceae	Canarium album Rausch	Cà na
Caesalpiniaceae	Peltophorum pterocarpum (DC.) Back.	Lim xẹt
Meliaceae	Azadirachta indica	Cóc hành

3. Forest and other Wooded Land Definition

Forest (Chazdon, et al., 2016):

- FAO (2000): Land with tree crown cover (or equivalent stocking level) of more than 10 % and area of more than 0.5 ha. The trees should be able to reach a minimum height of 5 m at maturity in situ. May consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground; or open forest formations with a continuous vegetation cover in which tree crown cover exceeds 10 %. Young natural stands and all plantations established for forestry purposes which have yet to reach a crown density of 10 % or tree height of 5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes but which are expected to revert to forest
- UNFCCC Change (2002) A minimum area of land of 0.05–1.0 ha with tree crown cover (or equivalent stocking level) of more than 10–30 % with trees with the potential to reach a minimum height of 2–5 m at maturity in situ. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown cover of 10–30 % or tree height of 2–5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest

Other wooded land:

- FAO (2000): Refer to vegetation types where the dominant woody elements are shrubs i.e. woody perennial plants, generally of more than 0.5 m and less than 5 m in height on maturity and without a definite crown. The height limits for trees and shrubs should be interpreted with flexibility, particularly the minimum tree and maximum shrub height, which may vary between 5 and 7 meters approximately.

4. NDVI Change Analyses Script for Python

```
##############################
#Author: Alexander Hollaus           #
#Script: NDVI Change Analyses     #
#Year: 2016                                 #
##############################


import time
import sys
import arcpy, string, sys
from arcpy import env
from arcpy.sa import *
import math
from optparse import OptionParser

sys.stdout.flush()
arcpy.CheckOutExtension("spatial")
arcpy.env.overwriteOutput = True

print 'set working directory'

for e in ['2002','2004','2005','2006','2007','2008','2009','2010','2011','2015','2016','2017']:

        arcpy.env.workspace = r'C:\viet\LS'+e
        folders = arcpy.ListWorkspaces()
        print 'load images'
        vadmin1 = 'C:/viet/HTStudyarea.shp'
        outdir = r'C:\viet\LS'+e

        bd4 = r'bandr.tif'
```

```
        bd5 = r'bandn.tif'

        print 'preprocessing'

        j=3
        for i in [bd4, bd5]:

                j=j+1
                suffix=str(j)

                bdscale=arcpy.sa.Float(Raster(i) * 1)
                print 'completed scale'
                print 'start set range; x <0.0 to 0.0'
                bda= Con(bdscale  < 0.0, 0.0, bdscale)
                bd= Con(bda  > 10000, 10000, bda)
                print 'completed set range - start clipping'
arcpy.Clip_management(in_raster=bd, out_raster='bd'+suffix+'cl.tif', in_template_dataset=vadmin1, nodata_value='0',
clipping_geometry='ClippingGeometry', maintain_clipping_extent='maintain_extent')

                print 'completed clipping band %s' %(suffix)

        bdred= 'bd4cl.tif'
        bdnir= 'bd5cl.tif'

        print 'finish with clipping'

        time.sleep(20)
        print 'sleep time is over'

        result = r'C:\viet\ndvi\NDVI'+e+'.tif'
        NIR = bdnir
        Red = bdred

        NIR_out = 'NIR.tif'
        Red_out = 'Red.tif'

        arcpy.CopyRaster_management(NIR, NIR_out)
        print 'Copied NIR band as raster'
        arcpy.CopyRaster_management(Red, Red_out)
        print 'Copied Red band as raster'

        Num = arcpy.sa.Float(Raster(NIR_out) - Raster(Red_out))
        Denom = arcpy.sa.Float(Raster(NIR_out) + Raster(Red_out))
        NIR_eq = arcpy.sa.Divide(Num, Denom)
        print 'Dividing'

        NIR_eq.save(result)
        print 'Successful, year '+e

print 'change analyses'

arcpy.env.workspace = r'C:\viet\ndvi'

x= ['2002','2004','2005','2006','2007','2008','2009','2010','2011','2015','2016','2017']
y= ['2004','2005','2006','2007','2008','2009','2010','2011','2015','2016','2017']

for e, j in zip(x, y):

        print e
        print j
        ndvia = 'ndvi'+e+'.tif'
```

```
        ndvib = 'ndvi'+j+'.tif'

        results = 'NDVI'+e+j+'.tif'
        change = arcpy.sa.Float(Raster(ndvia) - Raster(ndvib))
        change.save(results)
        print 'Finish'+e+'_'+j


print 'THE END'
```

5. Shimadzu TOC-V_{CPH} Calibration Curve for TC Determination in Laboratory of Faculty of Chemistry of VNU-HUS Hanoi, Vietnam

Table 21: Standards for the calibration curve for the TC determination in Hanoi.

KHP-Standards for Calibration Curve			
Std. No	Weight (mg)	C Conc. (mg)	Mean CNV
1	1	0.470498	73.39
2	2	0.940996	135.4
3	5	2.35249	317.2
4	10	4.70498	591.7

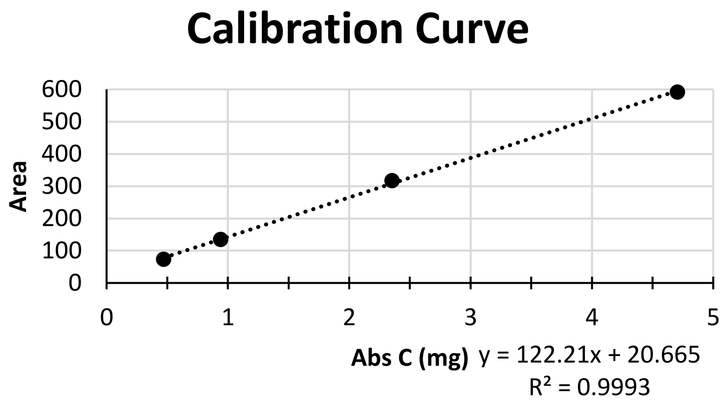


Figure 31: Calibration curve for the Shimadzu TOC-V_{CPH} for TC determination in Hanoi.

6. Biomass Distribution on a Percentage Basis in the Tree Compartments

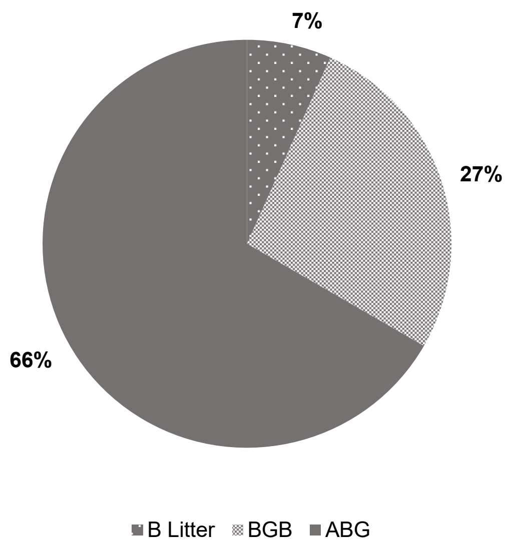


Figure 32: Biomass distribution in the compartments of AGB, BGB and B_{litter} in the natual forest class.

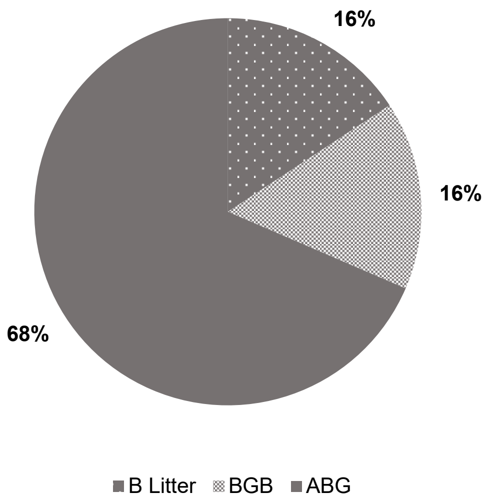


Figure 33: Biomass distribution in the compartments of AGB, BGB and B_{litter} in the plantation Am 2yr class.

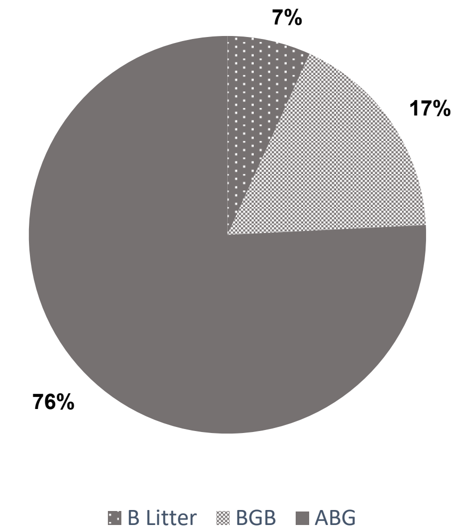


Figure 34: Biomass distribution in the compartments of AGB, BGB and B_{litter} in the plantation Am 5yr class.

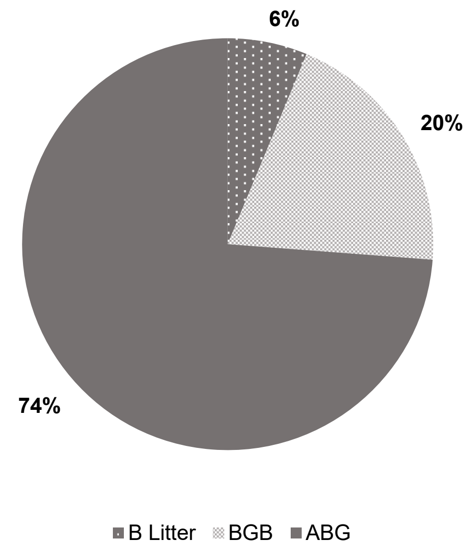


Figure 35: Biomass distribution in the compartments of AGB, BGB and B_{litter} in the plantation Ai 7yr class.

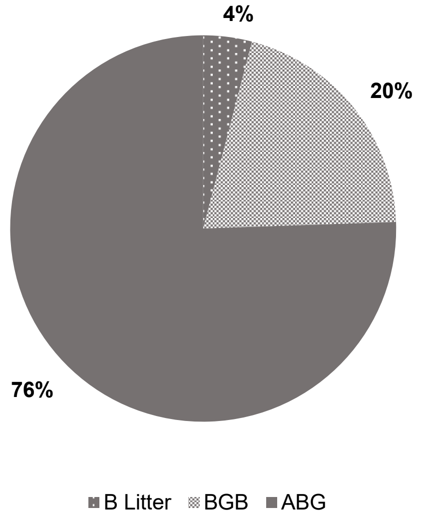


Figure 36: Biomass distribution in the compartments of AGB, BGB and B_{litter} in the plantation Ai 10yr class.

7. Soil pH in the three Cluster East, Central and West

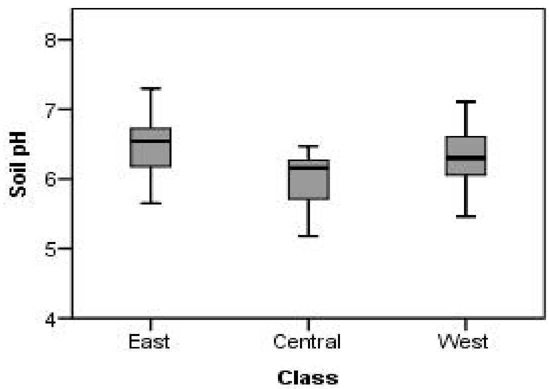


Figure 37: Boxplot of Soil pH_{H2O} in the three cluster east, west and central which are characterized by different soil colours.

8. Soil EC – p*H* Correlation

Table 22: Test of normality for soil EC and pH

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
EC uScm	0.218	212	0.000	0.647	212	0.000
pH H2O	0.051	212	0.200*	0.956	212	0.000

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

Table 23: Spearman correlation between soil EC and pH

Correlations

			pH H2O	EC uScm
Spearman's rho	pH H2O	Correlation Coefficient	1.000	0.566**
		Sig. (2-tailed)	.	0.000
		N	212	212
	EC uScm	Correlation Coefficient	0.566**	1.000
		Sig. (2-tailed)	0.000	.
		N	212	214

**. Correlation is significant at the 0.01 level (2-tailed).

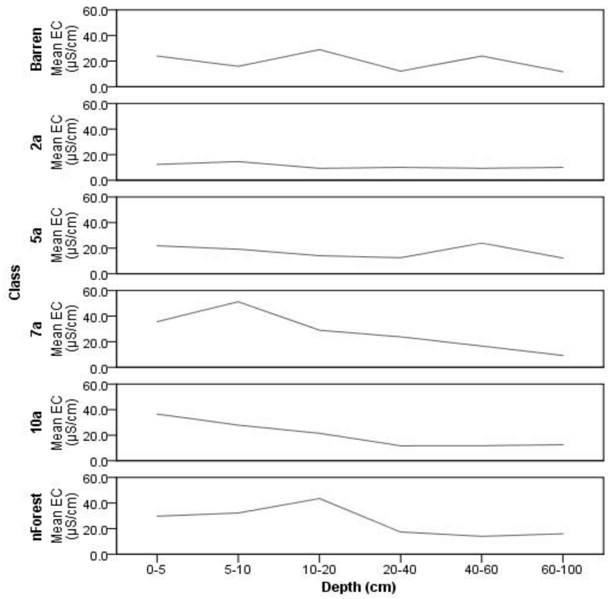


Figure 38: Profile of soil EC between 0-100 cm depth.

9. Anions and Cations

Table 24: Summary of anions and cations. Min., mean, max. and standard deviation for Barren: Barren land; Ai: Acacia indica; nForest: Natural forest.

Class		F (mg/l)	Cl (mg/l)	Br (mg/l)	NO_3 (mg/l)	PO_4 (mg/l)	SO_4 (mg/l)	Ca (mg/kg)	Mg (mg/kg)	K (mg/kg)	Na (mg/kg)
Barren	Minimum	0.042	0.024	0.166	0.142	0.090	0.014	2.03	1.60	51.42	4.51
	Mean	0.076	2.583	0.196	0.613	0.296	0.413	2.70	15.70	62.40	6.13
	Maximum	0.128	24.960	0.210	2.159	0.700	1.140	3.37	42.46	86.05	8.26
	SD	0.026	5.054	0.022	0.383	0.109	0.252	0.52	17.52	13.39	1.30
Ai 7yr	Minimum	.	0.700	0.210	0.320	0.260	0.280	.	.	.	.
	Mean	.	2.311	0.210	0.597	0.347	0.438	.	.	.	.
	Maximum	.	11.690	0.210	1.140	0.530	0.770	.	.	.	.
	SD	.	2.868	0.000	0.258	0.090	0.139	.	.	.	.
nForest	Minimum	.	0.730	0.210	0.470	0.250	0.310	10.57	62.23	105.74	8.86
	Mean	.	2.391	0.210	2.142	0.336	0.538	17.15	89.50	109.58	9.41
	Maximum	.	4.520	0.210	7.700	0.540	0.870	23.73	116.76	113.42	9.95
	SD	.	1.349	.	2.301	0.106	0.165	9.31	38.56	5.43	0.77

10. Total Nitrogen Pairwise Comparison

Table 25: Pairwise comparison of N_{tot} between the age classes. Statistic without outliers (N_{tot} >0.30%). Significance p <0.05.

N_{tot} (%)	Barren	Am (2yr)	Am (5yr)	Ai (7yr)	Ai (10yr)	nForest
	Mean	Mean	Mean	Mean	Mean	Mean
0-5	0.02_{a}	$0.02_{a,b}$	0.09_{b}	$0.07_{b,c}$	$0.04_{a,b}$	$0.06_{a,b}$
5-10	0.02_{a}	$0.02_{a,b}$	0.08_{b}	$0.06_{a,b}$	$0.03_{a,b}$	$0.07_{b,c}$
10-20	0.02_{a}	0.02_{a}	0.07_{b}	$0.04_{a,b}$	$0.04_{a,b}$	$0.05_{a,b}$
20-40	0.02_{a}	0.02_{a}	0.03_{a}	0.02_{a}	0.02_{a}	0.03_{a}
40-60	0.01_{a}	0.01_{a}	0.02_{a}	0.02_{a}	0.02_{a}	0.02_{a}
60-100	0.02_{a}	0.02_{a}	0.01_{a}	0.01_{a}	0.02_{a}	0.02_{a}

Note: Values in the same row and subtable not sharing the same subscript are significantly different at p< 0.05 in the two-sided test of equality for column means. Cells with no subscript are not included in the test. Tests assume equal variances.[1]
1. Tests are adjusted for all pairwise comparisons within a row of each innermost subtable using the Bonferroni correction.

Table 26: Pairwise comparison of N_{tot} between the depth in the classes. Statistic without outliers (N_{tot} >0.30%). Significance p <0.05.

N_{tot} (%)	0-5	5-10	10-20	20-40	40-60	60-100
	Mean	Mean	Mean	Mean	Mean	Mean
Barren	0.02_{a}	0.02_{a}	0.02_{a}	0.02_{a}	0.01_{a}	0.02_{a}
Am (2yr)	0.02_{a}	0.02_{a}	0.02_{a}	0.02_{a}	0.01_{a}	0.02_{a}
Am (5yr)	0.09_{a}	0.08_{a}	$0.07_{a,b}$	$0.03_{b,c}$	0.02_{c}	$0.01_{c,d}$
Ai (7yr)	0.07_{a}	$0.06_{a,b}$	$0.04_{b,c}$	0.02_{c}	$0.02_{c,d}$	$0.01_{c,e}$
Ai (10yr)	0.04_{a}	$0.03_{a,b}$	$0.04_{a,b}$	$0.02_{a,b}$	$0.02_{a,b}$	0.02_{b}
nForest	$0.06_{a,b}$	0.07_{a}	$0.05_{a,b}$	$0.03_{a,b}$	0.02_{b}	$0.02_{b,c}$

Note: Values in the same row and subtable not sharing the same subscript are significantly different at p< 0.05 in the two-sided test of equality for column means. Cells with no subscript are not included in the test. Tests assume equal variances.[1]
1. Tests are adjusted for all pairwise comparisons within a row of each innermost subtable using the Bonferroni correction.

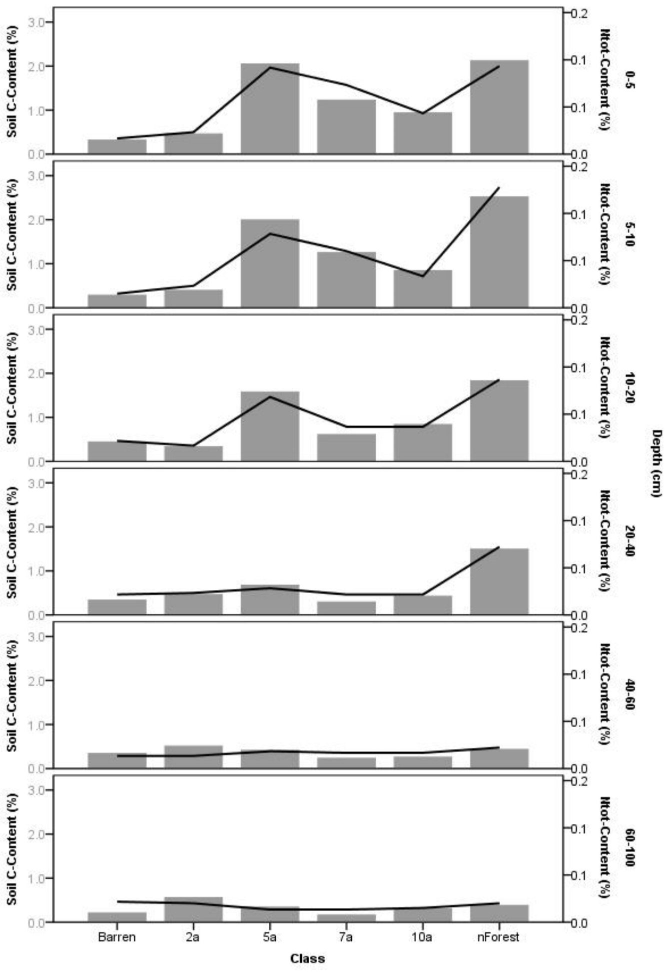


Figure 39: Comparison of C and N_{tot} content in soil between age classes and depth

11. DOC Concentration

Table 27: DOC Concentration in the classes and with depth with pairwise comparison between depth (p <0.05).

DOC (mg/l)	Depth (cm)							
	0-5		5-10		10-20		20-40	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Barren	9.30_a	(1.94)	7.09_a	(1.03)	8.36_a	(1.50)	5.27_a	(1.64)
2a	8.88_a	(2.51)	10.66_a	(1.64)	5.07_a	(0.98)	4.02_a	(0.94)
5a	16.48_a	(2.71)	$15.59_{a,b}$	(3.04)	10.74_a	(1.11)	6.25_b	(0.58)
7a	21.87_a	(4.20)	18.50_a	(2.00)	$15.93_{a,b}$	(3.54)	6.21_b	(0.26)
10a	15.72_a	(1.12)	14.65_a	(2.48)	$10.72_{a,b}$	(1.81)	4.67_b	(0.39)
nForest	35.35_a	(14.89)	31.39_a	(13.54)	34.73_a	(17.12)	11.04_a	(1.88)

Note: Values in the same row and subtable not sharing the same subscript are significantly different at p< 0.05 in the two-sided test of equality for column means. Cells with no subscript are not included in the test. Tests assume equal variances.[1]
1. Tests are adjusted for all pairwise comparisons within a row of each innermost subtable using the Bonferroni correction.

12. Regression of TC Content Results between Laboratory Analyses in Hanoi and Vienna

Variables
CContentvie — Carbon Content Results in % BOKU, Vienna
CContenthan — Carbon Content Results in % HUS, Hanoi
Outliers
Hierarchical cluster analyses to determine outliers by furthest neighbor method (complete linkage) and Euclidean distance in 10 clusters. Clusters with less than five cases were excluded of linear regression.

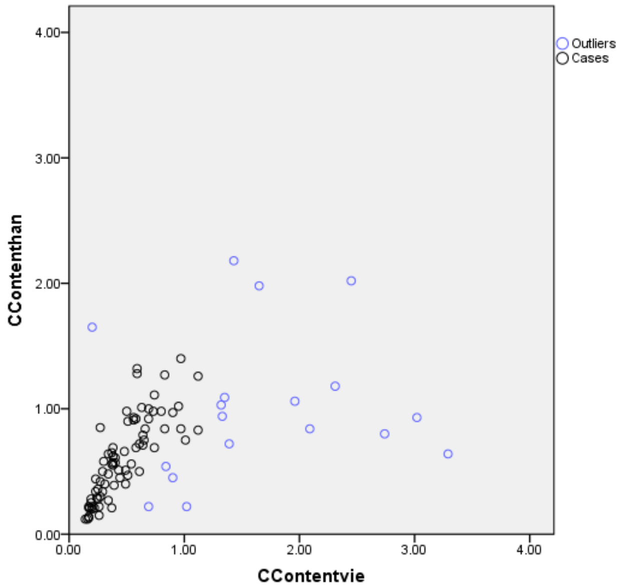


Figure 40: Scatter diagram show results of Outliers analyses.

Table 28: Linear regression between the C content analyses in Hanoi and Vienna.

Descriptive Statistics

	Mean	Std. Deviation	N
CContenthan	0.6087	0.32974	76
CContentvie	0.4750	0.25131	76

Correlations

		CContenthan	CContentvie
Pearson Correlation	CContenthan	1.000	0.811
	CContentvie	0.811	1.000
Sig. (1-tailed)	CContenthan	.	0.000
	CContentvie	0.000	.
N	CContenthan	76	76
	CContentvie	76	76

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	CContentvie[b]	.	Enter

a. Dependent Variable: CContenthan
b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.811[a]	0.657	0.653	0.19435

a. Predictors: (Constant), CContentvie
b. Dependent Variable: CContenthan

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.360	1	5.360	141.896	0.000[b]
	Residual	2.795	74	0.038		
	Total	8.155	75			

a. Dependent Variable: CContenthan
b. Predictors: (Constant), CContentvie

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.103	0.048		2.158	0.034
	CContentvie	1.064	0.089	0.811	11.912	0.000

Coefficients[a]

Model		95,0% Confidence Interval for B		Correlations		
		Lower Bound	Upper Bound	Zero-order	Partial	Part
1	(Constant)	0.008	0.199			
	CContentvie	0.886	1.242	0.811	0.811	0.811

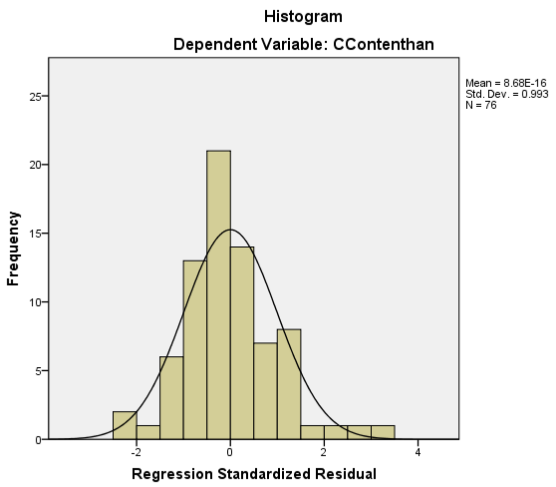
a. Dependent Variable: CContenthan

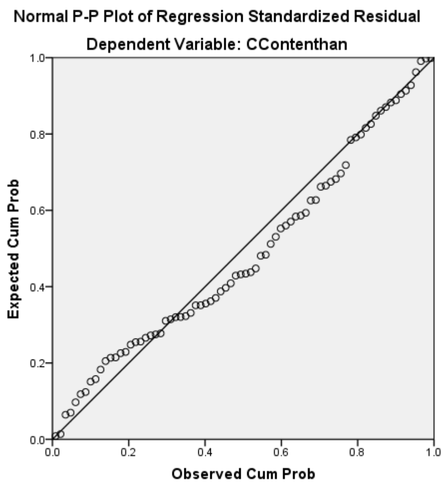
Residuals Statistics[a]

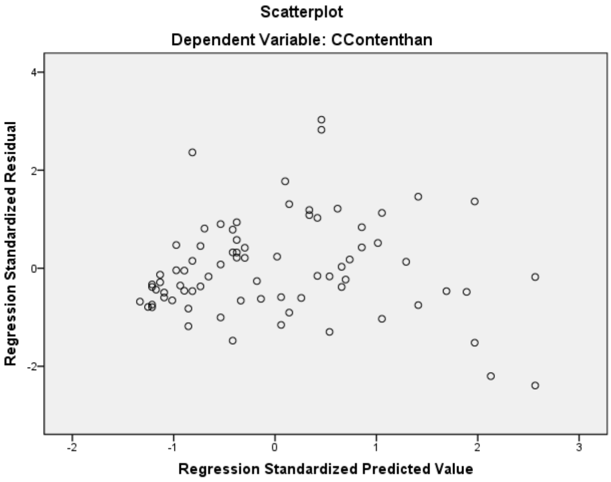
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	0.2523	1.2948	0.6087	0.26733	76
Residual	-0.46478	0.58899	0.00000	0.19305	76
Std. Predicted Value	-1.333	2.567	0.000	1.000	76
Std. Residual	-2.391	3.031	0.000	0.993	76

a. Dependent Variable: CContenthan

Charts







13. Correlation and Regression of TC and N_{tot} Content

Variables
CContentvie Total Carbon Content (Vienna)
SqrtN Square Root of Total Nitrogen Content
Outliers
Outliers are identified by the formula: Upper Outliers >= Q3+(2.2*(Q3-Q1); Lower Outliers <= Q1-(2.2*(Q3-Q1 (Iglewicz & Banerjee , 2001))

Table 29: Linear regression between TC and the square root of N_{tot} content.

Descriptive Statistics

	Mean	Std. Deviation	N
sqrtN	0.1576	0.04837	194
CContentvie	0.558866	0.4035667	194

Correlations

		sqrtN	CContentvie
Pearson Correlation	sqrtN	1.000	0.840
	CContentvie	0.840	1.000
Sig. (1-tailed)	sqrtN	.	0.000
	CContentvie	0.000	.
N	sqrtN	194	194
	CContentvie	194	194

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	CContentvie[b]	.	Enter

a. Dependent Variable: sqrtN
b. All requested variables entered.

Model Summary[b]

					Change Statistics					
Model	R	R Square	Adjusted Square	RStd. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	0.840[a]	0.705	0.703	0.02635	0.705	458.500	1	192	0.000	1.271

a. Predictors: (Constant), CContentvie
b. Dependent Variable: sqrtN

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.318	1	0.318	458.500	0.000[b]
	Residual	0.133	192	0.001		
	Total	0.452	193			

a. Dependent Variable: sqrtN
b. Predictors: (Constant), CContentvie

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95,0% Confidence Interval for B Lower Bound	95,0% Confidence Interval for B Upper Bound	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	0.101	0.003		31.317	0.000	0.095	0.108		
	CContentvie	0.101	0.005	0.840	21.413	0.000	0.091	0.110	1.000	1.000

a. Dependent Variable: sqrtN

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions (Constant)	Variance Proportions CContentvie
1	1	1.811	1.000	0.09	0.09
	2	0.189	3.099	0.91	0.91

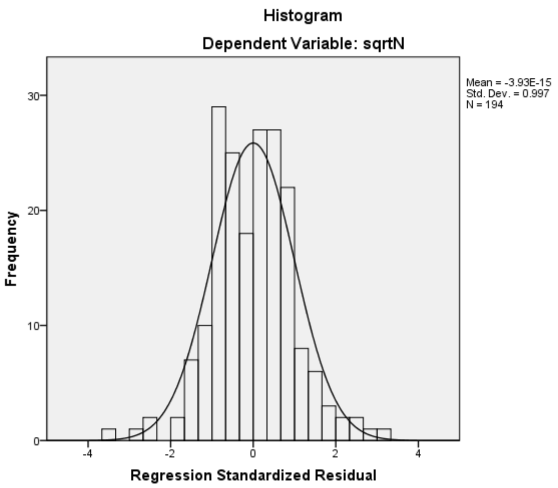
a. Dependent Variable: sqrtN

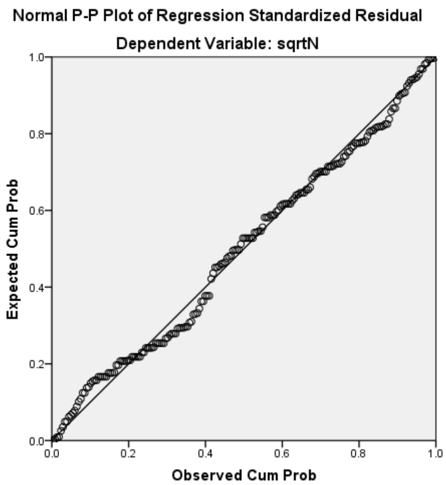
Residuals Statistics[a]

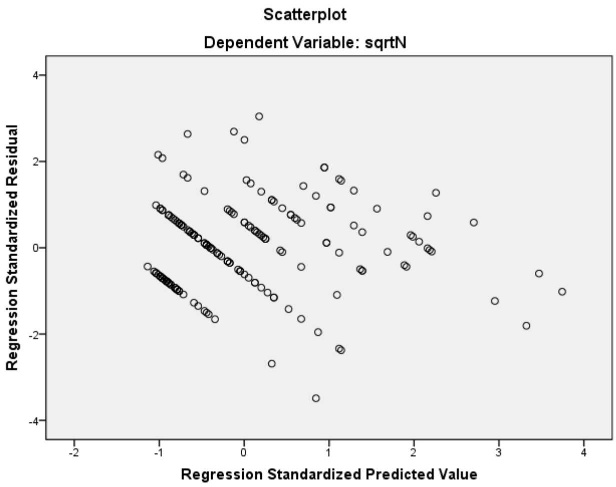
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	0.1114	0.3097	0.1576	0.04061	194
Residual	-0.09193	0.08019	0.00000	0.02628	194
Std. Predicted Value	-1.137	3.744	0.000	1.000	194
Std. Residual	-3.489	3.044	0.000	0.997	194

a. Dependent Variable: sqrtN

Charts







14. Comparison of TC Content between Class and Depth

Table 30: Kruskal-Wallis test between classes (0-5 cm).

Hypothesis Test Summary

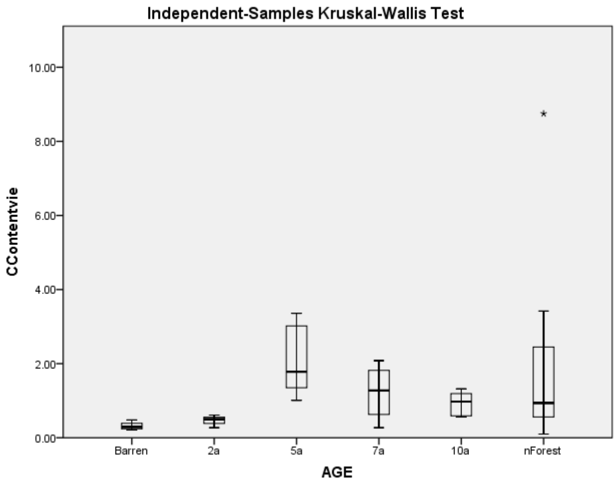
	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of AGE.	Independent-Samples Kruskal-Wallis Test	0.010	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test Summary

Total N	36
Test Statistic	15.122[a]
Degree Of Freedom	5
Asymptotic Sig.(2-sided test)	0.010

a. The test statistic is adjusted for ties.



Pairwise Comparisons of AGE

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Barren-2a	-4.667	7.448	-0.627	0.531	1.000
Barren-10a	-12.583	6.082	-2.069	0.039	0.578
Barren-nForest	-13.667	5.552	-2.462	0.014	0.207
Barren-7a	-14.750	6.082	-2.425	0.015	0.229
Barren-5a	-21.833	6.082	-3.590	0.000	0.005
2a-10a	-7.917	7.448	-1.063	0.288	1.000
2a-nForest	-9.000	7.022	-1.282	0.200	1.000
2a-7a	-10.083	7.448	-1.354	0.176	1.000
2a-5a	-17.167	7.448	-2.305	0.021	0.318
10a-nForest	-1.083	5.552	-0.195	0.845	1.000
10a-7a	2.167	6.082	0.356	0.722	1.000
10a-5a	9.250	6.082	1.521	0.128	1.000
nForest-7a	1.083	5.552	0.195	0.845	1.000
nForest-5a	8.167	5.552	1.471	0.141	1.000
7a-5a	7.083	6.082	1.165	0.244	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table 31: Kruskal-Wallis test between classes (5-10 cm).

Hypothesis Test Summary

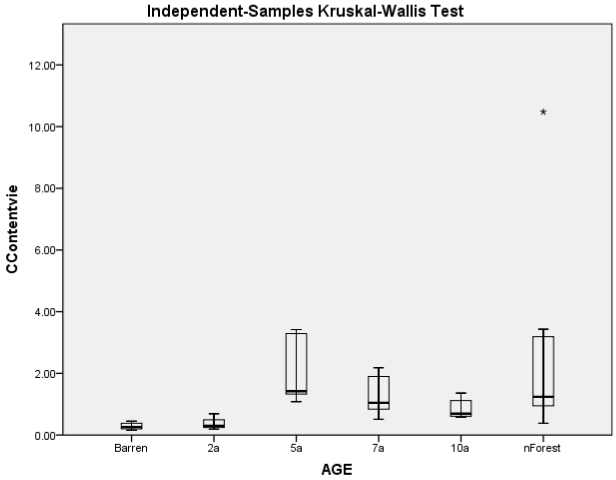
	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of AGE.	Independent-Samples Kruskal-Wallis Test	0.001	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test Summary

Total N	36
Test Statistic	20.866[a]
Degree Of Freedom	5
Asymptotic Sig.(2-sided test)	0.001

a. The test statistic is adjusted for ties.



Pairwise Comparisons of AGE

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Barren-2a	-2.083	7.448	-0.280	0.780	1.000
Barren-10a	-12.333	6.081	-2.028	0.043	0.638
Barren-7a	-16.500	6.081	-2.713	0.007	0.100
Barren-nForest	-18.306	5.551	-3.297	0.001	0.015
Barren-5a	-23.167	6.081	-3.810	0.000	0.002
2a-10a	-10.250	7.448	-1.376	0.169	1.000
2a-7a	-14.417	7.448	-1.936	0.053	0.794
2a-nForest	-16.222	7.022	-2.310	0.021	0.313
2a-5a	-21.083	7.448	-2.831	0.005	0.070
10a-7a	4.167	6.081	0.685	0.493	1.000
10a-nForest	-5.972	5.551	-1.076	0.282	1.000
10a-5a	10.833	6.081	1.781	0.075	1.000
7a-nForest	-1.806	5.551	-0.325	0.745	1.000
7a-5a	6.667	6.081	1.096	0.273	1.000
nForest-5a	4.861	5.551	0.876	0.381	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table 32: Kruskal-Wallis test between classes (10-20 cm).

Hypothesis Test Summary

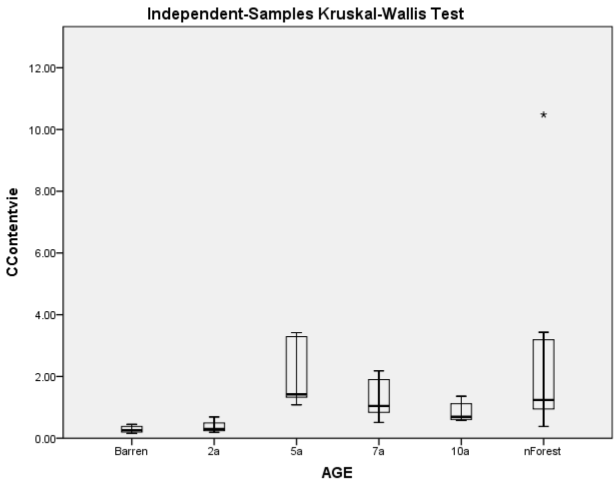
	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of AGE.	Independent-Samples Kruskal-Wallis Test	0.001	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test Summary

Total N	36
Test Statistic	20.866[a]
Degree Of Freedom	5
Asymptotic Sig.(2-sided test)	0.001

a. The test statistic is adjusted for ties.



Pairwise Comparisons of AGE

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Barren-2a	-2.083	7.448	-0.280	0.780	1.000
Barren-10a	-12.333	6.081	-2.028	0.043	0.638
Barren-7a	-16.500	6.081	-2.713	0.007	0.100
Barren-nForest	-18.306	5.551	-3.297	0.001	0.015
Barren-5a	-23.167	6.081	-3.810	0.000	0.002
2a-10a	-10.250	7.448	-1.376	0.169	1.000
2a-7a	-14.417	7.448	-1.936	0.053	0.794
2a-nForest	-16.222	7.022	-2.310	0.021	0.313
2a-5a	-21.083	7.448	-2.831	0.005	0.070
10a-7a	4.167	6.081	0.685	0.493	1.000
10a-nForest	-5.972	5.551	-1.076	0.282	1.000
10a-5a	10.833	6.081	1.781	0.075	1.000
7a-nForest	-1.806	5.551	-0.325	0.745	1.000
7a-5a	6.667	6.081	1.096	0.273	1.000
nForest-5a	4.861	5.551	0.876	0.381	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table 33: Kruskal-Wallis test between classes (20-40 cm).

Hypothesis Test Summary

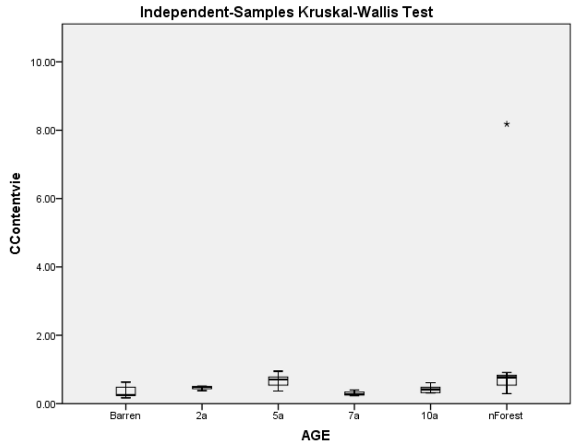
	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of AGE.	Independent-Samples Kruskal-Wallis Test	0.002	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test Summary

Total N	36
Test Statistic	19.388[a]
Degree Of Freedom	5
Asymptotic Sig.(2-sided test)	0.002

a. The test statistic is adjusted for ties.



Pairwise Comparisons of AGE

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
7a-Barren	1.583	6.080	0.260	0.795	1.000
7a-10a	-8.000	6.080	-1.316	0.188	1.000
7a-2a	10.000	7.446	1.343	0.179	1.000
7a-5a	18.250	6.080	3.002	0.003	0.040
7a-nForest	-18.778	5.550	-3.383	0.001	0.011
Barren-10a	-6.417	6.080	-1.055	0.291	1.000
Barren-2a	-8.417	7.446	-1.130	0.258	1.000
Barren-5a	-16.667	6.080	-2.741	0.006	0.092
Barren-nForest	-17.194	5.550	-3.098	0.002	0.029
10a-2a	2.000	7.446	0.269	0.788	1.000
10a-5a	10.250	6.080	1.686	0.092	1.000
10a-nForest	-10.778	5.550	-1.942	0.052	0.782
2a-5a	-8.250	7.446	-1.108	0.268	1.000
2a-nForest	-8.778	7.020	-1.250	0.211	1.000
5a-nForest	-0.528	5.550	-0.095	0.924	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table 34: Kruskal-Wallis test between classes (40-60 cm).

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of AGE.	Independent-Samples Kruskal-Wallis Test	0.357	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test Summary

Total N	36
Test Statistic	5.507[a,b]
Degree Of Freedom	5
Asymptotic Sig.(2-sided test)	0.357

a. The test statistic is adjusted for ties.
b. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

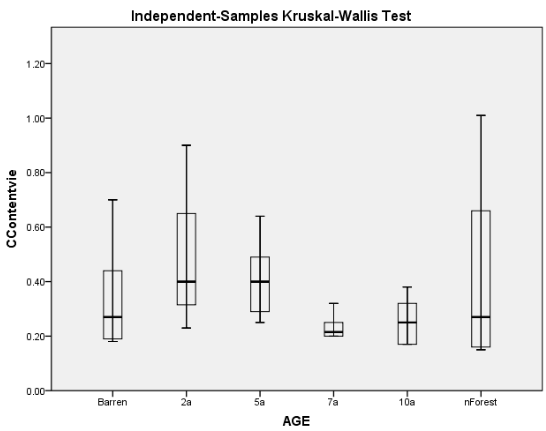


Table 35: Kruskal-Wallis test between classes (60-100 cm).

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of AGE.	Independent-Samples Kruskal-Wallis Test	0.114	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test Summary

Total N	34
Test Statistic	8.882[a,b]
Degree Of Freedom	5
Asymptotic Sig.(2-sided test)	0.114

a. The test statistic is adjusted for ties.
b. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

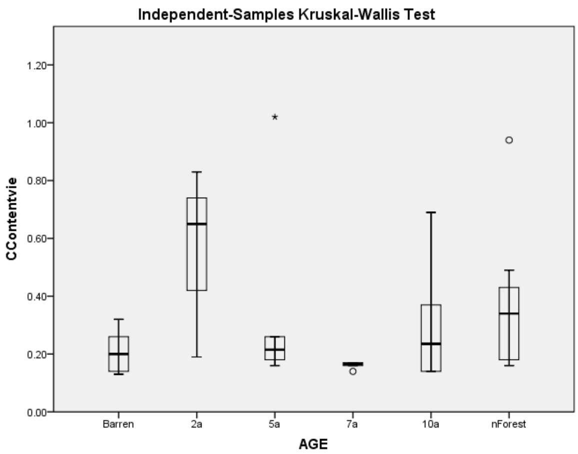


Table 36: Kruskal-Wallis test between depth layers (Barren Land).

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of depth.	Independent-Samples Kruskal-Wallis Test	0.186	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test Summary

Total N	36
Test Statistic	7.504[a,b]
Degree Of Freedom	5
Asymptotic Sig.(2-sided test)	0.186

a. The test statistic is adjusted for ties.
b. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

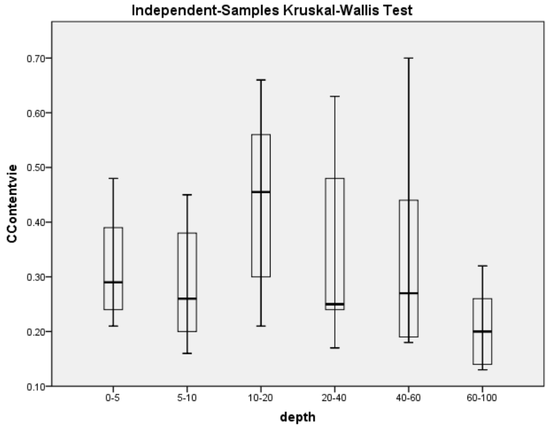


Table 37: Kruskal-Wallis test between depth layers (Am 2yr).

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of depth.	Independent-Samples Kruskal-Wallis Test	0.867	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test Summary

Total N	18
Test Statistic	1.865[a,b]
Degree Of Freedom	5
Asymptotic Sig.(2-sided test)	0.867

a. The test statistic is adjusted for ties.
b. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

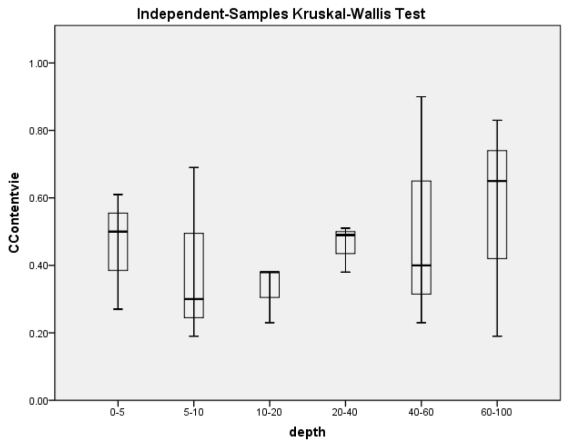


Table 38: Kruskal-Wallis test between depth layers (Am 5yr).

Hypothesis Test Summary

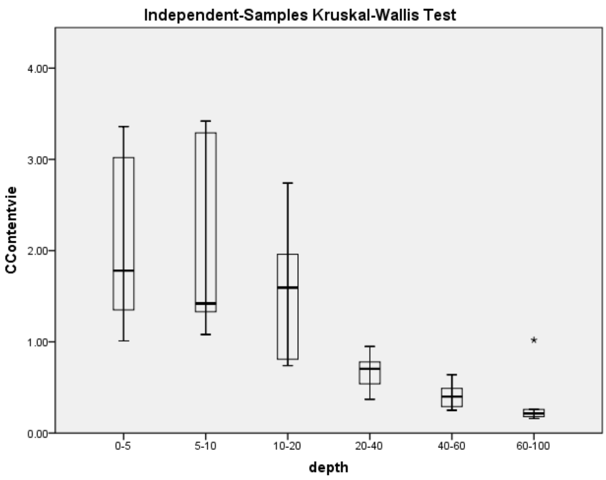
	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of depth.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test Summary

Total N	36
Test Statistic	26.368[a]
Degree Of Freedom	5
Asymptotic Sig.(2-sided test)	0.000

a. The test statistic is adjusted for ties.



Pairwise Comparisons of depth

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
60-100-40-60	3.000	6.082	0.493	0.622	1.000
60-100-20-40	8.083	6.082	1.329	0.184	1.000
60-100-10-20	18.917	6.082	3.110	0.002	0.028
60-100-5-10	21.667	6.082	3.562	0.000	0.006
60-100-0-5	22.333	6.082	3.672	0.000	0.004
40-60-20-40	5.083	6.082	0.836	0.403	1.000
40-60-10-20	15.917	6.082	2.617	0.009	0.133
40-60-5-10	18.667	6.082	3.069	0.002	0.032
40-60-0-5	19.333	6.082	3.179	0.001	0.022
20-40-10-20	10.833	6.082	1.781	0.075	1.000
20-40-5-10	13.583	6.082	2.233	0.026	0.383
20-40-0-5	14.250	6.082	2.343	0.019	0.287
10-20-5-10	2.750	6.082	0.452	0.651	1.000
10-20-0-5	3.417	6.082	0.562	0.574	1.000
5-10-0-5	0.667	6.082	0.110	0.913	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table 39: Kruskal-Wallis test between depth layers (Ai 7yr).

Hypothesis Test Summary

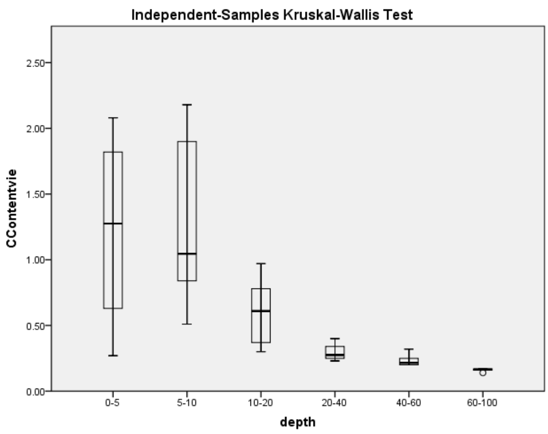
	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of depth.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test Summary

Total N	36
Test Statistic	28.987[a]
Degree Of Freedom	5
Asymptotic Sig.(2-sided test)	0.000

a. The test statistic is adjusted for ties.



Pairwise Comparisons of depth

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
60-100-40-60	7.333	6.078	1.206	0.228	1.000
60-100-20-40	12.000	6.078	1.974	0.048	0.725
60-100-10-20	19.833	6.078	3.263	0.001	0.017
60-100-0-5	24.333	6.078	4.003	0.000	0.001
60-100-5-10	26.500	6.078	4.360	0.000	0.000
40-60-20-40	4.667	6.078	0.768	0.443	1.000
40-60-10-20	12.500	6.078	2.056	0.040	0.596
40-60-0-5	17.000	6.078	2.797	0.005	0.077
40-60-5-10	19.167	6.078	3.153	0.002	0.024
20-40-10-20	7.833	6.078	1.289	0.198	1.000
20-40-0-5	12.333	6.078	2.029	0.042	0.637
20-40-5-10	14.500	6.078	2.385	0.017	0.256
10-20-0-5	4.500	6.078	0.740	0.459	1.000
10-20-5-10	6.667	6.078	1.097	0.273	1.000
0-5-5-10	-2.167	6.078	-0.356	0.722	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table 40: Kruskal-Wallis test between depth layers (Ai 10yr).

Hypothesis Test Summary

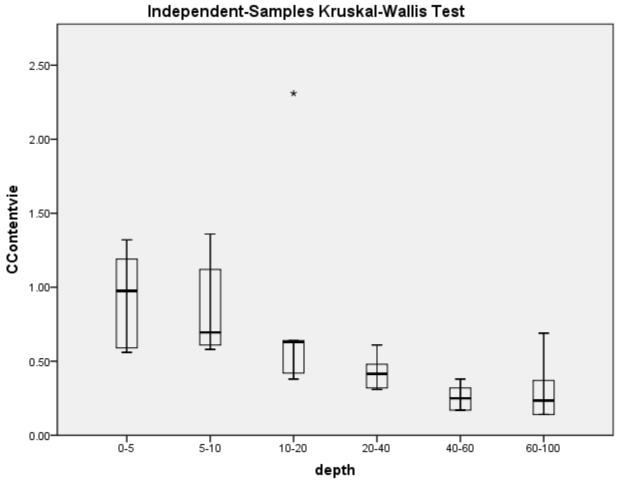
	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of depth.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test Summary

Total N	36
Test Statistic	22.648[a]
Degree Of Freedom	5
Asymptotic Sig.(2-sided test)	0.000

a. The test statistic is adjusted for ties.



Pairwise Comparisons of depth

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
40-60-60-100	-1.750	6.079	-0.288	0.773	1.000
40-60-20-40	7.917	6.079	1.302	0.193	1.000
40-60-10-20	16.000	6.079	2.632	0.008	0.127
40-60-5-10	20.167	6.079	3.317	0.001	0.014
40-60-0-5	20.667	6.079	3.400	0.001	0.010
60-100-20-40	6.167	6.079	1.014	0.310	1.000
60-100-10-20	14.250	6.079	2.344	0.019	0.286
60-100-5-10	18.417	6.079	3.029	0.002	0.037
60-100-0-5	18.917	6.079	3.112	0.002	0.028
20-40-10-20	8.083	6.079	1.330	0.184	1.000
20-40-5-10	12.250	6.079	2.015	0.044	0.658
20-40-0-5	12.750	6.079	2.097	0.036	0.540
10-20-5-10	4.167	6.079	0.685	0.493	1.000
10-20-0-5	4.667	6.079	0.768	0.443	1.000
5-10-0-5	0.500	6.079	0.082	0.934	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table 41: Kruskal-Wallis test between depth layers (Natural forest).

Hypothesis Test Summary

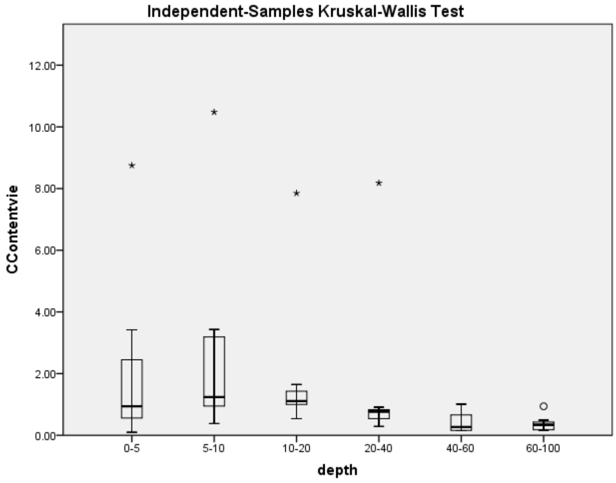
	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of depth.	Independent-Samples Kruskal-Wallis Test	0.002	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test Summary

Total N	52
Test Statistic	18.890[a]
Degree Of Freedom	5
Asymptotic Sig.(2-sided test)	0.002

a. The test statistic is adjusted for ties.



Pairwise Comparisons of depth

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
60-100-40-60	2.452	7.636	0.321	0.748	1.000
60-100-20-40	12.897	7.636	1.689	0.091	1.000
60-100-0-5	17.008	7.636	2.227	0.026	0.389
60-100-10-20	23.508	7.636	3.078	0.002	0.031
60-100-5-10	23.786	7.636	3.115	0.002	0.028
40-60-20-40	10.444	7.143	1.462	0.144	1.000
40-60-0-5	14.556	7.143	2.038	0.042	0.624
40-60-10-20	21.056	7.143	2.948	0.003	0.048
40-60-5-10	21.333	7.143	2.986	0.003	0.042
20-40-0-5	4.111	7.143	0.576	0.565	1.000
20-40-10-20	10.611	7.143	1.485	0.137	1.000
20-40-5-10	10.889	7.143	1.524	0.127	1.000
0-5-10-20	-6.500	7.143	-0.910	0.363	1.000
0-5-5-10	-6.778	7.143	-0.949	0.343	1.000
10-20-5-10	0.278	7.143	0.039	0.969	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

15. Correlation between TC Content and Soil Properties

Table 42: Correlation between TC and soil properties.

Correlations

			CContentvie
Spearman's rho	CContentvie	Correlation Coef.	1.000
		Sig. (2-tailed)	.
		N	214
	depth	Correlation Coef.	-0.537
		Sig. (2-tailed)	0.000
		N	214
	NContentvie	Correlation Coef.	0.839
		Sig. (2-tailed)	0.000
		N	214
	DOC@254	Correlation Coef.	0.682
		Sig. (2-tailed)	0.000
		N	155
	DOC@400	Correlation Coef.	0.647
		Sig. (2-tailed)	0.000
		N	155
	DOC@600	Correlation Coef.	0.511
		Sig. (2-tailed)	0.000
		N	155
	Cl	Correlation Coef.	-0.024
		Sig. (2-tailed)	0.860
		N	58
	F	Correlation Coef.	0.246
		Sig. (2-tailed)	0.493
		N	10
	PO4	Correlation Coef.	0.152
		Sig. (2-tailed)	0.303
		N	48
	SO4	Correlation Coef.	0.238
		Sig. (2-tailed)	0.072
		N	58
	NO3	Correlation Coef.	0.537
		Sig. (2-tailed)	0.000
		N	58
	Br	Correlation Coef.	-0.415
		Sig. (2-tailed)	0.307
		N	8
	EC	Correlation Coef.	0.464
		Sig. (2-tailed)	0.000
		N	214
	pH	Correlation Coef.	0.327
		Sig. (2-tailed)	0.000
		N	212
	Ca	Correlation Coef.	0.536
		Sig. (2-tailed)	0.215
		N	7
	Mg	Correlation Coef.	0.321
		Sig. (2-tailed)	0.482
		N	7
	K	Correlation Coef.	0.250
		Sig. (2-tailed)	0.589
		N	7
	Na	Correlation Coef.	0.357
		Sig. (2-tailed)	0.432
		N	7

Table 43: Correlation between TC content and clusters.

Correlations

			CContentvie
Spearman's rho	CContentvie	Correlation Coefficient	1.000
		Sig. (2-tailed)	.
		N	214
	Cluster	Correlation Coefficient	0.136*
		Sig. (2-tailed)	0.046
		N	214

*. Correlation is significant at the 0.05 level (2-tailed).

Table 44: Correlation between TC content and bulk density.

Correlations

			CContentvie
Spearman's rho	CContentvie	Correlation Coefficient	1.000
		Sig. (2-tailed)	.
		N	214
	Bulk Density	Correlation Coefficient	-0.320**
		Sig. (2-tailed)	0.000
		N	214

**. Correlation is significant at the 0.01 level (2-tailed).

Table 45: Correlation between TC content and E4/E6.

			CContentvie
Spearman's rho	CContentvie	Correlation Coefficient	1.000
		Sig. (2-tailed)	.
		N	214
	E4E6	Correlation Coefficient	0.240**
		Sig. (2-tailed)	0.003
		N	154

16. Relation between TC Content and Site Conditions

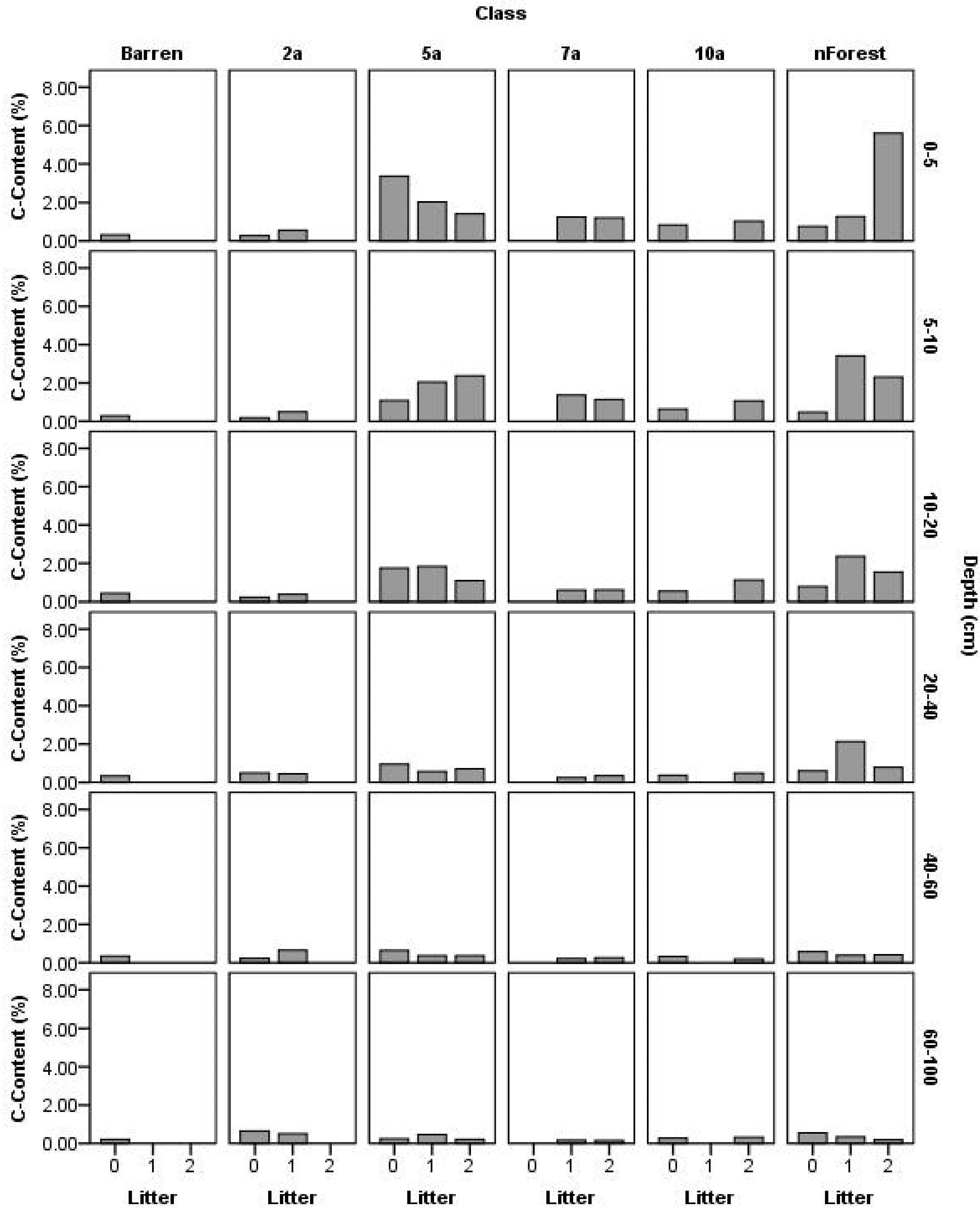


Figure 41: Relation between TC content in soil and litter cover: 0: low; 1: medium; 2: high.

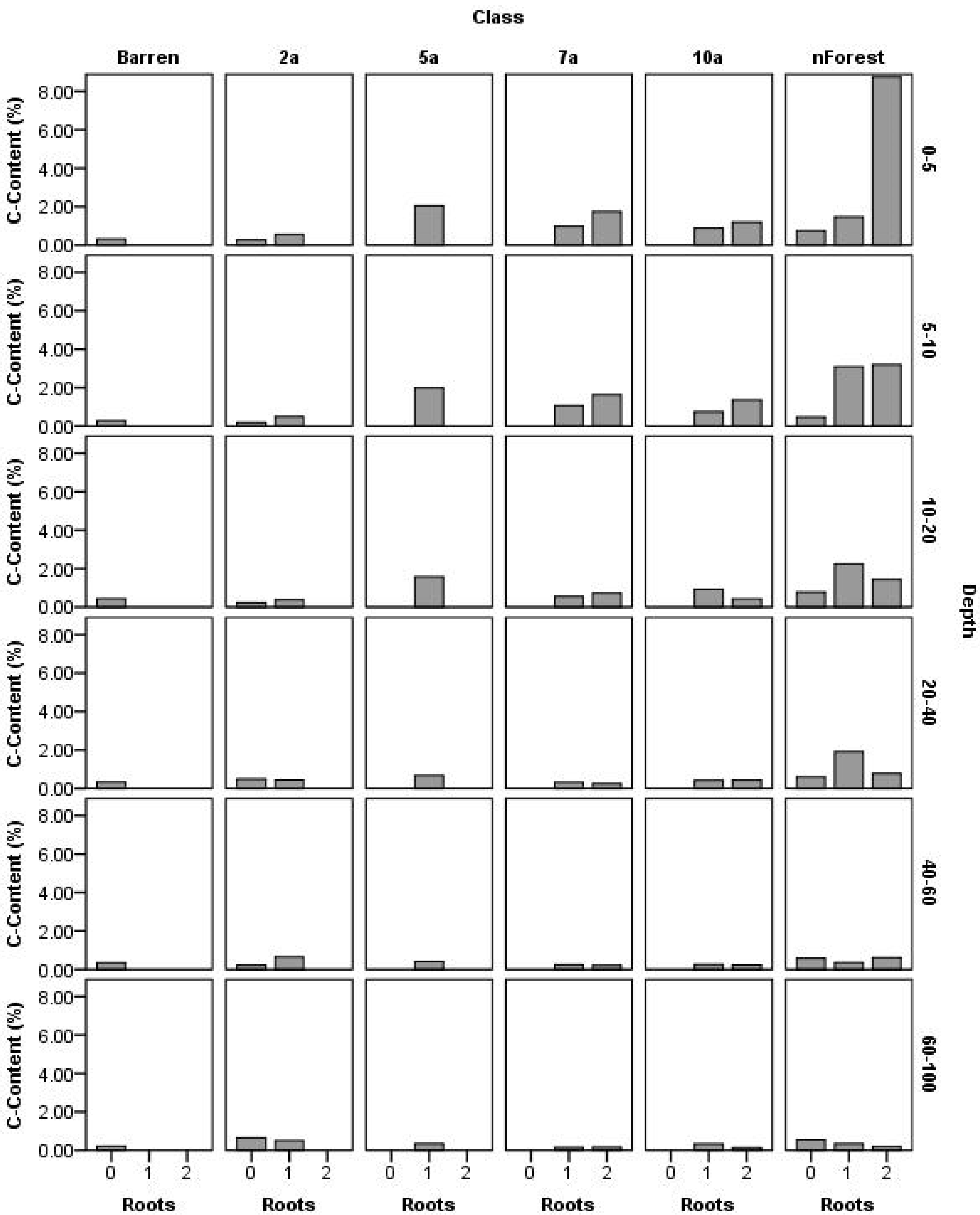


Figure 42: Relation between TC content in soil and root occurance:: 0: low; 1: medium; 2: high.

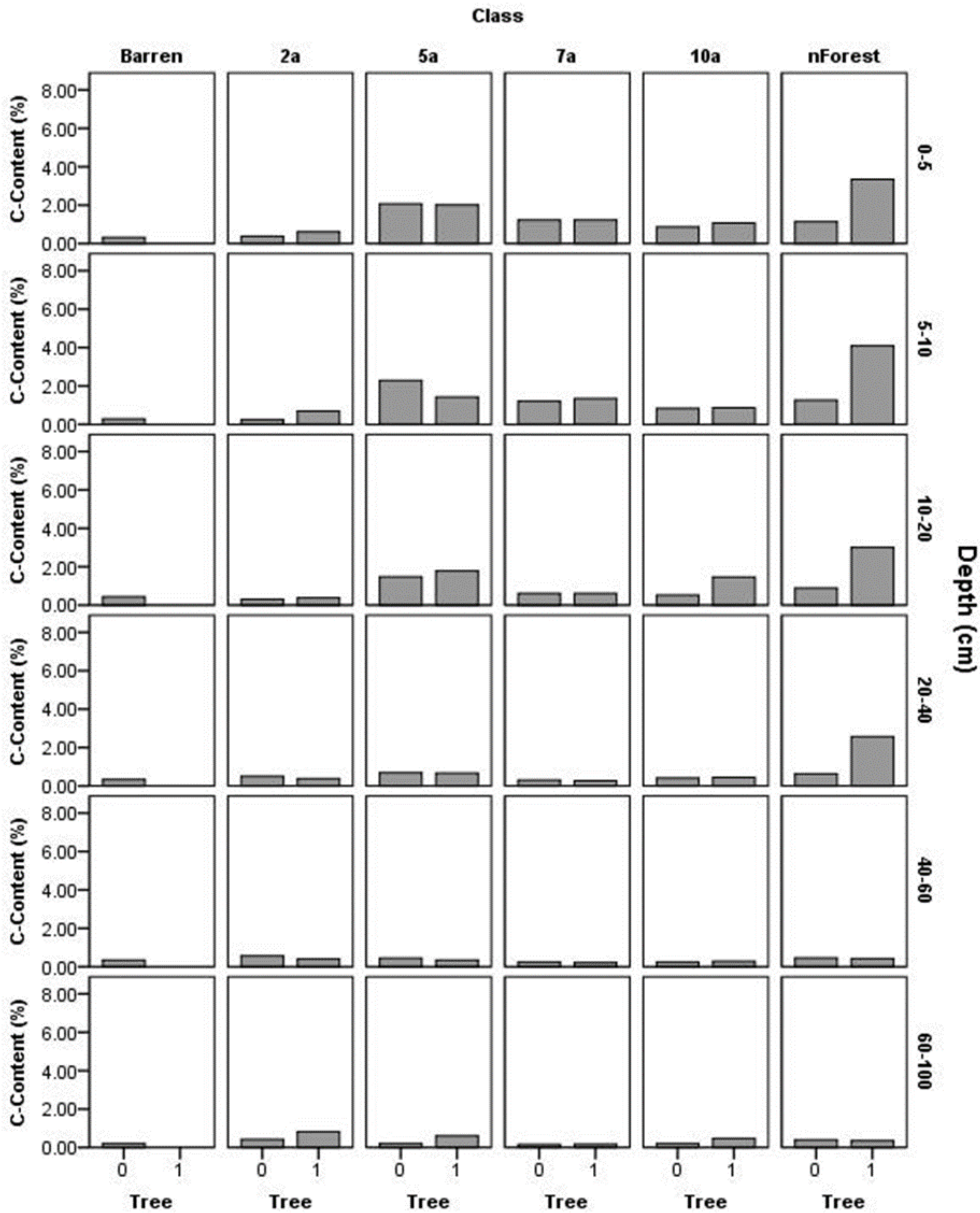


Figure 43: Relation between TC content in soil and tree (1) or non-tree (0) in proximity.

Table 46: Correlation between TC content and site conditions (0-100 cm).

Correlations

0-100cm			CContentvie
Spearman's rho	CContentvie	Correlation Coefficient	1.000
		Sig. (2-tailed)	.
		N	214
	Cluster	Correlation Coefficient	0.136
		Sig. (2-tailed)	0.046
		N	214
	litter	Correlation Coefficient	0.216
		Sig. (2-tailed)	0.001
		N	214
	roots	Correlation Coefficient	0.257
		Sig. (2-tailed)	0.000
		N	214
	AGE	Correlation Coefficient	0.256
		Sig. (2-tailed)	0.000
		N	214
	tree	Correlation Coefficient	0.221
		Sig. (2-tailed)	0.001
		N	214

Table 47: Correlation between TC content and site conditions (0-40 cm).

Correlations

0-40cm			CContentvie
Spearman's rho	CContentvie	Correlation Coefficient	1.000
		Sig. (2-tailed)	.
		N	144
	AGE	Correlation Coefficient	0.402
		Sig. (2-tailed)	0.000
		N	144
	roots	Correlation Coefficient	0.470
		Sig. (2-tailed)	0.000
		N	144
	litter	Correlation Coefficient	0.418
		Sig. (2-tailed)	0.000
		N	144
	tree	Correlation Coefficient	0.303
		Sig. (2-tailed)	0.000
		N	144
	Cluster	Correlation Coefficient	0.184
		Sig. (2-tailed)	0.027
		N	144

Table 48: Kruskal-Wallis test between site conditions (0-40 cm): Class.

Hypothesis Test Summary

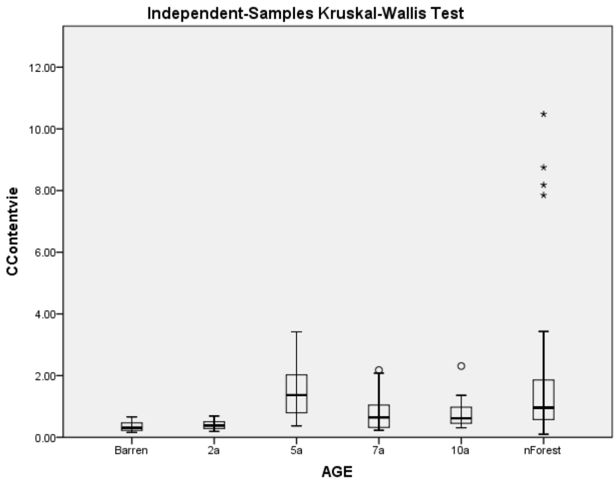
	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of AGE.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test
CContentvie across AGE

Independent-Samples Kruskal-Wallis Test Summary	
Total N	144
Test Statistic	58.050[a]
Degree Of Freedom	5
Asymptotic Sig.(2-sided test)	0.000

a. The test statistic is adjusted for ties.



Pairwise Comparisons of AGE

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Barren-2a	-9.625	14.746	-0.653	0.514	1.000
Barren-7a	-40.438	12.040	-3.359	0.001	0.012
Barren-10a	-43.042	12.040	-3.575	0.000	0.005
Barren-nForest	-63.194	10.991	-5.750	0.000	0.000
Barren-5a	-77.417	12.040	-6.430	0.000	0.000
2a-7a	-30.813	14.746	-2.090	0.037	0.550
2a-10a	-33.417	14.746	-2.266	0.023	0.352
2a-nForest	-53.569	13.903	-3.853	0.000	0.002
2a-5a	-67.792	14.746	-4.597	0.000	0.000
7a-10a	-2.604	12.040	-0.216	0.829	1.000
7a-nForest	-22.757	10.991	-2.070	0.038	0.576
7a-5a	36.979	12.040	3.071	0.002	0.032
10a-nForest	-20.153	10.991	-1.834	0.067	1.000
10a-5a	34.375	12.040	2.855	0.004	0.065
nForest-5a	14.222	10.991	1.294	0.196	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table 49: Kruskal-Wallis test between site conditions (0-40 cm): Roots.

Hypothesis Test Summary

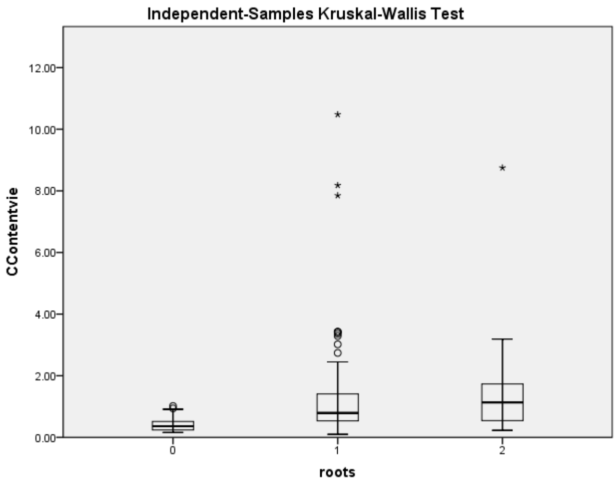
	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of roots.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test
CContentvie across roots

Independent-Samples Kruskal-Wallis Test Summary	
Total N	144
Test Statistic	36.671[a]
Degree Of Freedom	2
Asymptotic Sig.(2-sided test)	0.000

a. The test statistic is adjusted for ties.



Pairwise Comparisons of roots

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
0-1	-47.204	8.199	-5.757	0.000	0.000
0-2	-54.705	12.532	-4.365	0.000	0.000
1-2	-7.501	11.298	-0.664	0.507	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table 50: Kruskal-Wallis test between site conditions (0-40 cm): Litter.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of litter.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.

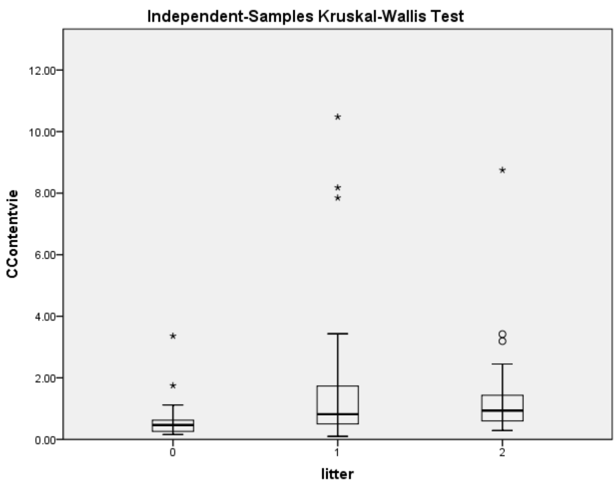
Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Kruskal-Wallis Test
CContentvie across litter

Independent-Samples Kruskal-Wallis Test Summary

Total N	144
Test Statistic	28.014[a]
Degree Of Freedom	2
Asymptotic Sig.(2-sided test)	0.000

a. The test statistic is adjusted for ties.



Pairwise Comparisons of litter

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
0-1	-34.837	8.180	-4.259	0.000	0.000
0-2	-41.805	8.772	-4.766	0.000	0.000
1-2	-6.968	8.772	-0.794	0.427	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table 51: Kruskal-Wallis test between site conditions (0-40 cm): Tree.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of tree.	Independent-Samples Mann-Whitney U Test	0.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

Independent-Samples Mann-Whitney U Test
CContentvie across tree

Independent-Samples Mann-Whitney U Test Summary

Total N	144
Mann-Whitney U	3035.000
Wilcoxon W	4025.000
Test Statistic	3035.000
Standard Error	230.554
Standardized Test Statistic	3.622
Asymptotic Sig.(2-sided test)	0.000

Table 52: Kruskal-Wallis test between site conditions (0-40 cm): Cluster.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CContentvie is the same across categories of Cluster.	Independent-Samples Kruskal-Wallis Test	0.013	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050.

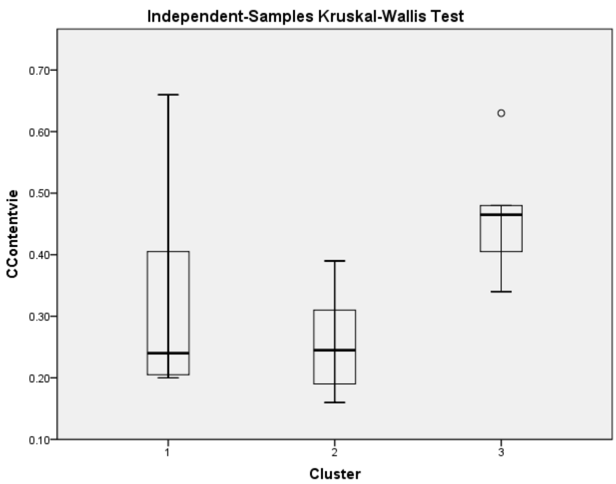
Independent-Samples Kruskal-Wallis Test

CContentvie across Cluster

Independent-Samples Kruskal-Wallis Test Summary

Total N	24
Test Statistic	8.687[a]
Degree Of Freedom	2
Asymptotic Sig.(2-sided test)	0.013

a. The test statistic is adjusted for ties.



Pairwise Comparisons of Cluster

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
2.00-1.00	2.125	3.527	0.602	0.547	1.000
2.00-3.00	-9.875	3.527	-2.800	0.005	0.015
1.00-3.00	-7.750	3.527	-2.197	0.028	0.084

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

17. TC Content Distribution for each Profile

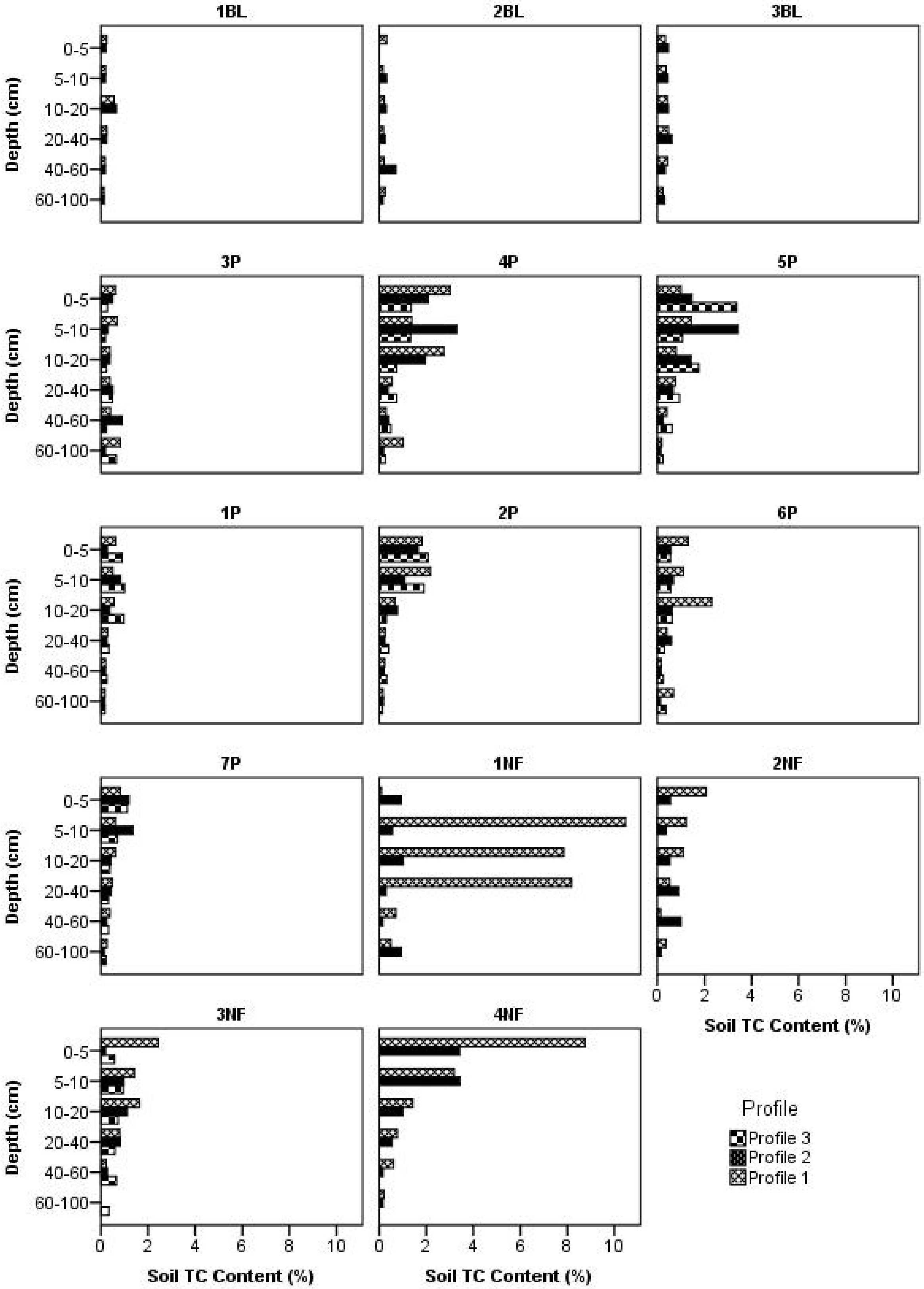


Figure 44: Overview of soil TC content at each plot and for each profile taken in the research area. DF: Barren land; FN: Natural forest; FR: Plantation.

18. Summary Soil Properties

Table 53: Overview of soil properties values for every profile taken in the research area. Sample number indicates profile ID (e.g. 1BL1) and depth of the sampling horizon (e.g. 5: sampling depth of 0-5 cm). BL: Barren land; NF: Natural forest; P: Plantation.

Sample ID	Depth (cm)	pH $_{H2O}$	EC (uS/cm)	Ntot (%)	TC (%)	CN Ratio	DOC (mg/l)	E4/E6
1BL1	0-5	6.69	20.0	0.24	0.02	16.25	16.68	4.90
	5-10	6.99	9.6	0.20	0.01	17.41	8.04	3.90
	10-20	6.72	22.0	0.56	0.02	25.56	12.71	4.21
	20-40	6.14	14.5	0.25	0.02	11.85	8.43	3.73
	40-60	5.79	5.6	0.18	0.01	13.94	3.64	2.53
	60-100	6.17	8.7	0.13	0.01	13.37	2.13	2.53
1BL3	0-5	6.68	18.5	0.21	0.01	18.21	5.93	3.28
	5-10	6.65	22.6	0.20	0.01	16.63	7.22	2.39
	10-20	6.25	21.2	0.66	0.03	22.32	7.74	2.84
	20-40	6.68	18.8	0.24	0.01	21.17	8.22	3.18
	40-60	6.02	102.3	0.19	0.01	20.76	5.89	3.29
	60-100	6.10	5.6	0.14	0.01	15.65	1.87	2.06
1NF1	0-5	7.14	85.9	0.10	0.01	16.90	142.41	11.21
	5-10	7.24	104.8	10.48	0.60	17.56	136.27	8.81
	10-20	7.06	109.6	7.85	0.41	19.22	167.62	10.68
	20-40	6.70	24.0	8.18	0.43	18.83	22.25	6.94
	40-60	6.77	15.7	0.70	0.04	17.87	7.96	9.75
	60-100	6.54	10.6	0.49	0.02	30.09	3.77	.
1NF2	0-5	6.14	11.4	0.94	0.06	16.47	7.48	3.96
	5-10	6.58	13.7	0.57	0.04	14.74	9.64	7.88
	10-20	6.67	14.1	1.02	0.06	18.58	8.04	6.88
	20-40	6.35	8.5	0.29	0.04	8.28	5.24	6.83
	40-60	5.88	8.6	0.15	0.03	5.71	.	.
	60-100	7.03	6.6	0.94	0.06	15.21	.	.
1P1	0-5	6.81	22.5	0.63	0.06	10.27	12.66	3.69
	5-10	6.94	37.0	0.51	0.05	10.89	21.69	4.51
	10-20	6.57	35.8	0.56	0.05	11.45	30.80	5.33
	20-40	6.49	16.4	0.29	0.03	9.50	5.45	3.71
	40-60	6.19	20.5	0.20	0.02	8.79	.	.
	60-100	6.05	7.7	0.17	0.02	8.44	.	.
1P2	0-5	6.45	16.7	0.27	0.03	10.19	7.87	5.82
	5-10	6.37	28.5	0.84	0.05	18.34	11.02	6.19
	10-20	6.64	48.3	0.37	0.03	14.29	17.37	5.60
	20-40	6.15	11.5	0.25	0.02	10.66	5.84	7.00
	40-60	5.11	29.9	0.20	0.02	8.82	.	.
	60-100	6.73	12.0	0.16	0.02	8.40	.	.
1P3	0-5	7.01	38.4	0.90	0.05	19.23	33.69	6.60
	5-10	6.77	31.2	1.01	0.04	22.74	19.66	5.51
	10-20	6.80	30.0	0.97	0.05	20.24	19.83	8.07
	20-40	6.62	71.3	0.34	0.02	14.69	6.19	5.06
	40-60	5.81	15.2	0.25	0.01	18.64	.	.
	60-100	6.22	7.8	0.17	0.01	12.69	.	.
2BL2	0-5	6.02	6.7	0.24	0.01	16.37	2.82	3.92
	5-10	5.71	11.9	0.16	0.01	11.99	4.68	3.53
	10-20	6.16	7.8	0.21	0.02	11.79	3.99	3.71
	20-40	6.42	9.3	0.17	0.02	10.09	.	.
	40-60	8.80	7.8	0.20	0.01	13.25	2.56	2.92
	60-100	6.16	7.8	0.26	0.07	3.81	.	.
2BL3	0-5	6.24	16.6	0.39	0.02	23.35	10.29	4.90
	5-10	6.26	11.4	0.32	0.02	16.04	4.89	5.00
	10-20	6.27	11.2	0.30	0.02	15.14	5.37	2.60
	20-40	5.45	8.8	0.25	0.02	15.89	2.95	2.92
	40-60	5.18	8.9	0.70	0.02	43.26	.	.
	60-100	6.27	10.2	0.16	0.02	10.12	.	.
2NF1	0-5	6.39	24.6	2.07	0.08	25.12	15.77	0.98
	5-10	6.95	43.0	1.24	0.05	25.52	38.74	0.99
	10-20	6.80	46.0	1.11	0.04	28.58	40.30	0.99
	20-40	6.10	20.3	0.53	0.02	25.32	16.03	0.98
	40-60	5.92	18.3	0.15	0.01	24.99	.	.
	60-100	6.06	14.1	0.37	0.01	37.99	.	.
2NF2	0-5	6.01	8.4	0.56	0.03	19.12	4.94	4.33
	5-10	6.47	16.0	0.38	0.02	20.72	5.84	6.08
	10-20	6.48	10.0	0.54	0.02	28.92	4.16	5.88
	20-40	6.20	22.4	0.91	0.02	49.36	11.02	10.08
	40-60	5.80	14.7	1.01	0.02	47.64	.	.
	60-100	6.07	15.4	0.17	0.01	23.11	.	.
2P1	0-5	6.57	34.3	1.82	0.09	20.46	21.00	6.38
	5-10	6.95	33.0	2.18	0.10	21.99	14.31	4.60
	10-20	6.55	19.6	0.66	0.03	23.04	8.48	3.42

	20-40	6.55	12.7	0.26	0.02	14.37	6.15	3.17
	40-60	5.65	14.0	0.23	0.01	25.64	.	.
	60-100	6.81	8.2	0.16	0.01	16.87	.	.
2P2	0-5	6.82	55.5	1.65	0.10	17.10	23.89	6.20
	5-10	7.30	134.9	1.08	0.06	17.39	20.09	5.79
	10-20	6.45	20.4	0.78	0.04	17.79	9.94	4.90
	20-40	6.52	14.6	0.23	0.02	11.66	6.27	5.75
	40-60	6.09	10.4	0.20	0.02	10.94	.	.
	60-100	6.55	8.4	0.17	0.01	11.92	.	.
2P3	0-5	6.55	46.4	2.08	0.11	19.29	32.09	9.06
	5-10	6.91	42.6	1.90	0.06	29.96	24.24	5.90
	10-20	6.39	19.8	0.30	0.02	19.99	9.17	5.68
	20-40	6.51	16.2	0.40	0.02	19.75	7.35	7.17
	40-60	6.08	9.5	0.32	0.02	16.24	.	.
	60-100	6.63	11.0	0.14	0.01	10.87	.	.
3BL1	0-5	6.95	15.6	0.34	0.02	19.36	8.82	20.50
	5-10	6.51	14.7	0.38	0.02	21.63	6.23	7.58
	10-20	6.12	16.6	0.43	0.02	20.91	7.57	10.75
	20-40	5.98	7.8	0.48	0.03	18.35	0.00	1.25
	40-60	6.35	7.8	0.44	0.02	26.17	.	.
	60-100	6.08	9.6	0.24	0.01	20.21	.	.
3BL2	0-5	6.68	66.7	0.48	0.02	24.73	11.28	7.12
	5-10	6.44	25.6	0.45	0.02	27.84	11.50	9.75
	10-20	6.60	95.1	0.48	0.02	24.83	12.79	15.13
	20-40	6.06	13.9	0.63	0.03	24.44	6.75	16.25
	40-60	6.37	11.2	0.34	0.01	36.86	.	.
	60-100	6.60	28.2	0.32	0.01	22.89	.	.
3NF1	0-5	6.43	28.3	2.45	0.11	22.31	34.17	7.76
	5-10	6.64	28.1	1.43	0.07	20.07	23.59	5.35
	10-20	6.65	47.1	1.65	0.08	20.04	31.45	5.88
	20-40	6.12	12.6	0.80	0.04	18.33	11.67	4.32
	40-60	.	12.7	0.22	0.02	12.69	.	.
	60-100	.	.	.	.	.	.	.
3NF2	0-5	6.82	26.3	0.20	0.01	16.92	18.32	9.16
	5-10	6.79	34.1	0.97	0.05	19.53	25.14	9.03
	10-20	6.42	15.6	1.12	0.05	22.71	7.66	10.25
	20-40	6.14	20.5	0.83	0.03	26.92	8.30	5.57
	40-60	6.37	15.6	0.27	0.02	14.49	.	.
	60-100	.	.	.	.	.	.	.
3NF4	0-5	6.58	20.8	0.58	0.03	17.45	7.87	5.82
	5-10	6.64	16.8	0.95	0.04	22.59	11.02	6.19
	10-20	6.85	20.3	0.73	0.03	25.43	17.37	5.60
	20-40	6.45	14.4	0.59	0.03	17.79	5.84	7.00
	40-60	6.36	8.7	0.66	0.03	20.71	.	.
	60-100	6.20	48.4	0.34	0.02	17.33	.	.
3P1	0-5	6.34	15.2	0.61	0.03	20.10	11.15	5.97
	5-10	6.30	12.5	0.69	0.04	15.66	12.84	7.16
	10-20	5.76	8.1	0.38	0.02	19.57	7.01	7.58
	20-40	5.56	8.9	0.38	0.02	17.06	5.41	6.50
	40-60	5.71	7.3	0.40	0.02	20.96	.	.
	60-100	5.20	13.0	0.83	0.02	41.40	.	.
3P2	0-5	5.58	12.8	0.50	0.03	15.38	11.63	6.07
	5-10	6.24	17.2	0.30	0.02	19.99	11.71	6.62
	10-20	6.15	9.3	0.38	0.02	19.34	3.94	11.75
	20-40	5.91	12.1	0.51	0.03	19.22	2.22	8.75
	40-60	6.21	11.2	0.90	0.01	83.32	.	.
	60-100	5.70	8.7	0.19	0.01	15.76	.	.
3P3	0-5	6.38	9.0	0.27	0.01	20.99	3.86	5.38
	5-10	6.33	14.0	0.19	0.01	19.57	7.44	6.56
	10-20	6.47	10.5	0.23	0.01	24.86	4.25	5.42
	20-40	5.83	9.1	0.49	0.02	24.84	4.42	7.58
	40-60	5.88	9.4	0.23	0.01	19.41	.	.
	60-100	5.46	8.5	0.65	0.03	24.95	.	.
4NF1	0-5	6.44	45.7	8.75	0.37	23.87	68.53	7.56
	5-10	6.29	23.2	3.19	0.14	22.79	20.87	3.99
	10-20	6.18	23.6	1.43	0.06	24.69	26.65	5.32
	20-40	6.29	23.2	0.77	0.02	31.48	13.44	6.56
	40-60	.	21.0	0.61	0.02	35.41	.	.
	60-100	5.64	9.5	0.19	0.01	21.92	.	.
4NF2	0-5	6.28	16.6	3.42	0.14	23.88	18.67	5.58
	5-10	6.17	10.5	3.43	0.14	23.88	11.41	3.29
	10-20	6.48	106.1	1.00	0.03	31.71	9.30	6.08
	20-40	5.95	10.6	0.54	0.02	34.55	5.54	4.33
	40-60	5.81	10.9	0.16	0.01	25.13	.	.
	60-100	5.64	7.2	0.16	0.01	18.45	.	.
4P1	0-5	6.82	28.8	3.02	0.14	21.50	27.43	8.29
	5-10	6.65	25.0	1.39	0.06	24.04	26.09	7.93
	10-20	5.83	14.6	2.74	0.13	20.76	13.53	6.85
	20-40	6.04	8.9	0.54	0.02	28.01	5.84	4.33

	40-60	5.96	40.6	0.29	0.02	17.83	.	.
	60-100	5.55	6.9	1.02	0.02	66.73	.	.
4P2	0-5	6.35	19.4	2.09	0.09	23.69	17.24	7.84
	5-10	6.63	11.3	3.29	0.11	28.83	7.96	8.67
	10-20	6.39	15.3	1.96	0.08	25.44	12.02	4.31
	20-40	6.23	15.0	0.37	0.02	22.12	5.24	8.75
	40-60	6.61	62.3	0.39	0.01	28.35	.	.
	60-100	6.01	21.9	0.18	0.01	30.71	.	.
4P3	0-5	6.51	28.7	1.35	0.06	22.48	9.51	4.90
	5-10	6.43	15.8	1.33	0.05	25.19	13.14	6.97
	10-20	6.30	11.2	0.74	0.04	19.16	7.57	6.35
	20-40	6.84	10.2	0.74	0.03	22.52	5.32	3.92
	40-60	5.65	7.9	0.49	0.03	19.20	.	.
	60-100	6.27	16.9	0.26	0.02	10.86	.	.
5P1	0-5	5.82	15.5	1.01	0.06	16.35	13.53	6.35
	5-10	6.47	15.7	1.45	0.06	24.34	11.59	3.02
	10-20	6.63	11.7	0.81	0.04	19.84	7.14	5.52
	20-40	6.41	13.6	0.78	0.04	21.80	4.98	3.29
	40-60	5.67	7.6	0.41	0.02	20.05	4.50	5.59
	60-100	6.30	6.6	0.19	0.01	13.06	5.32	4.90
5P2	0-5	6.54	23.3	1.47	0.08	17.80	20.09	6.48
	5-10	6.41	31.5	3.42	0.14	24.07	23.76	8.08
	10-20	6.20	15.5	1.44	0.06	23.46	11.50	7.65
	20-40	5.46	10.6	0.67	0.02	27.94	8.13	5.33
	40-60	6.36	8.6	0.25	0.01	19.24	.	.
	60-100	5.82	9.5	0.16	0.01	14.30	.	.
5P3	0-5	6.26	15.5	3.36	0.12	28.63	11.07	6.04
	5-10	6.28	15.8	1.08	0.05	23.67	11.02	6.76
	10-20	5.93	16.1	1.75	0.06	27.33	12.66	6.76
	20-40	6.41	16.8	0.95	0.04	25.23	8.00	15.00
	40-60	6.42	16.9	0.64	0.02	40.98	.	.
	60-100	6.05	11.6	0.24	0.01	21.61	.	.
6P1	0-5	6.65	21.7	1.32	0.05	27.29	14.87	4.40
	5-10	6.78	24.8	1.12	0.04	25.10	15.34	4.68
	10-20	6.63	38.8	2.31	0.09	25.86	18.10	4.87
	20-40	6.34	13.7	0.40	0.02	23.83	5.50	2.91
	40-60	6.24	12.5	0.17	0.01	18.29	3.77	6.08
	60-100	6.03	8.2	0.69	0.01	68.75	11.11	6.02
6P2	0-5	6.81	38.6	0.59	0.04	14.74	14.22	5.17
	5-10	6.28	19.4	0.69	0.04	16.48	12.02	6.04
	10-20	6.71	23.8	0.64	0.04	15.06	13.31	13.67
	20-40	6.76	13.9	0.61	0.03	21.38	5.71	3.82
	40-60	6.13	12.4	0.17	0.03	6.26	.	.
	60-100	6.24	10.9	0.14	0.02	5.68	.	.
6P3	0-5	6.88	23.9	0.56	0.03	21.72	11.76	7.19
	5-10	6.71	28.6	0.58	0.02	24.87	10.68	7.35
	10-20	6.67	19.4	0.64	0.03	19.32	9.64	7.12
	20-40	6.13	14.2	0.31	0.02	14.62	4.85	5.38
	40-60	6.59	18.8	0.26	0.02	11.78	.	.
	60-100	6.17	18.2	0.37	0.02	23.24	.	.
7P1	0-5	6.61	66.5	0.83	0.04	23.21	16.72	3.58
	5-10	6.40	20.5	0.61	0.02	24.85	11.37	6.03
	10-20	6.64	17.2	0.62	0.03	21.91	10.25	4.21
	20-40	6.01	9.8	0.48	0.02	27.67	4.68	2.24
	40-60	5.70	8.7	0.38	0.01	25.93	5.15	2.48
	60-100	6.24	12.1	0.26	0.02	17.12	.	.
7P2	0-5	6.68	37.8	1.19	0.06	21.48	19.79	6.71
	5-10	7.11	46.7	1.36	0.06	21.17	26.61	7.12
	10-20	6.46	18.0	0.42	0.01	32.26	7.14	9.13
	20-40	6.64	9.8	0.43	0.02	25.58	4.16	4.38
	40-60	5.93	8.2	0.24	0.01	21.50	.	.
	60-100	6.24	15.3	0.14	0.01	10.82	.	.
7P3	0-5	6.63	30.5	1.12	0.04	26.02	16.94	8.64
	5-10	6.89	27.2	0.70	0.02	28.07	11.89	8.12
	10-20	6.24	11.7	0.38	0.02	18.49	5.89	9.13
	20-40	5.86	8.7	0.32	0.02	18.23	3.12	4.25
	40-60	5.91	10.2	0.32	0.02	18.09	.	.
	60-100	5.63	10.7	0.21	0.01	22.30	.	.

Table 54: Overview of soil properties (Anions and Cations) values for every profile taken in the research area. Sample number indicate profile id (e.g. 1BL1) and depth of the sampling horizon (e.g. 5: sampling depth of 0-5 cm). BL: Barren land; NF: Natural forest; P: Plantation.

Sample ID	Depth (cm)	Ca	Mg	K	Na	Cl	PO4	SO4	NO3
1BL1	0-5	.	.	.	.	13.10	6.20	4.10	3.00
	5-10	.	.	.	.	3.80	4.10	2.80	3.60
	10-20	.	.	.	.	95.40	7.00	3.70	13.90
	20-40	.	.	.	.	12.20	3.80	3.50	3.70
	40-60	.	.	.	.	10.50	2.60	3.00	2.70
	60-100	.	.	.	.	19.40	3.00	2.90	4.40
1BL3	0-5	2.81	42.46	70.25	6.90	30.60	3.10	5.20	2.70
	5-10	2.19	33.17	86.05	5.78	82.50	2.80	4.70	4.90
	10-20	.	.	.	.	12.00	2.60	5.00	3.60
	20-40	.	.	.	.	113.10	2.70	3.50	3.20
	40-60	.	.	.	.	249.60	.	4.50	11.10
	60-100	.	.	.	.	184.70	3.00	3.00	3.20
1P1	0-5	.	.	.	.	9.80	3.00	3.90	6.20
	5-10	.	.	.	.	23.00	3.70	5.30	4.80
	10-20	.	.	.	.	11.30	2.90	5.60	4.30
	20-40	.	.	.	.	15.50	.	3.20	5.30
	40-60	.	.	.	.	116.90	2.60	4.20	8.50
	60-100	.	.	.	.	10.70	.	2.80	3.50
2BL2	0-5	.	.	.	.	4.80	2.80	4.00	4.80
	5-10	.	.	.	.	7.60	2.70	4.80	11.10
	10-20	.	.	.	.	10.10	2.60	6.20	4.50
	20-40	.	.	.	.	.	.	.	.
	40-60	.	.	.	.	73.40	.	7.80	3.90
	60-100	.	.	.	.	4.00	.	11.40	5.70
2BL3	0-5	.	.	.	.	34.80	2.90	9.40	4.90
	5-10	.	.	.	.	35.00	2.80	7.10	2.60
	10-20	.	.	.	.	61.10	3.00	6.30	6.10
	20-40	.	.	.	.	5.70	2.70	5.80	7.50
	40-60	.	.	.	.	6.50	.	7.90	5.90
	60-100	.	.	.	.	6.70	2.50	10.30	4.60
2P1	0-5	.	.	.	.	26.10	3.30	4.60	9.60
	5-10	.	.	.	.	12.20	5.30	5.00	5.00
	10-20	.	.	.	.	18.40	2.70	3.60	11.40
	20-40	.	.	.	.	18.60	.	3.00	3.90
	40-60	.	.	.	.	7.00	3.20	5.10	4.10
	60-100	.	.	.	.	15.50	.	2.90	3.20
3BL1	0-5	3.37	7.40	58.50	5.99	4.25	4.17	2.01	5.18
	5-10	2.67	6.57	53.17	5.35	3.03	3.89	1.69	10.90
	10-20	2.03	1.60	51.42	4.51	2.53	4.33	1.60	5.58
	20-40	.	.	.	.	0.54	2.42	2.29	4.65
	40-60	.	.	.	.	1.15	3.16	5.49	2.59
	60-100	.	.	.	.	2.76	2.43	4.32	1.42
3BL2	0-5	.	.	.	.	6.67	2.60	2.66	11.10
	5-10	.	.	.	.	7.02	2.60	3.83	9.36
	10-20	.	.	.	.	9.82	2.02	3.08	9.80
	20-40	.	.	.	.	-0.24	2.42	1.16	7.29
	40-60	.	.	.	.	0.19	1.62	5.29	4.88
	60-100	.	.	.	.	1.27	0.90	3.60	3.95
3NF1	0-5	23.73	116.76	105.74	8.86	7.50	5.40	6.30	28.50
	5-10	10.57	62.23	113.42	9.95	45.20	3.40	5.30	30.80
	10-20	.	.	.	.	33.60	3.80	8.70	77.00
	20-40	.	.	.	.	7.30	2.50	3.70	5.40
	40-60	.	.	.	.	9.80	.	3.10	6.90
	60-100	.	.	.	.	.	.	.	.
4NF1	0-5	.	.	.	.	29.50	4.20	6.10	14.90
	5-10	.	.	.	.	33.60	2.60	5.80	17.40
	10-20	.	.	.	.	20.00	2.50	5.00	7.20
	20-40	.	.	.	.	28.70	2.50	4.40	4.70
	20-40	.	.	.	.	33.50	.	3.70	6.70