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Allanblackia stuhlmannii – a tree under current domestication: what are the soil requirements?

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Cover: Fruit, sapling and root fragment of Allanblackia stuhlmannii (right), soil profile at Kibaoni (left).
Photos by Kajsa Alvum-Toll, 2012.

Abstract

Allanblackia is a genus of trees that grows in the rainforests of West, Central and Eastern Africa. Its big fruits contain seeds very rich in oil which has been used by local communities for cooking and making soaps. The native stands are threatened by overexploitation and the demand for the oil is much greater than the supply. Domestication programs, aiming at introducing the trees to small holder agroforestry systems, have been started for some of the species.

The main aim of this study was to investigate the soil requirements of *Allanblackia stuhlmannii* in terms of chemical and physical parameters, as revealed by the soil conditions in native stands. Another aim was to see if these varied along an altitudinal transect. The aim was also to conduct soil profile descriptions and collect climatic data. The hypotheses were that the soils would be acidic and highly weathered with low concentrations of plant available nutrients. Soils on lower altitudes were hypothesized to be less acidic and have higher concentration of nutrients. The soil description was expected to result in a Ferralsol or Acrisol.

The sampling and collection of data were conducted at five sites within the Amani Nature Reserve in the East Usambara, Tanzania. The soils were analyzed for bicarbonate extractable P, organic C, total N, electric conductivity, pH, C:N ratio and bulk density. Water infiltration rate was also measured. Soil samples from the soil profiles were also analyzed for texture, effective cation exchange capacity, exchangeable base cations, Al, Fe and Mn, effective base saturation, exchangeable acidity and oxalate and dithionite extractable Al, Fe and Mn.

The results showed that the soils had very low pH, generally below 4.5. Overall the concentration of nutrients was very low but there were higher concentrations of P, organic C and total N in the upper 10 cm compared to lower depths. There were differences between sites for all parameters but not a clear altitudinal effect. A slight altitudinal effect was observed for P in the upper 5 cm, with higher concentrations at lower altitudes, and for pH with lower pH at lower altitudes. The two soil profiles were classified as Ferralsol and Acrisol, which are typical red, highly weathered and leached tropical soils with poor chemical status. The climate was found to be of humid tropical character with rain during all months of the year.

This was a pilot study linking soil samples to native stands of *Allanblackia stuhlmannii.* Hopefully these results will be useful in the future domestication process by providing knowledge about the tree’s requirement on soil and climate. This information can help farmers successfully integrate the tree in their farming system and thereby improve their farm income as well as preserve the native forests.

Sammanfattning

Allanblackia är ett släkte av träd som växer i tropiska regnskogar i Väst-, Central- och Östafrika. Trädets stora frukter innehåller oljerika frön där oljan har använts av lokalbefolkningen för matlagning och tillverkning av tvålar. De naturliga bestånden är hotade av överexploatering och efterfrågan på oljan är mycket större än tillgången. Domesticeringsprogram med syfte att introducera trädet i småskaliga agroforestry-system har påbörjats för några av arterna.

Det huvudsakliga syftet med den här uppsatsen var att undersöka *Allanblackia stuhlmannii*'s krav på växtplats med avseende på kemikaliska och fysikaliska jordparametrar genom att analysera jord från naturliga bestånd. Vidare var syftet att se huruvida dessa varierade längs med en altitudtransekt. Syftet var också att utföra jordmånsprofilbeskrivning samt inhämta klimatdata. Hypotesen var att jordarna skulle ha lågt pH, vara starkt vittrade med låga koncentrationer av växttillgängliga näringsämnen. Jordar på lägre altituder förväntades ha högre pH samt något högre koncentration av näringsämnen. Jordmånsprofilbeskrivningen förväntades att resultera i en Ferralsol eller Acrisol.

Provtagning och insamling av data utfördes på fem lokaler i Amani Nature Reserve i East Usambara, Tanzania. Jordarna analyserades för P (extraherat med bikarbonat), organiskt C, total N, elektrisk konduktivitet, pH, C:N kvot och skrymdensitet. Jordens infiltrationskapacitet mättes också. Jordprover från jordmånsprofilerna analyserades dessutom för textur, effektiv jonbyteskapacitet, utbytbara baskatjoner, Al, Fe och Mn, effektiv basmättnadsgrad, utbytbar aciditet och oxalat- och ditionitlösligt Al, Fe och Mn.

Resultaten visade att jordarna hade mycket lågt pH, generellt under 4.5. Överlag var koncentrationerna av näringsämnen mycket låga men med högre koncentrationer av P, organiskt C och total N i de översta 10 cm jämfört med djupare skikt. Det var skillnader mellan lokalerna för alla parametrar men ingen tydlig effekt av altitud. En svag effekt av altitud observerades dock för P i de översta 5 cm, med högre koncentration på lägre altituder, och för pH med lägre pH på lägre altituder. Jordmånsprofilerna klassificerades till Ferralsol och Acrisol vilket är typiskt röda, starkt vittrade och urlakade tropiska jordar med låg kemisk status. Klimatet karaktäriserades som humitt tropiskt med regn under alla årets månader.

Det här var en pilotstudie där jag undersökte jordprover från naturliga bestånd av *Allanblackia stuhlmannii*. Förhoppningsvis kan dessa resultat vara av betydelse för det fortsatta domesticeringsarbetet. Kunskap om trädets krav på växtplats med avseende på jord och klimat är viktigt för att bönder ska kunna odla trädet framgångsrikt och därmed förbättra sin inkomst samtidigt som skogen bevaras från överexploatering.

Popular summary

Knowledge about the soil requirements of the Allanblackia tree can benefit rural poor and help preserving tropical forests

Allanblackia is a group of trees native to the rainforests of tropical Africa. They have long been important to local communities for their multipurpose use such as timber, shade tree, medicine, fodder etc. However, the most important product is the oil-rich seeds which are used for cooking or making soaps. During the last decade the oil has received great attention from the food industry because of its unique properties which are ideal for the production of spreads and soap. To meet the growing demand for the seeds, a domestication program was initiated in 2002 aiming to commercialize Allanblackia oil at the same time as the trees would be introduced to small scale farms.

Allanblackia stuhlmannii tree with many fruits. Photo by Kajsa Alvum-Toll.

Today, the seeds are collected from wild stands (see example on photo to the left) and the regeneration of the trees is threatened by overexploitation as are the forest where they grow. The main benefit by introducing the Allanblackia tree on small scale farms is that the fruits mature at a time when farmers generally have little other crops to sell and can thus help bridge the income gaps during the year. For local communities living in East Usambara, diversification and processing of farm produce are important alternatives and strategies to improve livelihoods.

So far, information about the soil requirements of the trees is poorly documented and this is important information to know if the trees are to be successfully integrated on farms and also in advising farmers on good farming practices.

Allanblackia fruit, seedling and root fragment (left), soil profile (right). Photo by Kajsa Alvum-Toll.

This study was performed within the Amani Nature Reserve in the East Usambara Mountains, Tanzania. Soil samples from five different sites with native stands of the local species of Allanblackia (*Allanblackia stuhlmannii*) were collected and later analysed in a lab at SLU (The Swedish University of Agricultural Sciences). The water infiltration rate was measured on site and two soil profiles were also examined. Climatic data on rainfall and temperature was collected. The different sites were located on different altitudes to investigate if there were any differences in soil properties related to altitude.

The results from the soil analysis showed that the native stands of this Allanblackia species were found on very acid soils with low concentrations of nutrients but high concentrations of aluminum. The soils were typical red, tropical soils dominated by sand and clay and with very poor chemical status. The infiltration rate was extremely high at all sites and the climate was characterized as tropical. The concentration of nutrients, organic carbon and total nitrogen was generally higher in the upper layers, probably associated to the organic material found there. Differences in soil properties related to altitude were generally not found.

From this study it can be concluded that this Allanblackia grows well on nutrient poor and acid soils. The tolerance for high aluminum concentrations, which normally is very toxic in high concentrations and which is common in acid soils, is a common phenomenon among several plants and crops in tropical regions. Another possible explanation to why the trees manage to grow well on poor soils could be some kind of symbiosis with mycorrhiza fungi facilitating the uptake of nutrients. Moreover it may be that this Allanblackia is an iron inefficient species and does not grow well on more fertile soils where the pH usually is higher making iron more difficult for plant roots to take up. Further studies are needed to elucidate this though.

Hopefully these results can help in the domestication process and may contribute to raising strong and viable seedlings in nurseries. The information can also help understand what promotes and disfavors the establishment and growth of the trees on farms and can be important information in advising on good farming practices.

Table of contents

Abbreviations

AEC	Anion Exchange Capacity
ANOVA	Analysis Of Variance
ANR	Amani Nature Reserve
BS	Base Saturation
BS_{eff}	Effective base saturation
CEC	Cation Exchange Capacity
CIAT	International Center for Tropical Agriculture
EC	Electric Conductivity
ECEC	Effective Cation Exchange Capacity
FAO	Food and Agriculture Organization of the United Nations
GPS	Global Positioning System
ICRAF	World Agroforestry Centre
IUCN	The World Conservation Union
NGO	Non-Governmental Organization
NTFP	Non-Timber Forest Products
NWFP	Non-Wood Forest Products
PPP	Private Public Partnership
SLU	Swedish University of Agricultural Sciences
SNV	Netherland’s Development Organization
TBA	Tropical Biology Association

1 Introduction

Today approximately 854 million people live in Sub-Saharan Africa and over half of these have agricultural and forestry activities as their main sources of livelihoods (FAOSTAT, 2012). Due to an increasing population with an increased demand for agricultural land as consequence, the rate of deforestation is increasing. In 2010 Africa was covered with 675 million hectares of forest, representing 23 % of the continent’s surface area, however this area is constantly decreasing with an average of 0.49 % per year (FAO, 2011). The forests are important for many reasons: biodiversity, carbon balances and they provide ecosystem services such as regulating the water supply. The majority of the world’s poorest local communities are also dependent on the forest for food, fodder, firewood, non-wood forest products (NWFP) such as medicine, resins, fruits and nuts (FAO, 2011). Trees can also provide shade for other agricultural crops and improve the soil by fixing nitrogen (N) from the atmosphere, retaining water, adding soil organic matter to the soil, preventing erosion etc. Many fruit trees also have an important religious and cultural value for many indigenous people (Akinnifest et al., 2008).

One such area where the forest is an important source of livelihood is the East Usambara Mountains in Tanzania. The area is well known for its unique ecosystem and has been recognized as one of the world’s biodiversity hotspots with many endemic species (Burgess et al., 2007). By establishing nature reserves that involve the local communities in finding alternative livelihood strategies and sources of incomes the forests can be preserved from overexploitation at the same time as the local communities are benefitted. Amani Nature Reserve (ANR), in East Usambara, has different projects together with the villages in Amani, including the Allanblackia project (Amani Nature Reserve, 2012). The Allanblackia tree is known for its big fruits with seeds very rich in oil which has been used by local communities for cooking and making soaps (Meshack, 2004). The Allanblackia seeds have received great attention from the food industry which has discovered that the fatty acids of the oil make it ideal for making spreads etc. Today the demand for the seeds and oil is much larger than the supply since the harvest only is done from wild stands in the forests. In 2002 a domestication program and a private public partnership (PPP) was established among Unilever, The World Agroforestry Centre (ICRAF), The World Conservation Union (IUCN), Netherlands Development Organization (SNV) and several NGO's and governmental organizations. The aim of the program is to domesticate Allanblackia by selecting germplasm with desirable traits such as time for flowering and fruiting, fruit size and to develop vegetative propagation techniques. With a successful domestication farmers can integrate the trees in their farming systems, harvest and sell the seeds sustainably and thus avoid overexploiting the forest (Novella Africa Initiative, 2012).

In tree nurseries, an enhanced seedling growth has been observed if forest soil from wild Allanblackia stands is incorporated in the potting mix (Munjuga et al., 2008). The reasons behind this positive effect are unknown but a positive plant-microbe interaction could be one explanation. However, the effects could also be due to soil chemical and physical characteristics, as soil requirements of Allanblackia are poorly documented, as are climatic requirements.

A project was carried out in collaboration between the Swedish University of Agricultural Sciences (SLU) and ICRAF. The project consisted of two parts, one of which was to investigate possible plant-microbe interaction in the form of mycorrhiza in native stands of *Allanblackia stuhlmannii*. The other part, presented in this report, aimed at investigating soil characteristics focusing on soil chemical and physical parameters. The field work for the project was conducted together but the onward work was carried out separately and results are presented in two separate master thesis reports.

The main purposes of this study were to characterize and describe the soil in terms of chemical and physical parameters and to investigate if these varied along an altitudinal transect. The parameters were investigated and described by analysis of soil samples and soil profile classifications. The hypothesis was that the soil would be highly weathered with low pH and generally low concentrations of plant available nutrients which is very common for tropical soils in these areas. Another hypothesis was that soils on lower altitudes would be slightly more fertile with less acidic pH and higher nutrient concentrations than those at higher altitudes, although the extent of this would depend on the range in altitude. The expected results from the soil classification were that the soils would belong to the 'tropical group' of soils according to FAO, for example Ferralsol or Acrisol. Furthermore, the sites where *A. stuhlmannii* grows were described in terms of characteristic vegetation, temperature and rainfall.

This was a pilot study aiming to gain information about *A. stuhlmannii*'s requirements on soil and climate which will provide important information in the process of domesticating the tree and successfully grow it on farms.

2 Background

2.1 The Eastern Arc Mountains and the East Usambara

The Eastern Arc Mountains (Fig. 1) covers an area of approximately 23.000 km^2 and form part of the Eastern Afromontane hotspot which is one of the world's richest places for biodiversity (Burgess et al., 2007). The mountains are very old dating at least 30 million years and possibly even older and are made up of rocks from the Precambrian period. They were formed by uplifting and are associated with the development of the Great Rift Valley. The rocks are very base poor due to a mixture of mainly migmatites and granites with a lot of quartz (Ministry of Natural Resources and Tourism, 2010). The Eastern Arc Mountains encompasses thirteen mountain blocks isolated from each other which have enabled a unique evolution of plants and animals within each block resulting in many endemic species. Many of the species are endangered (Burgess et al., 2007). There are nine protected areas within the mountains and they comprise a wide range of altitudes from lowland forests below 800 m to upper montane forest above 1800 m. Above the tree line montane grasslands and bogs are found (Ministry of Natural Resources and Tourism, 2010). The closeness to the Indian Ocean means that the mountains are under direct influence by the sea giving a humid and warm climate with rainfall well distributed over the year and evergreen montane forests. Some of the largest trees in the tropical rainforests of Africa such as *A. stuhlmannii*, *Allanblackia ulugurensis*, *Newtonia buchanii*, *Ocotea usambarensis*, *Cephalosphaera usambarensis* are found in these areas. The mountains have since long been a place for settlement and agricultural activities due to its favorable climate. As a result much of the initial forest has been cleared and transformed into farmlands and it is estimated that over 70 % of the former forest areas have been lost. The most affected areas are the submontane forests of the East Usambara and Uluguru (Ministry of Natural Resources and Tourism, 2010).

Figure 1. The Eastern Arc Mountains and the East Usambara. From: http://www.easternarc.or.tz/home

2.2 Allanblackia – distribution, biology and use

The Allanblackia tree belongs to the Clusiaceae family and to date nine different species have been identified and they share similar characteristics. They are all found in tropical forests from West to East Africa on altitudes ranging from 400-1800 m a.s.l. The climate in these regions is normally warm with high annual rainfall. The average annual temperature is approximately 18-20 ˚C and the maximum annual temperature 25-33 ˚C. The annual rainfall varies between 1200-2400 mm. Characteristic for many of these areas are also the strongly leached soils with low concentrations of base cations and acidic pH around 3-4 (Van Rompaey, 2005). *A. stuhlmannii* is endemic to Tanzania and is found in the Eastern Arc Mountains with the highest populations in the East Usambara at 800-1200 m altitudes on slopes of submontane to montane forest (Munjuga et al., 2010; Mwaura & Munjuga, 2007).

Figure 2. Allanblackia tree with fruits (left) and an Allanblackia fruit, sapling and root fragment (right).

All Allanblackia species are dioecious trees (separate female and male trees) which can grow up to more than 20 m of height (Fig. 2), have opposite leaves and white, pink or red very fragrant flowers. The tree has big, brown fruits (Fig. 2) which can weigh up to 7 kg and one tree can yield up to 300 fruits during a year but the average is 100-150 in a good season. The number of seeds found in the fruits, and shape and size of the fruits varies widely between individual trees within the species (Mathew et al., 2009; Peprah et al., 2009). The trees start to flower when around 12-20 years old and the fruiting takes place one year later during the same period of the year. The fruits fall to the ground when they are mature and the seeds are dispersed by monkeys and rodents who feed on the fruits. However, the natural regeneration of the tree is not adequate to maintain the population and many of the species are endangered, mainly due to the overexploitation of fruits by humans (Pye- Smith, 2009).

Allanblackia has multiple uses: timber for construction, shade tree in cocoa plantations, the roots, bark, leaves and seed extracts for medicine purposes, branches, leaves and seeds as fodder, seeds as bait in animal traps etc. The trees also function as shelter and homestead for birds and bees and the seeds are an important source of feed for the giant pouched rat, squirrels and monkeys (Orwa & Oyen, 2007; Meshack, 2004; Atangana et al., 2011; Ajibesin et al., 2008). Furthermore, an HIV-inhibitor, Guttiferone F, has been identified in *A. stuhlmannii* (Fuller et al., 1999). However the tree’s most important use is maybe its oil rich seeds. The oil consists mainly of stearic and oleic acids providing unique properties which are very interesting for the food industry. A very sharp melting point around 34 ˚C makes the oil solid in room temperature but melts in the mouth. This is ideal properties for making spreads and similar products. The oil also requires less modification and processing such as hardening etc compared to palm oil and therefore reduces the costs and facilitates the manufacturing of products (Pye-Smith, 2009).

In 2000 Unilever started to use Allanblackia oil for the production of soaps in Ghana and later decided to start using Allanblackia oil for some of their products instead of palm oil. However, the trees were only found in native stands in forests and the demand for the oil was much bigger than the supply. This resulted in the Novella Africa partnership in 2002 aiming at developing a new sustainable oil production industry on commercial scale based on Allanblackia oil. At the same time they would promote small-hold farmers to grow the trees on their farms, stimulating a local supply chain of seeds while preserving the forests (Novella Africa Initiative, 2012). Today, functional supply chains are available in Tanzania, Ghana and Nigeria and are under consideration in Cameroon and Liberia. In Tanzania the harvest activities are the most developed with 54 collection centers in the Eastern Arc Mountains. In 2004 the first commercial harvest of seeds took place and yielded approximately 4 ton, in 2008 the harvest had increased to 450 ton. However, the demand for the oil could exceed 200.000 t per year which cannot be provided today (Novella Africa Initiative, 2012).

2.3 Domestication of Allanblackia

ICRAF has since 1998 developed a participatory approach to tree domestication of high-value indigenous fruit and nut trees and medicinal plants in West and Central Africa. In this approach the local communities themselves participates throughout the domestication process by selecting, propagating and managing the trees. The aim is to help local communities to use the tropical forests in a more sustainable way by domesticating the trees and help farmers grow these trees in their fields. Several trees have been and are under way of being domesticated: *Irvingia gabonensis*, *Dacryodes edulis*, *Garcinia kola*, *Allanblackia spp*. etc (Tchoundjeu et al., 2006).

The Novella Africa partnership has since 2002 worked on the domestication of Allanblackia and very little was then known about the trees' biology or their distribution which is something that has been investigated and is known today (Van Rompaey, 2005; Peprah et al., 2009; Mathew et al., 2009). To help in the domestication process ICRAF joined the partnership in 2004. At the beginning a lot of work was put on collecting seeds, germplasm selection and on propagation. Trials in Ghana showed poor germination (Ofori et al., 2011), but the germination was enhanced after removal of the seed coat and if the seeds were incubated in polythene bags. Even with the improved germination there were still problems of determining the sex of the trees and the long time before fruiting which is not acceptable for farmers who need a quicker return to their investment. This resulted in a change in focus towards vegetative propagation where there has been greater success (Asaah et al., 2010; Anegbeh et al., 2006; Atangana et al., 2006; Ofori et al, 2008) by the participatory domestication approach. Some of the advantages with the vegetative propagation were the possibility to control the female to male ratio and to multiply trees with superior characteristics such as a more uniform growth, earlier fruiting, higher yield etc (Munjuga et al., 2008). By 2009, 10.000 smallholder farmers in Ghana and Tanzania had planted superior trees from the domestication program on their farms. The domestication process continues and there are still some problems related to the development and establishment of seedlings in the tree nurseries and on the farms. One key to solve these problems could be related to one or several soil parameters which today are poorly documented. This is important to know especially if the trees are to be planted in new areas outside their natural habitat.

2.4 Soil forming factors

A soil forming factor is a factor that influence the soil's properties and its formation and thus gives rise to different kinds of soils. The main soil forming factors are 1) climate, 2) vegetation, fauna and humans, 3) topography, 4) parent material and 5) time (Driessen et al., 2001).

2.4.1 Climate

Climate and especially temperature and rainfall have a large impact on the properties of a soil. The climate of the tropics varies considerably with rainforests, savannah, deciduous forest, desert steppes, alpine meadows etc with rain falling during one or several periods per year (Kalpagé, 1976). In general, however, tropical climate is characterized by more radiation per unit area and less variation in day length compared to temperate regions. The high temperature and rainfall speed up the decomposition of organic material, but also accelerates other processes such as weathering and leaching (Van Wambeke, 1992). Rainfall has a large impact on the intensity of leaching and is the main agent for chemical weathering, and affects the development of soil profiles. Climate also has an indirect effect by its influence on vegetation which in turn influences the soil (Young, 1976).

2.4.2 Vegetation, fauna and humans

Vegetation and soils are closely linked and the soil determines to a large extent the type of vegetation found at a site at the same time as the vegetation influences the soil properties e.g by the supply of organic matter, removal of nutrients from the root zone etc. There is often a concentration of organic material and nutrients in the upper soil horizon due to plant nutrient uptake and translocation. Compared to savannah the closed rainforests of the tropics have higher rainfall and provide more vegetation residues to the soil as they are one of the greatest net primary producers on earth (Young, 1976). These relatively undisturbed forests have a large nutrient reserve locked up in the vegetation and a very tight nutrient cycle which is very sensitive to disturbance. Due to the hot and humid climate the decomposition rate is very fast and even though the quantities of organic matter are big the leaf litter layer is normally thin. However, the often very low pH and high concentrations of aluminum may slow down the decomposition. The litter affects the chemical weathering by its organic acids and it is common with formation of complexes between aluminum (Al) and iron (Fe) oxides and humus. The A-horizon contains most of the organic material and is generally more fertile than deeper horizons due to the nutrients contained in or bound to the organic material (Ahn, 1993).

The different soil organisms found in the tropics are for example bacteria, archaea, fungi, different burrowing soil animals such as earthworms, insects etc. The most characteristic soil animals for the tropics are termites which may have a profound influence on soil properties. They are social animals living in mounds which can be several meters high and which consist mainly of soil particles. Fine sized particles dominate as building material since the termites cannot carry big particles (over 2 mm), and they therefore have a sorting function moving fine particles upwards while leaving behind gravels. The physical effects of the termites on the soil are thus associated with soil particle size, structure, bulk density, water infiltration capacity, penetration of roots etc. The soil can have a more stable aggregation due to termite excreta and the gallery system associated with the mounds creates greater aeration and root penetration. The chemical effects include modification of soil pH, organic matter, and concentration of nutrients. Since the termites can digest cellulose and lignin they can speed up the decomposition of these plant residues which otherwise are very stable and resistant to decomposition (Ahn, 1993).

Humans have an impact on soils through a number of different activities e.g the burning of vegetation which causes loss of nutrients, organic matter etc. The addition of manure or fertilizer can on the other hand increase the nutrient content and the organic matter content of the soil. Irrigation, drainage and flooding change the soil water regime and the redox potential of the soil. Different cultivation techniques replace soil profile horizons and terracing, over-cropping or -grazing can accelerate erosion (Young, 1976).

2.4.3 Topography

Topography has different effects on the soils by influencing the environmental factors such as temperature and rainfall. The topography also has an impact on soil drainage which is reflected by the colors of the soils. Upland, well drained soils are often red due to the presence of hematite (iron oxide, Fe_2O_3), whereas soils on middle or low slopes are more brown or yellow which is explained by the hydrated iron oxides due to moister soils. In valleys where the drainage can be very poor and the soil may be saturated with water for longer periods, the iron is reduced giving a blue or green color with mottles. Other elements such as manganese (Mn) can also be affected by varying reducing and oxidizing conditions. Moreover, the intensity of erosion, weathering and leaching can increase with a steep slope and transport dissolved substances down the slope (Young, 1976). Soils along a slope can be related to the topography. Such sequences of soils are called soil catenas and vary due to differences in parent material, differences in drainage and how they have developed. Upland soils often develop from the weathering of underlying rock whereas soils on lower slopes may have been formed from materials moving down the slope, called colluvium. Valley soils develop from the deposited material from wind or water, so called alluvium (Ahn, 1993).

2.4.4 Parent material

The material from which the soil is derived is called parent material and is often similar to the underlying rock, unless the soil has been transported to lower slopes. All rocks are made up of minerals with uniform chemical compositions and regular structures. Most minerals´ major component is silicon and the silicate minerals are being classified according to how the silicon ions are linked. The more direct links there are between the silicon-O-silicon the more resistant the mineral is to weathering. The resistance to weathering decreases as the substitution of silicon ions by other elements increases, e.g with Al^{3+}. Least resistant are volcanic glasses which lack the crystal structure whereas quartz, due to the absence of isomorphic substitution, is an example of a very resistant mineral. It therefore remains in the soil after other easily weathered minerals have disappeared (Van Wambeke, 1992).

The most important properties related to soil formation are how easy the rock is weathered and what element it releases. The resistance to weathering for different rocks depends on what kind of minerals that are dominating. The rocks are divided into felsic rocks with a high proportion of silicon and mafic rocks which contain relatively more metallic cations. The more silicon a rock contains the more felsic it is and the more quartz and feldspars are dominating. Granite which is a felsic igneous rock contains a large fraction of the very resistant quartz. Another factor determining how resistant a rock is to weathering is the permeability of the rock allowing water and acids to enter, exposing the rock for these and increasing its surface area. Granites and gneiss have this property and can be transformed into saprolite or rotten rock (Van Wambeke, 1992).

2.4.5 Time

Time is often referred to as the stage of development of a soil and the properties of a soil depend on the age of the soil. A quite inert material such as quartz may result in a very slow development or if the soil is developed in steep areas where the material will be transported downwards as soon as it has been formed, thus slowing down the processes of development of a soil cover. Furthermore, a low or limited degree of development may be explained by the fact that the soil is in the beginning of development. Mature soils have a greater degree of development where a subsoil underlying the surface horizon is formed (Ahn, 1993).

2.5 Soil forming processes and how they influence the soil

2.5.1 Weathering

Weathering is one of the most important soil forming processes in the tropics. There is both chemical and physical weathering where physical weathering is the breakdown of rock through the influence of temperature, pressure, ice etc. This type of weathering is dominating in arid regions where chemical weathering is inhibited by lack of water. These soils often contain gypsum and calcite and the parent material give rise to easily weathered silicate minerals such as biotite, hornblende and olivine which due to the arid climate have a nutrient reserve which slowly can be released through weathering. Chemical weathering involves chemical processes such as dissolution, carbonation, hydration and hydrolysis of primary minerals leading to formation of secondary minerals. Which secondary mineral that is formed depends on the type of primary mineral and its chemical composition, size, surface area etc and have a large effect on the properties of soils such as structure, cation exchange capacity (CEC) etc. An acid rock provides little base cations since it is to a large extent made up of insoluble quartz and the main secondary mineral being produced is kaolinite (a 1:1 clay mineral) which supplies little base cations. Since kaolinite has no permanent charge and very low CEC it also has a low capacity of binding nutrients. Secondary minerals from mafic rocks on the other hand provide more base cations and often have a larger capacity of binding nutrients due to a larger CEC (Eriksson et al., 2005). Many rainforest soils have a clay fraction dominated by kaolinite, Al and Fe oxides and hydroxides, but few 2:1 minerals. The dominating 1:1 minerals and the lack of 2:1 lattice minerals distinguish tropical soils from temperate soils and even though they often have very high clay content they remain very friable. This type of clay has good physical conditions for root penetration but cannot retain nutrients well (Ahn, 1993).

The hot and humid climate of the tropics promotes rapid chemical weathering and since the parent material often is very old the soils have undergone a very long weathering process. In the first stage of weathering the most soluble substances are removed such as sulfates and nitrates and later cations such as calcium (Ca), sodium (Na), magnesium (Mg) and potassium (K) are removed. In the last step silicon and silicates are removed, except quartz which is very resistant to weathering due to its stable form. The most resistant compounds are sesquioxides or Al- and Fe-oxides (Al_2O_3 and Fe_2O_3) and these are thus accumulated in the soil by the constant loss of silica (Young, 1976).

An indication of the degree of weathering is the percentage of silt compared to sand as the larger surface area of silt makes it more easily attacked by weathering; the less silt/sand ratio the further the weathering has proceeded. The silica/sesquioxide ratio (SiO_2/R_2O_3 where R is Al or Fe) is also a measure of the weathering since silica is being removed whereas Al remains in the soil (Ahn, 1993).

2.5.2 Leaching

Weathering and leaching are closely interlinked. The release of elements by weathering determine to which extent they can be leached, at the same time as the intensity of the leaching affects how much minerals that are removed from the weathering matrix and how much that is precipitated into secondary minerals. How much water that enters the soil depends on the intensity of rainfall, vegetation cover, condition of the soil such as water content, structure, texture etc. If the rainfall is less than the evapotranspiration there can be a net upward transportation of water and often an accumulation of salts and substances which is common in arid regions. When the rainfall is larger than the evapotranspiration and the soil is permeable, there is a net downward flow of water. With large volumes of percolating water, base cations and alkalinity (HCO_3^-, anions of organic acids) are lost from the profile to such an extent that the pH decreases. The soil pH and redox potential in turn influence the solubility of compounds and elements. Dissolved carbon dioxide from the atmosphere forms carbonic acid, organic acids add more acidity and water running through an acid soil becomes more acid and thus a stronger leaching agent (Kalpagé, 1976).

Since exchangeable bases are highly soluble and easily leached, the base saturation (BS) of the soil is a good indicator of the intensity of leaching of the soil and most freely drained rainforest soils have very low BS (Young, 1976).

2.5.3 Translocation of clay

Another common process in the tropics is the translocation of clay and the formation of a clay enriched soil horizon or the formation of new clay minerals in a B-horizon. Very fine particles can be moved downwards in the profile by the percolating water and be accumulated in lower horizons, in down slope areas or lost to drainage water. It is most often the finest clay particles that are translocated from the topsoil down to an illuviated or enriched subsoil, called an argillic horizon. The illuviated horizon should contain clay that has been moved from an eluviated upper horizon and should contain more clay than the eluviated horizon. Evidence of clay migration are so called clay cutans and shiny ped faces, which is clay that have been deposited on ped surfaces or in pores and voids giving a shiny appearance (Kalpagé, 1976).

2.6 Common soils in the tropics

Characteristic soils of the tropics are the typical red and yellow soils of the wet tropical and subtropical regions all characterized by high soil temperatures and moisture that promotes rapid and intense weathering with most primary minerals, except quartz, being lost. The surpluses of rain leads to strong leaching resulting in acid soils with low BS, and soil organic matter thus make up an important part of their fertility. The group of soils sharing these characteristics comprises Plinthosols, Ferralsols, Alisols, Nitisols, Acrisols and Lixisols (Driessen et al., 2001).

2.6.1 Plinthosols

These are soils containing a plinthite which is an iron-rich, humus-poor mixture of kaolinite clay and quartz forming a hardpan. Plinthosols originate mostly from basic rocks and the presence of iron is necessary. They are common in level-to-sloping land with fluctuating groundwater level and are found in the wet tropics but also in drier parts of Africa, northern Australia and Southeast Asia. The formation of plinthite involves the accumulation of sesquioxides and segregation of iron into mottles due to repeated wetting and drying. If the plinthite hardens it does so irreversibly to form petroplinthite which involves crystallization of iron compounds to goethite ($FeO(OH)$) and the dehydration of goethite to hematite (Fe_2O_3). The soils have high concentrations of sesquioxides and no or very few weatherable minerals and often have very low CEC and BS. The low fertility of the soils and the hard plinthite limit their suitability for agricultural activities (Driessen et al., 2001).

2.6.2 Ferralsols

Ferralsols are deeply weathered, nutrient poor, red or yellow soils. They have diffuse horizon boundaries, the clay mineral is mainly kaolinite and the concentration of sesquioxides is generally high. These soils are common on very old, stable landforms in the humid tropics on the continental shield of South America and Africa. Ferralitization is a common process which is a very advanced stage of hydrolysis where all weatherable minerals have disappeared. This process results in an accumulation of Fe and Al and is favored by low pH and low concentrations of dissolved weathering products. If the parent material is rich in iron a common weathering product is ferrihydrite, $FeOH_3$, which gives the soils its red color. The formation of ferrihydrite is favored by high iron concentration, low organic matter content, high temperature and a pH above 4.

Ferralsols are also characterized by a very stable micro-aggregation giving good porosity and permeability and favorable infiltration rates. This contributes to very good physical properties of Ferralsols that make them less susceptible to erosion. However, these soils are very chemically poor and have a low CEC. The poor nutrient status, and the high capacity to fix added phosphorus (P), makes them unsuitable for agriculture (Driessen et al., 2001).

2.6.3 Alisols

Alisols are very acid soils with subsoil showing an accumulation of high-activity clay minerals, such as illite, vermiculite and smectite having a high CEC due to their large surface area. They exist on Al-rich parent material on hilly or undulating land in the humid tropics of Latin America, West Indies, West Africa, some parts of East Africa and Southeast Asia. Alisols are less weathered than Ferralsols. The formation of these soils involves the hydrolysis of primary minerals and the leaching of silica, followed by a redistribution of clay and weathering of the secondary high activity clays. The process liberates soluble Al or Fe and results in a very infertile soil with often toxic levels of plant available Al. The potential for adsorbing nutrients is high but the presence of nutrient reserves depends on the composition of the remaining weatherable minerals. Due to its low nutrient content and very high level of Al, these soils are not favorable for cultivation, unless the crops are tolerant to high Al concentrations (Driessen et al., 2001).

2.6.4 Nitisols

Nitisols are well-drained, deep and red soils with diffuse horizon boundaries. The subsurface horizon has more than 30 % clay and moderate to strong angular blocky structure that easily falls apart into shiny, nutty elements. These soils are often found on level to hilly land under tropical forest to savannah mostly in tropical Africa on higher altitudes but also on lower altitudes in Asia, South America etc. A Nititsol is formed through ferralitization and nitidization which is the formation of strongly angular, shiny pedfaces in the subsurface horizon as a result of micro-swelling and shrinking. The diffuse horizon boundaries and the crumb subangular blocky structure are due to homogenization by soil fauna. Another characteristic is the content of free and active iron. Even though the clay is dominated by low-activity clays, with relatively low surface area resulting in low capacity of retaining cations, the CEC is higher for Nitisols than for most other tropical soils, explained by the high clay content. The BS can vary between 10-90 % and the pH is normally around 5-6.5. Nitisols are among the most productive soils in the tropics with deep and porous subsoil and good drainage and permeability enabling root penetration (Driessen et al., 2001).

2.6.5 Acrisols

These soils are characterized by an accumulation of low-activity clays in an argic horizon and a very low BS. They are found mostly on acid rock with hilly or undulating topography and are common in Southeast Asia, the Amazon Basin, Southeast USA and in West and East Africa. Acrisols often have a thin surface horizon overlying an albic horizon which is whitish to yellow and overlies the stronger colored argic horizon. The mineralogy of Acrisols are similar to the other tropical soils with no or very few weatherable minerals left but with high concentrations of Al and Fe oxides and a dominance of kaolinite. They have a quite weak microaggregation due to the depletion of sesquioxides in the upper horizons. As many other tropical soils Acrisols have low content of plant nutrients, high capacity for P-fixation and high levels of Al in the soil solution which limits their use for agriculture (Driessen et al., 2001).

2.6.6 Lixisols

Like Acrisols, Lixisols have an argic sub-horizon with low-activity clays and are highly weathered soils. However unlike the Acrisols they have moderate to high BS, explained by an accumulation of bases and low leaching which give rise to a high BS even though a very high degree of weathering. These soils are often found under savannah or woodland vegetation in tropical, subtropical or warm temperate regions with a pronounced dry period. They have a thin brown surface horizon overlying a redder argic horizon and it is often difficult to see a clear evidence of clay illuviation other than an increase in clay content. The Lixisols often have better chemical properties than Ferralsols and Acrisols: e.g absence of Al-toxicity due to their higher pH (Driessen et al., 2001).

3 Material and Method

This project consisted of six parts: identification and description of sites, soil sampling, water infiltration rate measurements, soil profile descriptions, soil analyses and soil profile classifications. The field work was conducted during a six weeks period between the 28th of August and 3rd of October at five different sites located within the Amani Nature Reserve in the East Usambara Mountains, Tanzania. Laboratory analyses were done at SLU Uppsala, Sweden.

3.1 Study site

Amani Nature Reserve (S 5°05′, E 38°40′) is located in Tanga region approximately 32 km northwest from the nearest town Muheza and 75 km from Tanga. The reserve comprises 8389 ha of lowland semi-deciduous forest to submontane evergreen forest and is found in the southern part of the East Usambara Mountains. The area is characterized by large differences in altitude ranging between 150-1100 m.a.s.l. The climate is of typical monsoonal character with rainfall in mainly two seasons and an average annual temperature of 20.6 ˚C. The soils are highly weathered, acid and nutrient poor derived from old, acidic bedrock. (Hamilton, 1989a and b).

3.2 Field activities

3.2.1 Identification and description of sites

Before the start of the field work five representative sites with native stands of *Allanblackia stuhlmannii* were chosen. The criteria of the sites were that they should have both adult and young (2-3 years old) Allanblackia trees and that they should be located at different altitudes. After characterization of several sites, five were decided upon as good representatives (Table 1). The sites were characterized in terms of the associated vegetation, the slope was measured and GPS coordinates recorded. Five young Allanblackia trees were marked at each site. Climatic data of recorded rainfall and temperature was collected from a meteorological station at Marikitanda tea research station, approximately 10 km from Amani Nature reserve head office. Exposed bedrock was sampled from Derema I, Monga and Mbomole.

Table 1. The five selected sites

Site	Name	GPS coordinates	Elevation (m.a.s.l.)	Slope (%)
1	Derema I	S 05º05.074’, E 038 º38.096’	910	58
2	Derema II	S 05 º04.929’, E 038 º37.723’	988	31
3	Monga	S 05 º05.496, E 038 º36.077’	1035	19
4	Mbomole	S 05 º05.769’, E 038 º37.744’	944	43
5	Kibaoni	S 05 º05.432, E 038 º38.451’	816	43

3.2.2 Soil sampling and minor soil profile description

At each site, at the same spot or close nearby (within 1 meter) where young Allanblackia trees were found, five pits were dug to a depth of approximately 50 cm (Fig. 3). Before sampling, a minor soil profile description was carried out to get an overview of the variation of the soils at the different sites. Soil samples were thereafter taken from four depths using metallic cylinders (5 cm Ø), with three replicates per layer. The different depths were 0-5 cm, 5-10 cm, 10-20 cm and 20-40 cm. Samples from each layer were put in plastic bags.

Figure 3. A pit for soil sampling at Derema I.

3.2.3 Water infiltration rate measurements

At each site, the water infiltration rate of the soil was measured using three plastic cylinders (10.2 cm Ø; 22.4 cm depth). Above ground vegetation and litter were removed before the cylinders were pounded 3 to 5 cm into the ground. The soil was pre-wetted by pouring water (approximately 20 liters per cylinder) into the cylinders. After 20 minutes the cylinders were topped up with water and the time it took for the cylinders to run dry was measured. Three replicates per site were measured. The infiltration rate was calculated by dividing the height of the cylinders by the time it took for them to run dry.

3.2.4 Soil profile description

The simple soil profile observations performed during soil sampling were the basis for the decision on where and how many soil profile descriptions were to be conducted later. The sites at the highest, Monga (1035 m.a.s.l.), and lowest altitude, Kibaoni (816 m.a.s.l.) were selected. At each site a pit was dug to a depth of approximately 150 cm and the description was done according to FAO’s guidelines for soil description (FAO, 2006a). Soil was sampled from each horizon.

3.2.5 Preparation of samples

All soil samples were left to air dry at the Amani Nature Reserve head office. Before bringing the soil back to Sweden for analysis, fresh plant residues and visible stones were removed and each fraction was weighed. A representative sub-sample of approximately 250-270 g of each sample was taken for analysis.

In Sweden the sub-samples were left to dry in a drying room with a temperature of approximately 35-40 ˚C and then sieved through a 2 mm plastic sieve to separate the fine earth fraction from stones and gravels. Each fraction was weighed. Dry matter content of the air-dried soil was determined for a subset of samples by drying at 105 ˚C. A graph of dry matter content versus organic carbon concentration was done from which an equation was obtained. With the equation the dry matter content of the rest of the samples could be calculated. All data are presented per dry weight (DW).

3.3 Laboratory work

3.3.1 Soil analysis

Plant-available P was estimated as bicarbonate extractable phosphate (Watanabe & Olsen, 1965). Organic carbon (C) and total N were measured by high temperature induction furnace combustion using LECO CN2000. Electric conductivity (EC) was measured by mixing 15 g of soil with 30 ml of deionized water. The suspension was shaken for 1 h and left to stand overnight. The EC was then measured in the supernatant liquid using an inoLab, Cond 720 laboratory conductivity meter. The soil water suspension was stirred for 30 seconds and then pH (H_2O) and, after addition of 0.01 M calcium chloride ($CaCl_2$), pH ($CaCl_2$) were measured according to Sumner (1994). Concentration of exchangeable base cations was measured in 1 M ammonium acetate extraction (Brix, 2008) with some modifications such as 15 g of soil was weighed and mixed with 100 ml 1 M ammonium acetate. The solution was shaken for 1.5 h and then filtered through Munktell 00K paper instead of centrifugated. Exchangeable acidity was measured in 1 M potassium chloride (KCl) extract and titration to pH 8.3 (Anderson & Ingram, 1993). Effective CEC (ECEC) was calculated as the sum of the exchangeable acidity and the base cations according to Anderson & Ingram (1993). Effective base saturation (BS_{eff}) was calculated as the sum of the exchangeable base cations divided by ECEC. Oxalate extractable Fe, Al and Mn was measured using a method described in ICP forests (2010) and dithionite extractable Fe, Al and Mn was measured using the Holmgren method (van Reuwijk, 2002). The dry bulk density of the soil was calculated by dividing the mass of oven-dry soil by the volume of the soil cylinders. The concentration of exchangeable base cations, BS_{eff}, ECEC, exchangeable acidity, oxalate and dithionite extractable Fe, Al and Mn were only analyzed for samples from the profile descriptions and for one of the small pits. The samples for the soil profile descriptions were also analyzed for texture by the hydrometer method (Day, 1965). Bulk density was on the other hand not calculated for these pits. Percentage water dispersible clay was measured for soil samples 75-150 cm from Kibaoni with the aim to determine the diagnostic horizon ferralic horizon. The hydrometer method was used (Day, 1965) but without adding any dispersing agent but only mixing soil and water.

3.3.2 Soil classification

The soil classification was carried out according to World reference base for soil resources 2006 (FAO, 2006b).

3.3.3 Statistical methods

The results were statistically analyzed using JMP® 9.0.0, except the results for the soil profile descriptions and on exchangeable base cations, BS_{eff}, ECEC and exchangeable acidity, dithionite and oxalate extractable Fe, Al and Mn for the pit from Derema II. The main effects altitude and soil depth and their interactions were tested by ANOVA (followed by Tukey’s test when significant effects were found) and multiple linear regressions. When needed the data were log-transformed to achieve normal distribution of the residuals. Equations for regression analysis were made in Excel.

4 Results

4.1 Associated vegetation and climatic data

In table 2 different tree species growing together with *A. stuhlmannii* are shown. Some species such as *Cephalosphaera usambarensis*, *Maesopsis eminii*, *Tabernaemontana usambarensis*, *Myriathus holstii* and *Newtonia buchananii* existed at all sites whereas several other species were restricted to only one site; *Synsepalum msolo*, *Phytelephas macrocarpa*, *Beilschmiedia kweo*, *Rauvolfia caffra*, *Syzygium spp*. and *Landolphia kirkii* were only identified at Kibaoni.

Table 2. Species grown together with A. stuhlmannii at the different sites

Species	Life form	Derema I	Derema II	Monga	Mbomole	Kibaoni
Cephalosphaera usambarensis	tree^1	x	x	x	x	x
Maesopsis eminii	tree^2	x	x	x	x	x
Allanblackia stuhlmannii	tree^1	x	x	x	x	x
Tabernaemontana usambarensis	tree	x	x	x	x	x
Cyathea manniana	shrub	x				
Clidemia hirta	shrub	x			x	x
Albizia spp.	tree	x	x		x	
Myriathus holstii	tree	x	x	x	x	x
Newtonia buchananii	tree	x	x	x	x	x
Parianari excelsa	tree		x	x	x	x
Sorindeia madagascariensis	tree		x	x	x	
Athocleista grandiflora	tree		x	x	x	x
Psidium spp.	tree		x			
Dracaena usambarensis	shrub		x		x	
Harungana madagascariensis	tree			x		
Ficus sur	tree			x		
Macaranga kilimandscharica	tree				x	
Polyscias fulva	tree				x	
Synsepalum msolo	tree					x
Phytelephas macrocarpa	palm					x
Beilschmiedia kweo	tree					x
Rauvolfia caffra	tree					x
Syzygium spp.	tree					x
Dregea abyssinica	climber			x		x
Landolphia kirkii	climber					x

1 Endemic species to East Usambara

2 Invasive species to East Usambara

January- March are the warmest months in the study area with an average temperature of 22.6 ˚C (Fig. 4). The coldest months are July-August with an average temperature of 17.8 ˚C (Fig. 4).

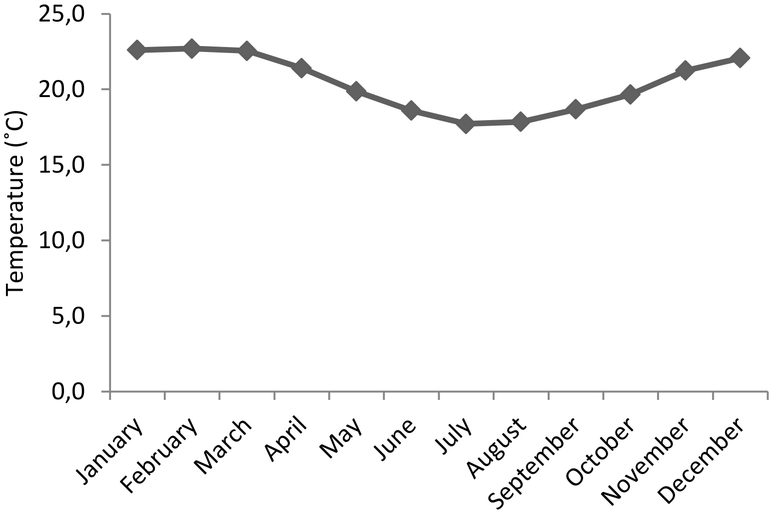


Figure 4. Average monthly temperature (˚C) 1993-2010.

The highest rainfalls are generally during March-May which is the long rains and the other peak during October-December which corresponds to the short rains (Fig. 5). The total rainfall is on average 816 mm during the long rains and 457 mm during the short rains.

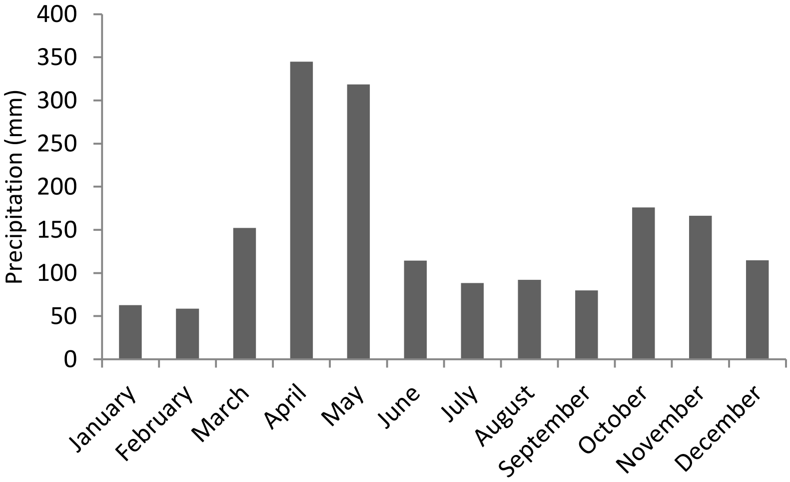


Figure 5.Total monthly precipitation (mm) 1967-2010.

4.2 Infiltration rates

The infiltration rate varied from 2120-6840 mm/h but was overall very high at all five sites (Table 3).

Table 3. Average infiltration rate (mm/h) at the different sites (n=3)

Derema I	Derema II	Monga	Mbomole	Kibaoni
6840	4450	2120	5190	3260

4.3 Soil profile description

4.3.1 Soil profile 1 – Kibaoni

Location and site

Tanzania, Tanga region, Muheza district, Amani division, Amani ward, Shebomeza village. Close to Derema tea factory (approximately 1.5 km by road) and approximately 500 m to river. Sloping land, straight and concave slope, positioned on middle slope. Site: S 05º05.386’, E 038 º38.435’, slope: approximately 43 %. Elevation: 834 m.a.s.l.

Parent material

Gneiss dominated by quartz and feldspar and some occurrence of mica, hornblende and garnet from the Proterozoic period (2500 – 542 million years ago) (Lundqvist, S., pers. comm., 2013).

Vegetation and land use

Evergreen broad-leaved forest slightly disturbed by clearing. Land use: Nature reserve.

Brief description of the soil profile

Darker upper layers with more organic material, more roots and some soil animals, overlaid layers with moderate blocky and sub-angular structure but which very easily broke into a small, crumbly and porous structure. From 41 cm, many small pores and small white quartz minerals occurred. Pieces of charcoal were found across the horizon around 50 cm. From 75 cm the profile was dominated by very porous, weathered rock fragments (2-10 cm) and the color of the soil appeared more pink/reddish.

A_{h1} (0-2 cm); Abrupt, smooth boundary; dark brown (7,5YR 3/3) moist, sandy clay with much organic material; weak granular; many medium-coarse roots and common very fine-fine roots; ants, cockroaches, larvae common.

A_{h2} (2-36 cm); Clear, smooth boundary; brown (7,5YR 4/4) moist, sandy clay/clay with very few weathered, very porous sub-rounded/rounded rock fragments; fine to medium moderate blocky sub- angular; many medium-coarse roots and few very fine-fine roots.

B_{o1} (41-65 cm); Gradual, wavy boundary; reddish brown (5YR 4/8) moist, clay with few weathered, very porous sub-rounded/rounded rock fragments, medium to coarse moderate blocky sub-angular; common medium-coarse roots and few very fine-fine roots; pieces of charcoal at 50 cm across the horizon.

B_{o2} (75-150 cm); reddish brown (5YR 4/8) moist, clay/sandy clay with abundant 2-10 cm weathered, very porous sub-rounded/rounded rock fragments; medium moderate blocky sub-angular; common medium-coarse roots and few very fine-fine roots.

Biogeochemical properties (Table 4, 5 and 6)

The clay content varied between 39 % - 52 % and was lower in the upper 36 cm and increased slightly in the upper B_{o1} to decrease again in B_{o2}. The silt fraction varied between 10-18 % with the highest content in the lower A_{h2}-horizon and upper B_{o1}. The sand content was the highest in the upper 17 cm and in the B_{o2}-horizon. The soil type was classified as sandy clay in the upper 17 cm and the lower B_{o2}-horizon and as clay for the rest.

The soil pH was generally very low throughout the profile with slightly higher pH in the A-horizon and the lower part of the B_{o2}-horizon. The EC and the concentrations of organic C and total N were highest in the A-horizon and decreased further down in the profile.

The bicarbonate extractable P concentration was very low throughout the profile although somewhat higher in the upper 2 cm, and decreased rapidly with no measurable P available at lower depths. The concentration of base cations, ECEC and BS_{eff} were low throughout the profile with slightly higher values in the upper 0-2 cm. From 2 cm the concentration of exchangeable Al, Fe and Mn (KCl) decreased with depth and from 17 cm the exchangeable acidity decreased. The concentrations of dithionite extractable Al and Fe were higher in the B horizons whereas oxalate extractable Al varied throughout the profile and the concentration of oxalate extractable Fe was quite constant. For Mn, both dithionite and oxalate extractable concentrations decreased with depths.

Soil classification

Vetic, Acric Ferralsol (Humic, Alumic, Clayic)

4.3.2 Soil profile 2 – Monga

Location and site

Tanzania, Tanga region, Muheza district, Amani division, Mbomole ward, Sakale village. Located in a small forested area, near tea plantations, between the Monga trail (30-40 m) and the main road between Monga and Ndola (250 m). Sloping land, positioned on upper part of the slope. Site: S 05º05.486’, E 038 º36.079’, slope: approximately 19 %. Elevation: 1039 m.a.s.l.

Parent material

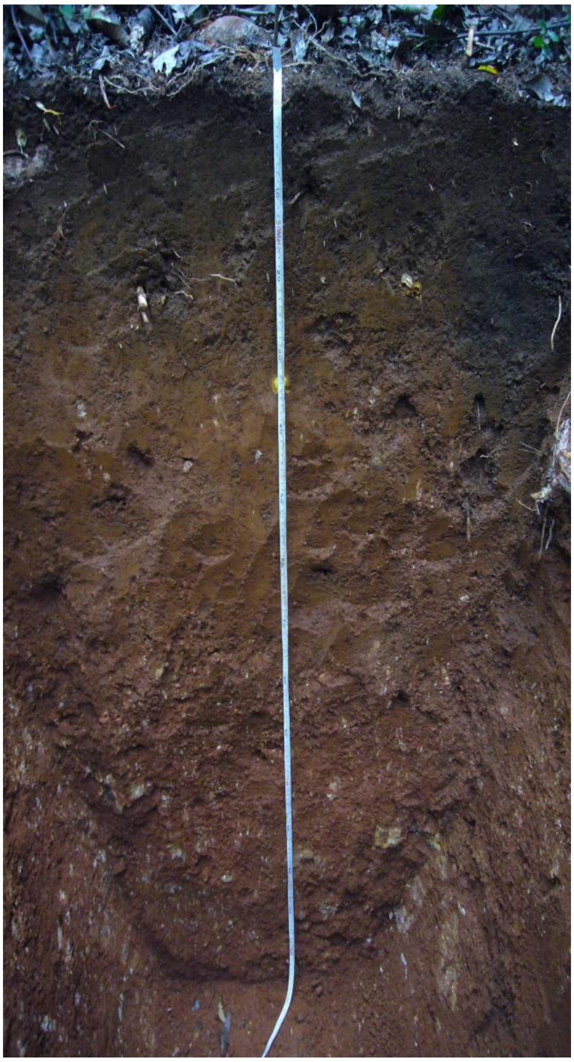
Gneiss dominated by quartz and feldspar, containing less garnet and being more rotten compared to Kibaoni. From the Proterozoic period (2500 – 542 million years ago) (Lundqvist, S., pers. comm., 2013).

Vegetation and land use

Evergreen broad-leaved forest disturbed by clearing of trees and collection of fruits and other non- timber forest products (NTFP). Land use: Nature reserve

Brief description of the soil profile

Top soil browner with more organic material, roots, some occurrence of soil animals and a big hole at 10 cm, overlying layers with moderate blocky sub-angular structure but which very easily broke into a small, crumbly and porous structure. When aggregate broke, many pores became visible with shiny, grey/purple, mud or clay covered coatings. Small, white, glass like quartz minerals occurred throughout the profile but became more common from 25 cm. From 70 cm the profile was dominated by very porous, weathered rock fragments (2-10 cm) and the color of the soil appeared more pink/reddish.



A_h (0-15 cm); Gradual, wavy boundary; brown (7,5YR 4/4) moist; clay/clay loam; very few medium rock fragments; weak granular; many medium-coarse roots and common very fine-fine roots; a few soils animals such as ants, larvae, beetles.

B_{t1} (25-57 cm); Diffuse, wavy boundary; reddish brown (5YR 4/8) moist; clay; fine-coarse, sub-rounded, weathered, very porous rock fragments common, medium to coarse moderate blocky sub-angular; many medium-coarse roots and very few very fine-fine roots.

B_{t2} (70-150 cm); reddish brown (5YR 4/8) moist; clay; fine-coarse weathered, very porous sub-rounded/rounded rock fragments dominant; medium moderate blocky sub-angular; few medium-coarse roots.

Biogeochemical properties (Table 4, 5 and 6)

The clay content varied between 40-59 % and was highest in B_{t1} and upper $B_{t2.}$ The fraction of silt was the highest in A_h and decreased with depth but increased in the lower part of B_{t2}. The content of sand varied between 29-41 % and was highest in A_h and B_{t2}. A_h was classified as clay/clay loam and the other horizons as clay.

The soil pH was generally very low throughout the profile with slightly higher values in A_h and B_{t1}. The EC and the concentrations of organic C, total N and base cations were highest in A_h and decreased with depth. The ECEC was relatively constant in the profile although somewhat higher in A_h. The BS_{eff} was higher in A_h and decreased slightly further down in the profile.

The bicarbonate extractable P concentration was generally very low but was higher in A_h, lower in B_{t1} and increased slightly again in B_{t2}. The concentration of exchangeable Al and Fe (KCl) varied irregularly whereas Mn decreased with depth. The exchangeable acidity was the highest in A_h, then decreased to increase again. The concentrations of dithionite extractable Al and Fe were highest in the B horizons down to 100 cm. The concentration of dithionite extractable Mn decreased to 70 cm and then varied in deeper layers. For oxalate extractable Mn the concentration decreased with depth and the same for oxalate extractable Al after 57 cm. For oxalate extractable Fe the concentration was quite constant throughout the profile.

Soil classification

Vetic Cutanic Acrisol (Alumic, Humic, Profondic, Clayic, Chromic).

Table 4. Particle size distribution and textural class for soil profiles 1 and 2

		Particle size distribution (% of fine soil)				
Depth (cm)	Horizon	<0.002 (mm)	0.002-0.06 (mm)	0.06-2 (mm)	Textural class	>2 mm (%)
Kibaoni						
0-2	A_{h1}	39	10	51	sandy clay	3.0
2-17	A_{h2}	41	10	49	sandy clay	3.0
17-36	A_{h2}	46	15	39	clay	1.0
36-41	Boundary	-	-	-	-	-
41-56	B_{o1}	52	18	30	clay	1.0
56-65	B_{o1}	49	13	38	clay	2.0
65-75	Boundary	51	11	38	clay	8.0
75-105	B_{o2}	45	17	38	clay	11.0
105-150	B_{o2}	42	10	48	sandy clay	13.0
Monga						
0-15	A_h	40	19	41	clay/clay loam	2.0
15-25	Boundary	-	-	-	-	-
25-40	B_{t1}	54	17	29	clay	0
40-57	B_{t1}	59	14	27	clay	10.0
57-70	Boundary	59	13	28	clay	8.0
70-100	B_{t2}	57	12	31	clay	24.0
100-150	B_{t2}	50	16	34	clay	34.0

Table 5. Chemical data for soil profiles 1 and 2

Depth	Horizon	pH		EC	Org	Total	C:N	Bicarbonate
(cm)		H_2O	$CaCl_2$	(µS/cm)	C (%)	N (%)		extract. P (µg g-1)
Kibaoni								
0-2	A_{h1}	4.9	4.5	350	8.27	0.63	13	7.45
2-17	A_{h2}	4.3	3.8	59.3	2.26	0.20	11	0.72
17-36	A_{h2}	4.3	3.8	37.8	1.57	0.13	12	0.00
36-41	Boundary	-	-	-	-	-	-	-
41-56	B_{o1}	4.3	3.7	31.5	1.21	0.09	14	0.00
56-65	B_{o1}	4.2	3.7	29.3	0.89	0.07	12	0.00
65-75	Boundary	4.2	3.7	35.9	0.93	0.07	13	0.18
75-105	B_{o2}	4.3	3.8	32.5	0.76	0.06	13	0.18
105-150	B_{o2}	4.4	3.9	32.5	0.55	0.04	13	0.13
Monga								
0-15	A_h	4.6	4.0	81.5	2.74	0.26	10	1.66
15-25	Boundary	-	-	-	-	-	-	-
25-40	B_{t1}	4.7	4.0	25	1.19	0.11	11	0.23
40-57	B_{t1}	4.6	3.9	28.1	1.18	0.11	11	0.13
57-70	Boundary	4.6	3.9	26.2	1.06	0.10	12	0.23
70-100	B_{t2}	4.5	3.8	29.9	1.00	0.09	12	0.27
100-150	B_{t2}	4.4	3.9	23.5	0.55	0.04	14	0.48

Table 6. Chemical data for soil profiles 1 and 2

		Oxalate			Dithionite			KCl			Exchange-able acidity	Ammonium acetate					
Depth	Horizon	Al	Fe	Mn	Al	Fe	Mn	Al	Fe	Mn		Ca	K	Mg	Na	ECEC	BS_{eff}
(cm)		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	$cmol_c$	$cmol_c$	$cmol_c$	$cmol_c$	$cmol_c$	$cmol_c$	%
Kibaoni																	
0-2	A_{h1}	1330	1030	240	6380	38380	393	18.3	1.60	50	0.44	4.63	0.44	4.53	0.07	10	95.7
2-17	A_{h2}	1580	1080	108	7170	50460	160	163	2.19	7.68	1.95	0.08	0.07	0.15	0.03	2.25	13.5
17-36	A_{h2}	1750	1010	61	9130	65900	119	160	1.45	2.69	1.84	0.03	0.03	0.07	0.03	1.98	6.78
36-41	Boundary	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
41-56	B_{o1}	1500	970	32	8360	70090	84	142	1.79	2.24	1.64	<0.02	0.01	0.03	0.03	1.69	4.1
56-65	B_{01}	1480	1020	22	9360	71270	82	132	1.25	1.80	1.59	<0.02	0.01	0.02	0.02	1.63	3.6
65-75	Boundary	1430	1100	16	8580	61680	68	128	1.40	1.30	1.60	<0.02	0.02	0.03	0.03	1.64	3.7
75-105	B_{o2}	1410	1100	8	8360	61780	62	113	0.65	1.10	1.38	0.03	0.02	0.03	0.03	1.45	5.0
105-150	B_{o2}	1350	1130	7	8340	72800	59	75.3	0.40	1.00	0.98	<0.02	0.01	0.03	0.05	1.02	5.6
Monga																	
0-15	A_h	2030	1410	479	7730	50680	552	90.5	0.85	29.88	1.15	1.05	0.11	0.61	0.03	2.92	60.5
15-25	Boundary	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25-40	B_{t1}	1360	1120	48	11320	74690	104	64	3.34	2.99	0.79	0.81	0.02	0.30	0.04	1.92	58.6
40-57	B_{t1}	1630	1430	34	12300	79070	87	73.8	2.80	0.85	0.91	0.72	0.02	0.36	0.05	2.01	54.7
57-70	Boundary	1570	1380	16	11880	84380	70	85	3.39	0.45	1.09	0.43	0.02	0.29	0.03	1.82	40.3
70-100	B_{t2}	1350	1090	9	11370	81710	224	98.5	8.19	0.35	1.14	0.26	0.02	0.23	0.03	1.64	30.8
100-150	B_{t2}	1260	730	2	8010	65430	39	80.2	7.04	0.15	0.85	0.10	0.01	0.13	0.03	1.09	22.3

4.4 Soil analysis of transect sites

For the different concentrations of bicarbonate extractable P, organic C and total N, and for EC and bulk density a similar trend was found where depth was the most significant factor (ANOVA) (Table 7) with higher concentrations and higher EC, but lower bulk density in the upper layers. The variation in concentrations and amounts was generally large between the replicates and greatest in the upper layers. For all parameters there were differences between sites at some or at all depths (Appendix 1).

The pH (H_2O and $CaCl_2$) correlated and both varied greatly between replicates and between sites and there was no significant effect of depth on pH (H_2O) but on pH ($CaCl_2$) (Table 7). There was a weak but significant correlation between altitude and pH (H_2O and $CaCl_2$) for all depths (Table 8) with higher pH at higher altitudes in comparison to lower altitudes.

The concentration of organic C was low (in average 2.22 % at 10-20 cm and 1.49 % at 20-40 cm), apart from in the upper 0-10 cm (Table 7). Depth thus had a significant effect on organic C concentration with much lower concentrations at 20-40 cm compared to 0-5 cm. No altitudinal effect was seen (Table 8). Depth also had a significant effect on the amount of organic C and deeper layers had significantly higher amounts of organic C than upper layers (Table 7).

The total N concentration was highest at 0-5 cm and decreased with depth (Table 7). There was a significant correlation between depth and total N and deeper layers had significantly lower concentration than upper layers. There was no correlation found between altitude and the total N concentration (Table 8). Depth had a significant effect on the amount of total N and deeper layers had more total N compared to shallow layers (Table 7). No altitudinal effect was seen.

The concentrations of bicarbonate extractable P were overall very low at all depths and sites (Table 7). Depth had a significant effect on P concentration and P concentration at 0-5 cm and 20-40 cm were the significantly highest and lowest, respectively (Table 7). Furthermore, P concentrations at 0-5 cm were significantly higher at lower altitudes (Table 8) than at higher altitudes. The amount of bicarbonate extractable P also differed significantly between depths. At 0-5 cm there was also a weak correlation between altitude and the amount of P with slightly higher amounts at lower altitudes (Table 8).

The variation in EC between the different depths was big with much higher values in the upper layers compared to deeper layers (Table 7). At 20-40 cm there was a significant correlation (Table 8) between altitude and EC where lower altitudes had higher EC in comparison to higher altitudes, although the difference was slight.

The C:N ratio differed significantly between some depths (Table 7). The C:N ratio below 10 cm was higher at lower altitudes compared to higher altitudes (Table 8).

Deeper soil layers had significantly higher bulk density than shallow layers (Table 7) but there was no correlation between altitude and bulk density.

Table 7. Min, max and mean values for different parameters and depths. Values followed by different letters show significant differences between the depth layers ($p<0.05$)

	pH (H_2O)	pH ($CaCl_2$)	C		N		Bicarbonate extract. P		EC	C:N	Bulk density
Depth			%	g m^{-2}	%	g m^{-2}	µg g^{-1}	g m^{-2}	µS cm^{-1}		g cm^{-3}
0-5 cm											
Min	3.55	3.13	3.63	0.34	0.28	0.025	1.78	1.80E-05	134	12.4	0.49
Max	5.56	5.27	25.7	0.63	1.59	0.042	23.2	7.91E-05	743	16.2	2.02
Mean	4.54	4.13^{a}	7.29^{a}	0.44^{a}	0.52^{a}	0.032^{a}	5.99^{a}	3.54E-05^{a}	294^{a}	13.7^{ab}	1.39^{a}
5-10cm											
Min	3.58	3.31	2.24	0.25	0.18	0.020	1.27	1.41E-05	54.7	11.5	1.47
Max	5.60	5.20	6.22	0.47	0.49	0.037	8.16	6.83E-05	240	14.5	2.43
Mean	4.44	3.99^{ab}	3.67^{b}	0.34^{b}	0.28^{b}	0.026^{b}	3.19^{b}	2.95E-05^{a}	137^{b}	13^{c}	1.96^{b}
10-20 cm											
Min	3.90	3.57	1.48	0.37	0.11	0.028	0.83	2.10E-05	30.2	10.9	1.95
Max	5.32	5.73	3.23	0.71	0.24	0.050	2.27	5.13E-05	125	15.4	2.63
Mean	4.40	3.99^{ab}	2.22^{c}	0.51^{c}	0.17^{c}	0.039^{c}	1.51^{c}	3.50E-05^{a}	65.6^{c}	13.3^{bc}	2.35^{c}
20-40 cm											
Min	3.93	3.62	0.89	0.54	0.066	0.040	0.39	2.10E-05	20.6	11.8	2.03
Max	5.05	4.33	1.95	1.02	0.14	0.069	1.56	7.20E-05	74.4	17.4	3.02
Mean	4.38	3.87^{b}	1.49^{d}	0.76^{d}	0.11^{d}	0.053^{d}	0.89^{d}	4.50E-05^{b}	35.3^{d}	14.1^{a}	2.56^{d}
P value	ns*	0.037	<0.001	<0.001	<0.001	<0.001	<0.001	0.0002	<0.001	0.0002	<0.001

* not significant

Table 8. The effect of altitude on the different parameters for each soil depth illustrated by slope of regression and P values from linear regressions. No effect of altitude is marked with - .

	pH (H_2O)	pH ($CaCl_2$)	C		N		Bicarbonate extract. P		EC	C:N	Bulk density
Depth			%	g m^{-2}	%	g m^{-2}	%	g m^{-2}	µS cm^{-1}		g cm^{-3}
0-5 cm											
Slope of regression	0.0043	0.0048	-	-	-	-	-0.0168	-0.00000007	-	-	-
P value	0.0029	0.0019	-	-	-	-	0.0089	0.0316	-	-	-
5-10cm											
Slope of regression	0.0030	0.0033	-	-	-	-	-	-	-	-	-
P value	0.0127	0.0046	-	-	-	-	-	-	-	-	-
10-20 cm											
Slope of regression	0.0020	0.0026	-	-	-	-	-	-	-	-0.0079	-
P value	0.0353	0.0197	-	-	-	-	-	-	-	0.0029	-
20-40 cm											
Slope of regression	0.0020	0.0009	-	-0.0008	-	-	-	-	-0.0903	-0.0083	-
P value	0.0074	0.0298	-	0.0153	-	-	-	-	0.0035	0.0235	-

The chemical analysis of samples from the pit at Derema II (Table 9) revealed quite similar characteristics as the soil profiles at Kibaoni and Monga with low concentration of base cations and ECEC for 10-40 cm with slightly higher concentrations at 0-10 cm. The BS_{eff} was high for 0-20 cm but decreased considerably at 20-40 cm. The concentration of Al increased with depth and for Fe and Mn the concentrations increased down to 20 cm. The exchangeable acidity also increased with depth. Dithionite extractable Al and Fe increased with depth whereas Mn decreased. The concentration of oxalate extractable Al was higher at lower depths whereas the concentration of oxalate extractable Fe varied. Oxalate extractable Mn decreased with depth.

Table 9. Chemical data for one pit at Derema II

	Oxalate			Dithionite			KCl				Ammonium acetate					
	Al	Fe	Mn	Al	Fe	Mn	Al	Fe	Mn	Exchangeable acidity	Ca	K	Mg	Na	ECEC	BS_{eff}
Depth (cm)	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	$cmol_c$	$cmol_c$	$cmol_c$	$cmol_c$	$cmol_c$	$cmol_c$	%
0-5	1230	1420	248	8100	58840	313	0.3	0.70	1.90	0.056	13.0	0.26	5.28	0.10	18.6	99.7
5-10	1180	1350	191	9930	68280	274	0.80	0.05	7.13	0.052	7.40	0.11	2.64	0.08	10.2	99.5
10-20	1420	1140	112	11800	78010	179	24.4	0.60	7.59	0.34	2.38	0.06	0.69	0.05	3.46	90.2
20-40	1770	1240	37	15220	107080	87	84.2	0.25	1.55	1.05	0.26	0.02	0.12	0.04	1.46	27.9

5 Discussion

5.1 Selection of sites

In the East Usambara *A. stuhlmannii* occurs on quite steep slopes on altitudes above 800 m.a.s.l. (Munjuga et al., 2010), which can indicate that they have special requirements on altitude and topography, and - related to this – on temperature, vegetation etc. This motivated why the sampling was located along an altitudinal transect. Trees in the Amani Nature Reserve were only found at 816 -1035 m.a.s.l. and the selection of sites was mainly determined and restricted by where native stands of *A. stuhlmannii* were found. For this reason two of the sites, Monga and Mbomole, were also not located along the attempted transect line albeit on different altitudes than the other sites.

Overall the location of Allanblackia occurred on quite steep slopes which could be explained by the fact that when mature fruits fall they continue to fall down the slope where the seeds at some point can germinate after being buried by the giant rat occurring in the area. Often, the saplings were found downhill from the mother tree. Moreover, it appears that if the canopy cover is too dense the small seedling will not germinate so therefore we could not find any young trees where the canopy was very dense. This has also been observed in a minor student project connected to the Tropical Biology Association (TBA) (Elinge & Ndayishimiye, 2003). The chosen sites were representative and at the same time located where the sampling was practicable, they also met the requirements on the occurrence of both old and young trees.

5.2 Associated vegetation and climatic data

One of the objectives of this report was to characterize associated vegetation to *A. stuhlmannii* and to obtain climatic data. Some species were identified at all five sites such as *Cephalosphaera usambarensis*, *Maesopsis eminii*, *Tabernaemontana* *usambarensis*, *Myriathus holstii* and *Newtonia buchananii*. These species are all very common in East Usambara and around Amani (Ministry of Natural Resources and Tourism, 2010) and occur in moist evergreen forests of the region. Other species were only identified at some of the sites. The associated vegetation was identified by our field guide and no published methodology was used. The plants observed at each site were noted and as the field work proceeded more species were identified (Table 2). This was probably due to the fact that our field guide got used to the task and not necessarily that more species actually were found. This information may therefore be quite uncertain and should not be interpreted as a real difference in vegetation between sites but rather gives some examples of species found together with *A. stuhlmannii*. Similar associated vegetation should give rise to more or less similar plant litter and organic material which influence organic C, pH, nutrient concentrations etc and should therefore result in quite similar properties of the soil between sites if one considers the influence of vegetation on soil formation. However, it is very difficult, if not impossible, to isolate just one soil forming factor since there are many interactions affecting the soil (Van Wambeke, 1992).

The results from the climatic data (Figs. 4 and 5) showed characteristic rain patterns and temperature for monsoon climate common to areas close to the Indian Ocean, with a hot and humid climate with two peaks of rainfall (Hamilton, 1989b). The long and short rains are followed by drier periods but even during these months there is enough rainfall for cultivation and the favorable climate makes it possible to grow crops all year around (Hamisi, pers comm., 2012).

5.3 Soil profiles and transect sites

One objective with this study was to describe the soil profiles within the study area. Since the altitude of the two selected profiles did not vary greatly the soils did not differ greatly in their characteristics and had some similar features. They were however classified as two different soils. Soil profile 1 was classified as Vetic, Acric Ferralsol (Humic, Alumic, Clayic), emphasizing the low ECEC, the accumulation of clay, the organic C concentration, having an Al saturation of more than 50 % in major part of the profiles, and the high clay content. Soil profile 2 was classified as Vetic Cutanic Acrisol (Alumic, Humic, Profondic, Clayic, Chromic), referring to the low ECEC, the clay coatings found at the inside of the aggregates, the high concentrations of Al, the organic C concentration, the change in clay content with depth, the high clay content and the intense color of the soil.

Both soil profiles had a high content of sand, very low pH, low concentrations of nutrients and an accumulation of sesquioxides (Table 4, 5 and 6) which was expected and confirms the hypothesis that the soil belongs to the “tropical” group of soils according to FAO. Profile descriptions from another study conducted in Kwamsambia, quite close to Amani, and on similar altitudes found the soils to be highly leached, acidic and with low fertility. Soils on lower altitudes, in Kwamgumi, were on the other hand less leached, had higher concentrations of base cations and were slightly more fertile (Hamilton, 1989a). The soils on similar altitudes to the ones in my study were classified as Orthic and Xanthic Ferralsols and Acrisols, thus very similar to the soils in my study. Further comments on the soils from Hamilton (1989a) were that upland soils were quite deep, around 1.5 m, and that they were dominated by rotten rock from 1 m. In my study, the profiles were dominated by rotten rock from approximately 70 cm, and below 150 cm there were many stones and the soil was too hard to dig. In my study charcoal was found in one of the profiles, which also was found by Hamilton (1989a) and could be a remnant from earlier settlement in the area.

The generally low pH throughout the soil profiles and in soils from the transect sites reflected the old age (Proterozoic era) of the mountain range (Lundqvist, S., pers. comm., 2013), leaving time for advanced weathering and leaching of base cations. The parent material was identified as gneiss which is an acid rock dominated by weathering resistant minerals such as quartz and feldspar (Lundqvist, S., pers. comm., 2013). This type of rock is common in the Eastern Arc Range. The wet climate (Figs. 4 and 5) conducive to extensive weathering and leaching explaining the low concentration of base cations and the low ECEC which is very common for soils in the tropics (Young, 1976). The low concentration of base cations was also illustrated by the very low BS_{eff}, especially for soil profile 1, except for the A-horizon where the organic material containing more base cations results in higher BS_{eff}. In soil profile 2 the BS_{eff} was much higher at lower depths compared to soil profile 1 explained by higher concentrations of Ca and Mg. However in A_h the BS_{eff} was lower than for soil profile 1 and the reasons behind these differences are unknown. The concentrations of base cations in the soils were in the same range as found in the soil profile description by Hamilton (1989a) and similar to other studies on Ferralsols and Acrisols (Opala et al., 2013; Ngome et al., 2011; Daroub et al., 2003; Kifuko et al., 2007). These types of soils are often dominated by kaolinite which due to its low negative charge and specific surface area results in a low capability of binding nutrients and participating in other surface reactions. This characteristic of kaolinite and the positive charges of sesquioxides result in an anion exchange capacity (AEC) that is often higher than CEC in Ferralsols. ECEC is often a more realistic measure than CEC at a fixed near neutral pH on very acid soils (Eriksson et al., 2005). Thus ECEC was preferred here when economic limitations prohibited determination of both. Neither was the AEC determined, and therefore the relationship between the CEC and AEC for these particular soils is unknown. The slightly higher ECEC observed in the upper horizons is presumably associated to the organic material which can contribute largely to the CEC of tropical soils.

Acid oxalate extractable and dithionite extractable Al and Fe is used as a measure of active oxides and can also be an indication of accumulation of sesquioxides and the results showed that especially the subsoil of the two profiles contained high concentrations of these (Table 6). This indicates a soil with a lot of pH dependent charges and high P-fixing capacity (McKeague & Day, 1966). To enable comparison with data from soil investigations in the region plant-available P was estimated as bicarbonate extractable phosphate (Watanabe & Olsen, 1965), as recommended by The Tropical Soil Biology and Fertility Institute (Anderson and Ingram, 1993). The concentrations of plant-available P were overall very low throughout the profiles and in the soil from the transect sites. This has also been found in other studies from Tanzania and Kenya (Opala et al., 2013; Ngome et al., 2011; Daroub et al., 2003; Kifuko et al., 2007). The low concentrations are probably largely due to the fixation of P by the sesquioxides, which normally dominate soils such as these (Ahn, 1993). There was, however, a small increase in concentrations in the deepest layers (Table 5). This was probably related to the almost total lack of roots in these whereas roots would have taken up P from the overlying subsoil layers and translocated it to the topsoil via litter-fall. (Rubio et al., 2012; Bhat & Nye., 1973; Saleque & Kirk., 1995). The resulting organic material in the upper layers can explain the higher availability of P found there and also the lower concentrations of dithionite extractable Al and Fe.

The infiltration rate was extremely high at all sites (Table 3). The measurements were to be conducted using a protocol from the International Center for Tropical Agriculture (CIAT) measuring during 3 h, but since the infiltration rate was so high only one reading could be done to be able to note a very high infiltration. Also, the measurement may not be so accurate due to the fact that the water infiltrated extremely fast and that single infiltration rings were used. Similar results have, however, been found in another study from the East Usambara (Bruen, 1989). The infiltration rate was reported to be extremely high and the soils were not saturated even after 2.5 h of measurement, resembling what we saw during our measurements. The high infiltration rate can probably be explained by the large amount of roots and root channels found in the profiles. Another explanation to the high infiltration rate could be the stable micro- aggregates found in both profiles.

Another objective with this study was to characterize soil chemical and physical properties along an altitudinal transect. The results showed that all the soils had very low pH and concentrations of plant available P, and that organic C and total N were concentrated in the upper layers. This was expected results and is common features for many tropical soils. Depth had a strong impact on several variables, but although there were differences between sites the altitude had a very little effect. The hypothesis that soils on lower altitudes should be slightly more fertile with less acidic pH and more nutrients was thus generally not supported. The effect of altitude was however observed for P at 0-5 cm (Table 8) with a weak trend of higher concentrations at lower altitudes. A possible explanation could be that leached nutrients from upland soils are accumulated on lower altitudes. However, since all sites were located on quite high altitudes and on steep slopes it seems less likely. Furthermore, since P is strongly fixated in these types of soils it is not likely that P will leach to lower altitude soils. Altitude also seemed to have an effect on pH with lower pH at lower altitudes, which is opposite results to what Hamilton (1998) found in a study conducted in the East Usambara. Hamilton observed differences in pH at different altitudes, similar to the ones in my study. He found the pH at 1050 m.a.s.l. to be 4 and at 850 m.a.s.l. 6.5, which he explained by the wetter climate at higher altitudes. He also observed that the higher altitude soils had a humus accumulation in the upper 10 cm, which was not observed in this study. However, differences in parent material and vegetation etc between sites may explain the different results between the studies.

Depth thus had the most significant effect for all parameters except for pH. The concentrations of P, organic C and total N were higher in the upper 10 cm (Table 7) which could be explained by the higher content of organic material found in these layers. The differences between depths partly disappeared when looking at the amount of P, C and N (g m^{-2} depth layer $^{-1}$) (Table 7) where the bulk density was taken into account. The differences in thickness between the layers also explain the different results between concentrations and amounts. These results illustrate the risk to overestimate the content of nutrients in the surface horizons if looking at concentrations, especially if it is an organic horizon. However, even though one person conducted all the sampling practical difficulties made it difficult to be consistent and this may have had an impact on the bulk density and the amounts of organic C, total N and available P, why these results should be interpreted carefully. Nevertheless, it is clearly illustrated that the amounts of organic C, total N and plant-available P was dependent on soil density and depth as well as the concentration. For example the upper and thinner layers had higher concentrations of organic material, and thus had lower bulk density, which inferred smaller amounts of organic C, total N and available P than in the deeper and thicker layers.

5.4 Implications for growing Allanblackia on farms

The areas where the Allanblackia species grow, from West to East Africa, are characterized by warm and humid climate with an excess of rainfall, tropical vegetation and highly weathered, nutrient poor and acid soils which have undergone intensive leaching (FAO-Unesco, 1977). Literature confirms that *Allanblackia* *parviflora* is found on well drained, acid soils (pH 3.8-4.1) with low concentration of nutrients and low BS (Van Rompaey, 2005; Orwa & Oyen, 2007). It may be that the species have adapted to grow on very poor soils and that they have developed a tolerance for high Al concentrations, which normally is toxic to plants in high concentrations and which is common in acid soils. The tolerance for high Al concentration is a common phenomenon among several plants and crops in tropical regions for example tea, cassava, rubber, oil palm and coffee (Ahn, 1993). Along with this study another project examining possible plant-mycorrhiza interaction was conducted. Mycorrhiza is known to facilitate nutrient uptake, especially of P, for plants and most plants live in symbiosis with some kind of mycorrhiza fungi (Marschner & Dell, 1994). Such a symbiosis, facilitating nutrient uptake, can be one reason to why Allanblackia manage to grow so well on poor soils.

One of the aims with the domestication of Allanblackia is to integrate the tree in agroforestry systems at small holder farms. Many of the farms are located in the same area as the native stands and therefore one can assume the soils to be similar and well suited for Allanblackia's requirements on soil properties. However, if the tree is to be introduced to new areas the soil may be quite different to the soil requirements of Allanblackia species. It is therefore important to know these requirements to be able to estimate the chance of success and, if deemed satisfactory, how the soil requirements can be met to improve the growing conditions. It could for example be that Allanblackia are Fe inefficient species (Marschner, 2012) and do not grow well on more fertile soils because they are prone to Fe deficiency if pH is too high (above e.g pH 6). If Allanblackia is integrated in farming systems, the pH of the soils may be higher than in the native areas due to application of soil amendments and fertilizers or inherent soil composition. This can make Fe less available and cause deficiency and limited plant growth. Further studies are needed to elucidate this though. On the other hand can addition of nutrients probably benefit the growth of Allanblackia as well as for arable crops. If the growing conditions of Allanblackia are optimized and the competition from other species is reduced, it is also possible that there will be a broader range of suitable soil requirements and environment for optimal growth of Allanblackia as compared to the natural environment where there is more competition.

In Ghana Allanblackia is grown together with cacao and function as a shade tree providing the crop with favorable microclimate (Pye-Smith, 2009). In a study by Meshack (2004) in Amani the farmers said that they use Allanblackia as stake for climber crops and for providing shade for cardamom. Moreover they said that Allanblackia could be planted as a farm boundary but also scattered and they appreciated the tree as an agroforestry tree. However, some farmers stated that Allanblackia was not compatible with maize, cassava, beans and potatoes, which may be a problem since these are very important crops in the area. It is also important that Allanblackia is compatible with other crops in terms of soil requirements. Furthermore, bringing Allanblackia into the field can attract animals such as the giant rat which may attack other crops such as maize and cassava (Jamnadass et al., 2010). Characteristic for agroforestry systems are their multipurpose functions helping farmers to diversify their production and thereby improving their livelihoods. Since Allanblackia trees already are used for several purposes, they should be well suited for agroforestry systems even though their integration to such a system and the impacts it would have needs to be further investigated.

The main benefit of growing Allanblackia is the extra income for farmers generated by the selling of seeds. The main fruiting period of Allanblackia is December-February when the income from other agricultural activities is the lowest (Mathew et al, 2009). Consequently the income from Allanblackia seeds come during a very important time of the year for many farmers enhancing their economic situation. Integrating the trees in farming systems will also help preserve the natural stands and the biodiversity in ANR. Possible risks with introducing new species to farming systems could be the effects it may have on other crops which is something that should be more carefully examined in future studies. Examples on associated risks could be new pests and diseases which could move onto the crops.

There are several advantages with the participatory domestication approach such as a clear poverty reduction focus, the income from the trees are often very important for women and children, immediate implementation of new techniques on farm and village level, and it is based on low cost and simple technology, builds on and takes into account traditional and cultural uses of trees, promotes local level processing and development of entrepreneurism etc. (Simons & Leakey, 2004). The close two-way communication makes it possible to find solutions to the poor establishment of Allanblackia in the farms. It also helps in trying to meet and fulfill the soil requirements of Allanblackia, once these are known and investigated further, as much as the natural conditions found in situ permit.

This was a pilot study of the soil and climatic requirements of *A. stuhlmannii* and no other investigation of this had been done before. This is important information for the future domestication work of the tree and may help to raise strong and viable seedlings in nurseries. The information can also help understand what promotes and disfavors the establishment and growth of the trees on farms and can be important information in advising on good farming practices. Examples of future studies that would be of value is to compare with the other Allanblackia species to see what kind of soil requirements they have and if there are any possible plant-microbe symbiosis. It could also be useful to investigate if the seedlings will suffer from e.g Fe deficiency if the soil pH is higher. Furthermore it would be interesting to conduct trials incorporating different rates of soil from native stands and also with inoculation with myccorhizal fungi to see the effects it may have.

6 Conclusions

The soils associated to *A. stuhlmannii* were classified as Ferralsol and Acrisol according to FAO classification. These are typical red, highly weathered and leached tropical soils with poor chemical status but somewhat better physical properties due to the stabile micro-aggregation. The climate was tropical with high rainfall and temperatures, which together with long and intensive weathering explains the occurrence of this soil type.

The soils were found to have very low pH and concentrations of nutrients, which was one of the hypotheses. Organic C, N, base cations and bicarbonate extractable P were concentrated in the upper layers and probably associated with the organic material. ECEC was generally low but higher values were observed in the upper layers. Concentrations of exchangeable Fe and Al (KCl) were high. Differences in soil parameters that were correlated with altitude were few and small and thus do not generally support the hypothesis about the altitudinal effect. There was, however, a slight altitudinal effect for P in the upper layers, with higher concentrations at lower altitudes and for pH, with lower pH at lower altitudes. Larger effects may have been observed if there had been a larger variation in altitude between sites.

This was a pilot study on soil samples collected directly under native stands of *A. stuhlmannii*. Hopefully these results can be important for the future work in the domestication process and help farmers integrate the tree more successfully in their farming system. For local communities living in East Usambara, diversification and processing of farm produce are important alternatives and strategies to improve livelihoods and the Allanblackia project is a good and viable example of this. However, more research on the effects of the integration of the trees on farms is needed to be able to provide reliable and adequate information and advice to the farmers.

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Appendix 1

Each error bar is constructed using a 95% confidence interval of the mean

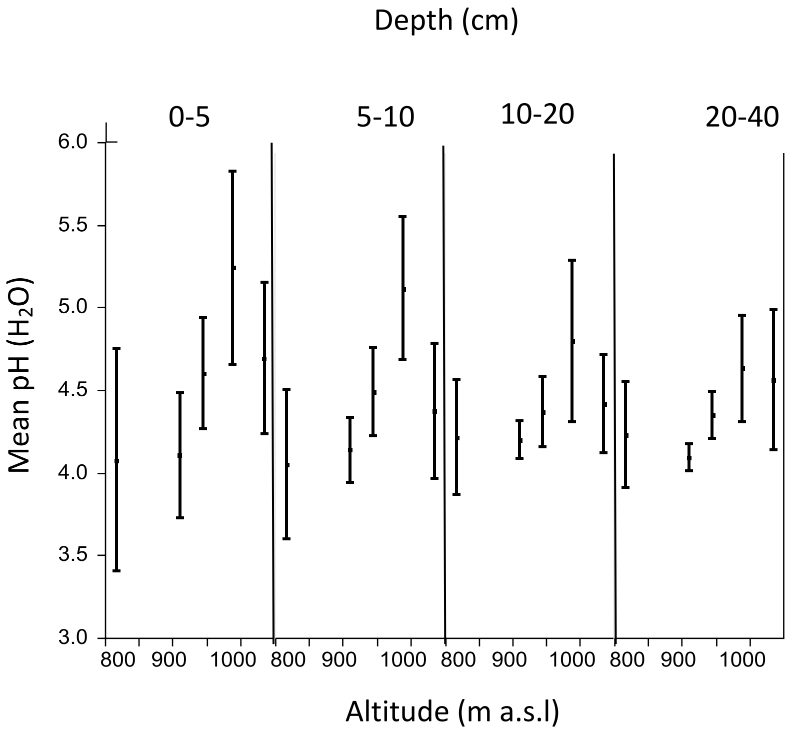

Figure 1. Mean pH (H_2O) at different depths (cm) and altitudes (m a.s.l).

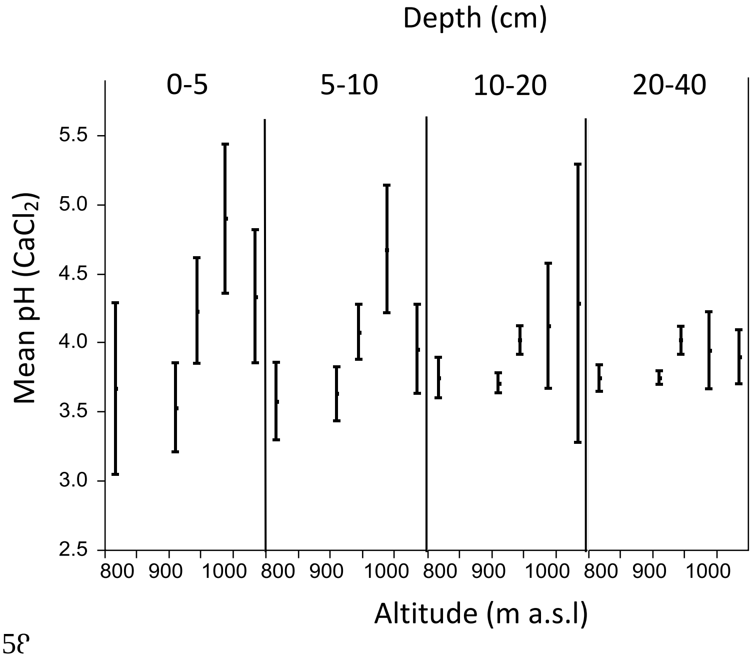

Figure 2. Mean pH ($CaCl_2$) at different depths (cm) and altitudes (m a.s.l).

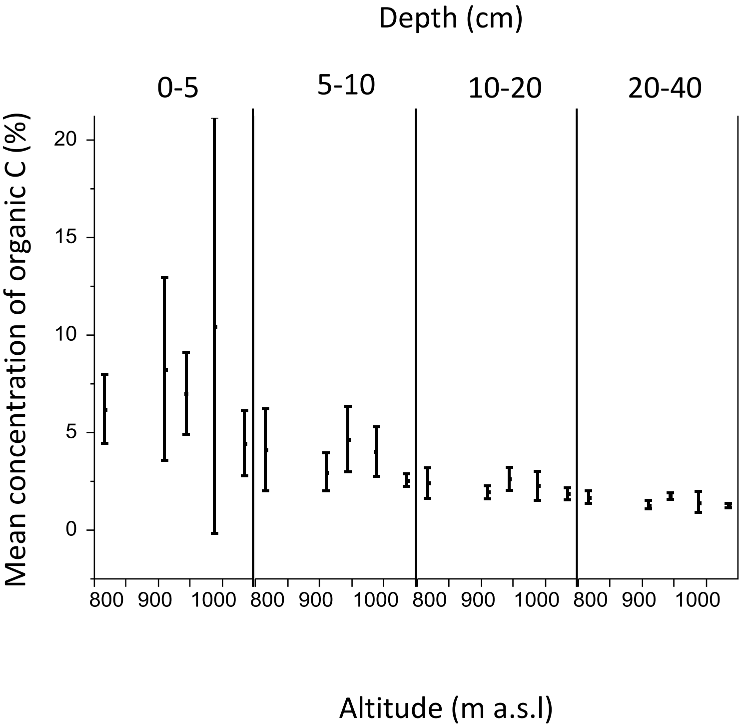

Figure 3. Mean concentration of organic C (%) at different depths (cm) and altitudes (m a.s.l).

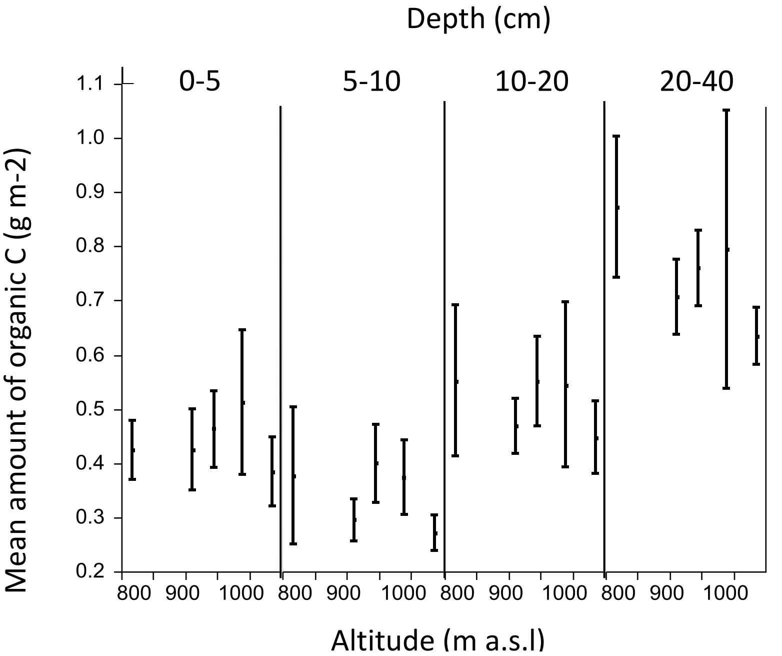

Figure 4. Mean amount of organic C (g m-2) at different depths (cm) and altitudes (m a.s.l).

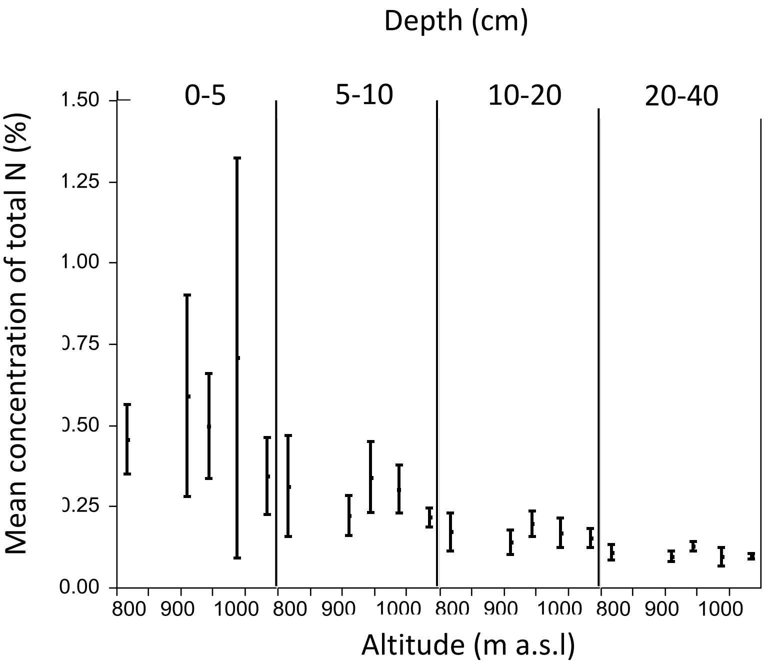

Figure 5. Mean concentration of total N (%) at different depths (cm) and altitudes (m a.s.l).

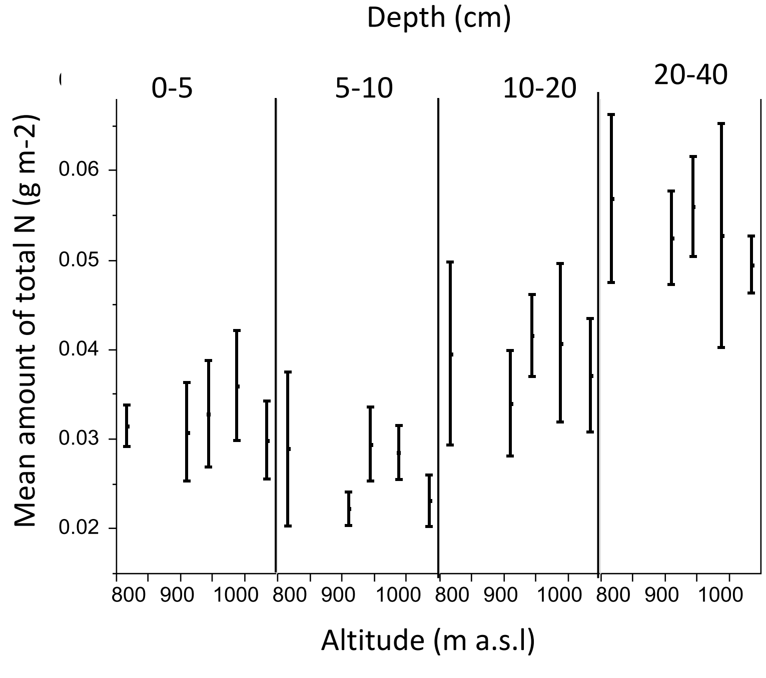

Figure 6. Mean amount of total N (g m-2) at different depths (cm) and altitudes (m a.s.l).

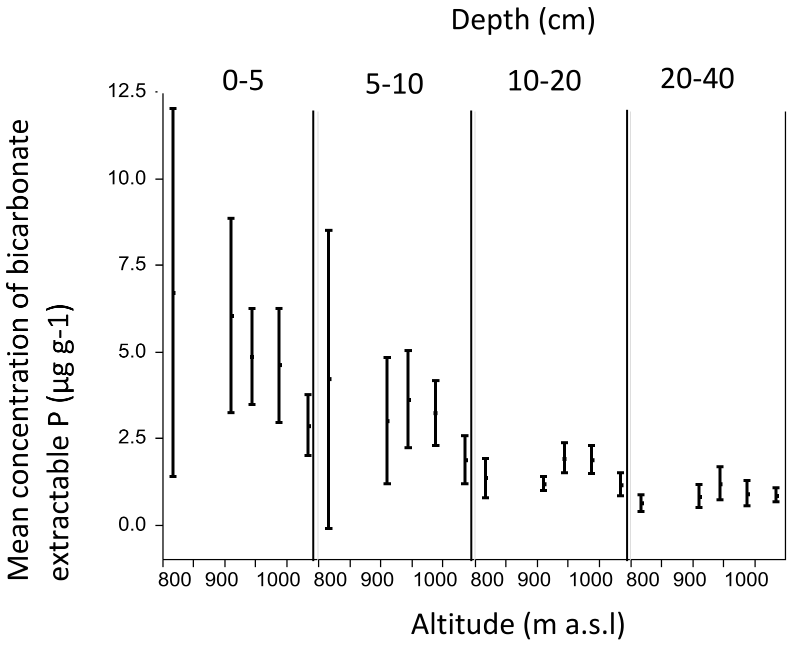

Figure 7. Mean concentration of bicarbonate extractable P (µg g-1) at different depths (cm) and altitudes (m a.s.l).

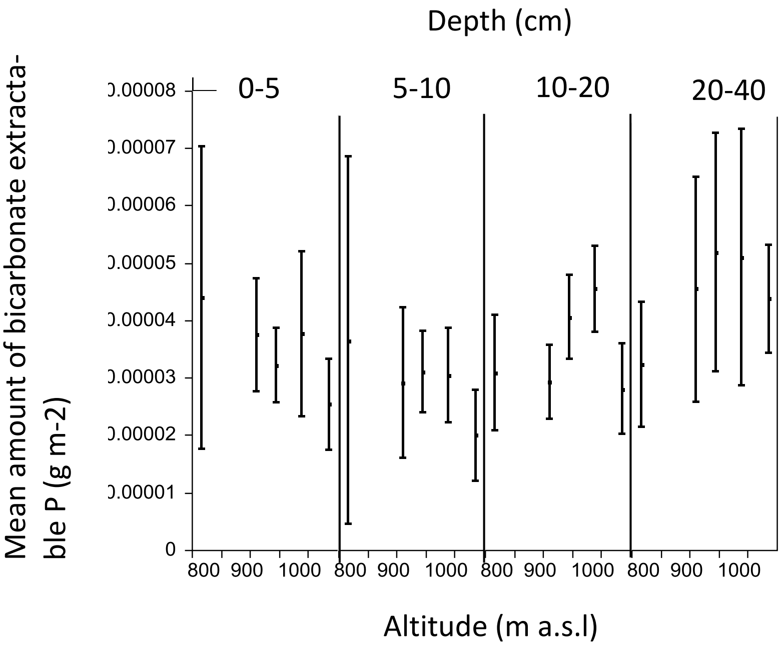

Figure 8. Mean amount of bicarbonate extractable P (g m-2) at different depths (cm) and altitudes (m a.s.l).

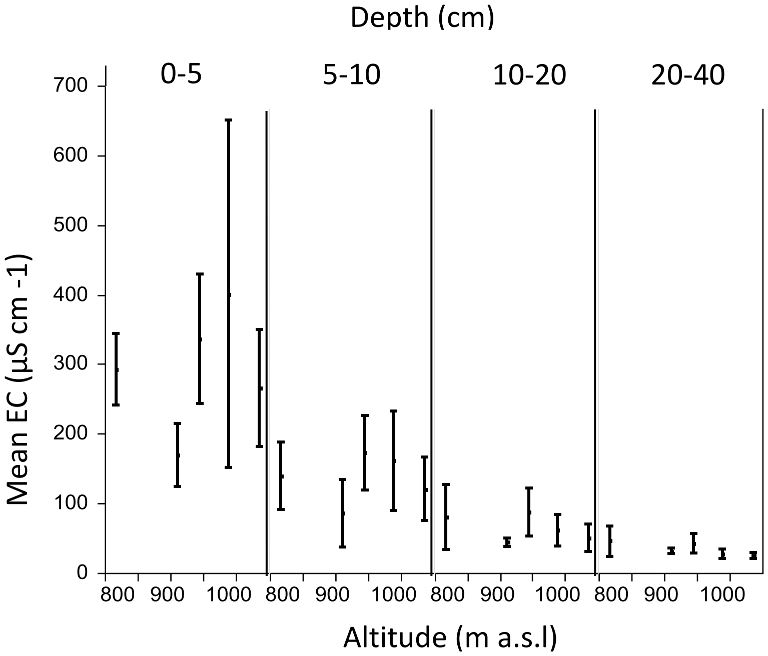

Figure 9. Mean EC (µS cm-1) at different depths (cm) and altitudes (m a.s.l).

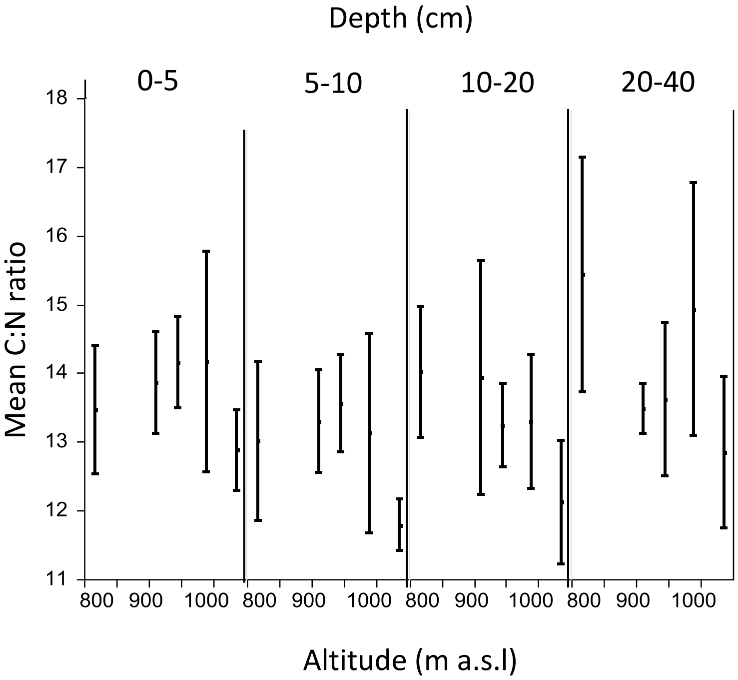

Figure 10. Mean C:N ratio at different depths (cm) and altitudes (m a.s.l).

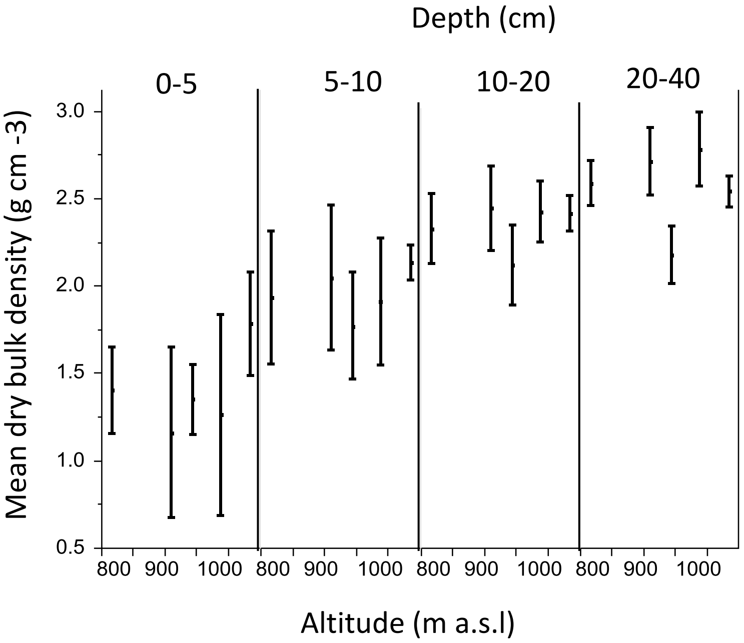

Figure 11. Mean dry bulk density (g cm-3) at different depths (cm) and altitudes (m a.s.l).