DIPLOMA THESIS

Above and below ground interactions between bananas and selected indigenous tree species in Uganda

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September 2012

Acknowledgement

First of all I would like to express my appreciation and thankfulness to the farmers and people in Uganda for their hospitality, cooperation and support.
My special thanks go to John Makofu, my research assistant who left his family for four months in order to gather field data. Without his support the field work wouldn't have been possible.

Next I would like to say thank you to my supervisor Ao. Univ. Prof. Dr. Georg Gratzer and co supervisor Ao.Univ.Prof. Dipl.-Ing. Dr.nat.techn Helmut Schume.

Thanks to Dr. Lalisa Duguma for the revision of the thesis.

Many thanks also to my parents for supporting me during my studies, to my wife Maria and my children Jael and Fridolin for their understanding and for giving me the time I needed.

Last but not least thanks and praises to the almighty and ever living creator Jah Rastafari for making us part of this unique and wonderful creation and for giving me the power to go my own way.

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Abstract

This study was conducted in central Uganda at selected villages within Nakaseke district. After a participatory selection process, based on the farmers' assessment of suitable tree species for agroforestry, in particular for intercropping with banana, *Albizia coria* and *Ficus thonningii* were selected for further research on the above ground and below ground interaction between banana and tree component. As the majority of studies on the influence of shade on banana yield and growth has been carried out with shade produced through shade cloth (NORGROVE, 1998), this study determines the response of bananas to altering shading intensities under the canopy of indigenous trees. The light interception of 79 *A. coria* and 81 *F. thonningii* trees at different size and age classes was estimated using hemispherical photography to quantify the amount of potential solar radiation penetrating through it, in dependency of tree size. Furthermore, the farmers' assessment of the quality of shade produced by the photographed trees was evaluated. Additionally the light interception rate that reached 40 *Mpologoma* mats, growing under the canopy of an *A. coria* tree at the research site Bagwe was captured by taking a hemispherical photograph above each mat. At the same site, the underground interactions in terms of nutrient and water availability for bananas were sampled in different spatial arrangements. Soil moisture was measured during the rainy and the dry season, using a Trase 1 TDR-system. During the same time period, the growth parameters and characteristics of the banana mats at the research site were documented. Despite the highly significant correlation between the measured tree growth parameters, height, crown and stem diameter, there was no correlation between growth parameters and percentage of light transmission that reaches the area under the canopy.

The above ground effect of *A. coria* in terms of shading did not show a statistically relevant decrease in yield for none of the different shading intensities above the *Mpologoma* mats. A yield increasing effect from shading was not found. However, the overall effect of the *A. coria* on banana yield seems to be still positive: whereas out of 37 banana mats under the tree, only one plant broke down because of wind during the rainy season, 24 plants from a total of 66 mats in the pure banana stand were lost. Considering that the area outside the canopy was manured, and soil analyses did not show significant

differences in the nutrient availability between the manured and unmanured sites, the soil improving effect of *A. coria* was as strong as the manure, applied to the plantation. Through the presence of *A. coria* in the banana plantation, plants and soil remained healthy and productive without additional input and at the same time, soil fertility of the other fields did not suffer a negative nutrient balance due to the removal of organic matter towards the banana plantation.

Zusammenfassung

Die Studie wurde in Zentraluganda, in ausgesuchten Dörfern im Verwaltungsbezirk Nakaseke durchgeführt. *Für Albizia coria* und *Ficus thonningii*, zwei heimische Baumarten, die von den Bauern als geeignete Nachbarn für Bananen gesehen werden, wurde die Lichtinterzeption entlang eines Gradienten von 79 *A. coria* und 81 *F. thonningii* Bäumen in verschiedenen Größen und Altersklassen wurde mittels hemisphärischer Photographie quantifiziert und der Einschätzung der Bauern gegenübergestellt. Weiters wurde die Reaktion von 40 *Mpologoma* auf unterschiedliche Beschattungsintensitäten, bzw. auf Konkurrenz um Wasser und Nährstoffe, unter der Krone eines *A. coria* Baumes untersucht. Dafür wurden für die gesamte Plantage Bodenfeuchtigkeit, Nährstoffverfügbarkeit und Wachstumsparameter der Bananenmatten dokumentiert. Trotz der höchst signifikanten Korrelation zwischen den gemessenen Baumwachstumsparametern Höhe, Kronen und Stammdurchmesser, korrelieren diese nicht mit der unter dem Baum eintreffenden Strahlungsmenge. Der von *A. coria* verursachte Schatten wirkte sich weder positiv noch negativ auf die im Schatten wachsenden Bananen aus. Die Tatsache, dass von den 37 unter dem Baum wachsenden Bananenmatten nur eine Pflanze durch Windeinwirkung umgebrochen wurde, während 24 Pflanzen von insgesamt 66 Matten im puren Bananenbestand abbrachen, hebt die Funktion von *A. coria* als Schutz vor Windschäden hervor. Durch die Boden verbessernden Eigenschaften von *A. coria* in der Bananenplantage konnte das Ertragsniveau im ungedüngten Kroneneinflussbereich ohne zusätzlichen Input gleich hoch wie auf den gedüngten Flächen gehalten werden.

1 Background information

Bananas and plantains (Musa spp.) are cultivated in over 100 countries in tropical and subtropical regions on an area of approximately 10 million hectares. The annual production reaches up to 88 million metric tons. In terms of gross value of production, banana/plantain is the developing world's fourth most important food crop after rice, wheat and maize (FRISON & SHARROCK 1998).

In sub-Saharan Africa, especially in the humid forests and the mid-altitude regions bananas are even the second most important food crop after cassava and provide more than 25% of food energy requirements for about 70 million people (KARAMURA 1998).
Besides ensuring food security, bananas are an important source for minerals and Vitamin A, C, and B6 (FRISON & SHARROCK 1998).

Uganda, the worlds biggest plantain producer with a production of 9.231 million tons per year (FAO 2009a), is located in the great lakes region in east Africa where Bananas (Musa spp.) are a staple food for more than 20 million people. The great lakes region is reported to have the highest banana per capita consumption of the world (KARAMURA et al. 1998). Uganda's dessert banana production allocates place 20 among the worlds biggest producers with 0.615 million tons yearly (FAO 2009a).

From 2001 to 2006 44.6 % of the total tonnage of food produced in Uganda were bananas, followed by root crops with 26.8 %, cereals with 11.2 %, beans and peas with 3,1% and oil seed with 2.8 % (UGANDA HUMAN DEVELOPMENT REPORT 2007).
For more than 70% of Uganda's farmers, bananas are a major food crop and source of income.
Bananas cover almost 30% of the utilized agricultural land (UGANDA HUMAN DEVELOPMENT REPORT 2007) and are estimated to provide 30% of the calories, 10% of protein and 5% of fat for the entire population (KALYEBARA 2006). This estimation has to be reduced by the fact that in 2005 the per capita consumption of 142,49 kg plantain

made up a bit more than 1/7th of the 2360 kcal/capita/day that were consumed by Ugandans (FAO 2009 b; FAO COUNTRY PROFILE 2005).
Because of its perennial nature, long plantation life and stable yields Musa spp. is regarded as the most important crop for food security in most parts of central, western and eastern Uganda.
Coastal hybrids in Uganda commonly called “exotic” banana are important for beer, juice and gin production and have, despite a recent decrease in production, a high export and industrial potential (KALYEBARA 2006). Besides ensuring food security and income for the rural poor, bananas also have important medicinal, cultural and industrial uses (KARAMURA et al. 1998).

1.1 Banana production systems

From eastern to southern Africa bananas are grown under diverse agro-ecological and socio-economic conditions. Different cultivars occupy a wide range of ecological zones from lowlands at sea level up to highlands above 2000 m. The East African Highland banana (Musa AAA-EA) is the dominant cultivar on altitudes between 1000-2000 m. Below and above this altitude its growth is reported to be retarded.
In the lowlands, the production is dominated by Plantains (Musa AAB) and dessert bananas (Musa AAA) (KARAMURA et al. 1998). Coastal hybrids of AB, AAB, and ABB genotypes are mainly grown in the lowlands of central and eastern Uganda (KALYEBARA 2006).
The socioeconomic conditions associated with banana production are equally multifaceted and range from subsistence over the production for the local market and cultural/medicinal uses up to commercial production for the export market (KARAMURA et al. 1998).
KARAMURA et al. (1998) divided Musa production systems into three broad categories, namely backyard garden system, subsistence system and commercial/plantation system.
She states that although this is a rough simplification of the variability found in reality it is important to work out the attendant characteristics of each system in order to predict the suitability of technology uptake pathways.

Banana backyard garden systems are characterized by the minor economic and/or subsistence value of banana, which results in small plots and low inputs. The system is found in peri-urban areas, where the main income is gained through paid employment, or in areas where other crops have a higher commercial or subsistence value. As the banana production is just supplementary to other food crops, farmers usually pay very limited attention to crop management practices. In consequence this system tends to show a high pest and disease infestation and may infest other production systems in the vicinity.

Banana subsistence systems are the most common banana production systems and responsible for more than 87% of the global banana/plantain production. Although the main purpose of the system is food security, the commercial interests are growing hand in hand with the rapidly expanding local banana markets.

Subsistence farmers are characterized through limited access to cropland and financial resources. The challenge is to meet all dietary needs from a piece of land, ranging from 0.25 to 5 ha through intercropping and agroforestry with bananas. Meeting this demand the system is highly complex in terms of crop-crop, crop-soil interactions and crop management practices in general. Among other factors the population pressure and the resulting effects on land use and management practices have led to a depletion of the natural resources, which in consequence raised the pest and disease pressure in subsistence systems. As farmers are lacking financial resources to buy chemical treatment and research failed to find alternatives, pest and diseases are up to nowadays one of the biggest production constraints for subsistence farming systems.

Banana plantation systems are the least complex systems as they are largely monocultivar and have only one objective, namely maximization of profit. Further on, they can be characterized by well defined cropping cycles of 2-5 years, an export oriented dessert banana production and high yields between 40-60 tons.

In contradiction to the backyard and subsistence systems, whose success is highly dependent on the condition of the surrounding environment, the plantation system is more independent, but has on the same time a much higher impact on the environment through the use of chemical additives and heavy machines (KARAMURA et al. 1998).

1.1.1 Production constraints

The production is dominated by small scale farmers who grow bananas for subsistence and /or income generation. The majority of them are pure subsistence farmers (55%), followed by 39% of semi-commercial and a small but growing proportion of pure commercial farmers (6%) (KALYEBARA 2006).

The tendency of stagnating and declining plantain yields per hectare has been obvious within the last 20 years (FAO 2009b). In the same time the population almost doubled and showed an estimated growth of 13 million people (UGANDA BUREAU OF STATISTICS 2009). Recent data from selected key food crops show that while the areas under cultivation are rising, the yields per ha are declining. This implies a drop in productivity and per capita output (UGANDA HUMAN DEVELOPMENT REPORT 2007). Although the harvested area of plantain has been expanding from 1.302.000 ha in 1988 to 1.680.000 ha in 2008 (FAO 2009b) it is clear that without raising the yields food security is under threat (BEKUNDA 1999).

Nowadays the declining yields in parts of western region and most parts of central and eastern region have led to the replacement of banana with annual crops and at the same time to a general production shift from the central region where the estimated production has fallen to 6 t/ha to the western region where it is 17 t/ha (KALYEBARA 2006). In some areas the problem of declining yields is being aggravated through the lifetime reduction of banana plantations from about 50 years to only 5 to 10 years (LAMBOLL et al. 2000).

The Ugandan National Banana Research Programme (UNBRP) states that numerous interrelated factors have caused the recent development in the banana sector, namely:

"Socioeconomic constraints, low genetic diversity, declining soil fertility, a pest complex involving banana weevils, parasitic nematodes, a number of diseases, and post harvest problems" (LAMBOLL et al. 2000, p. 2)

Through the combination of a favourable climate for crop production and high population densities, areas like the East African highland are in particular susceptible for land degradation through nutrient mining and erosion (BRIGGS and TWOMLOW 2002). The rising population went hand in hand with land use intensification, diminishing farm sizes and reduced fallow periods (LAMBOLL et al. 2000). In the case of Uganda the population increased between 1980 and 1990 by 43%, while the application of nitrogen-based fertilizers dropped by 64% and the use of phosphorus fertilizers declined by 45%. Because farmers are lacking money to buy the imported fertilizers, degraded and unproductive land has been replaced through former forests.

Due to this development Uganda's forest cover was reduced from 11000 km2 in 1960 to 6000 km^2 in 1986.

Since these forest soils have low inherent soil fertility, the major source of available plant nutrients is mineralized organic matter. If forest soils are cultivated without replenishing organic matter that is being removed through erosion and harvest, the cycle of land degradation and deforestation starts again (BEKUNDA and WOOMER 1996).

BRIGGS and TWOMLOW (2002) state that beside soil erosion, poor conservation methods and nutrient removal through harvest, also the transfer of crop residues to more profitable parts of the farming system, like banana gardens is responsible for nutrient mining.

Consequently, the banana gardens and other favoured fields near the homestead remain their nutrient balance through a net transfer of organic matter from unproductive and more distant fields on the hillside. This inherent nutrient imbalance makes the whole system unsustainable and in a long term it has to collapse unless the organic resource management is being improved (BRIGGS and TWOMLOW 2002).

Furthermore the genetic variability of bananas in Uganda is currently very limited and additionally being threatened by the susceptibility of many preferred cultivars to pest and diseases. On top of these constraints the impact of HIV and the political instability and insecurity during the 1970s and 1980s have aggravated the situation (LAMBOLL et al. 2000).

In particular for Uganda's rural poor, which is about 40% of the rural population (10 million), expanding the cropping area won't be a solution because they are lacking financial resources. This means that the main burden of the above described development will remain on the backs of small scale farmers (IFAD 2008).

BEKUNDA (1999) and KALYEBARA (2006) state that without improving the production system and hence soil fertility the replacement of bananas with annual crops will be useless because also alternative staple crops won't perform well on degraded former banana fields.
As most of Ugandan small scale farmers cultivate Musa spp. in agroforestry systems, improving the Musa spp. yield and in consequence soil fertility depends on understanding and improving the Musa-agroforestry system holistically as well as the interactions between the different components (BEKUNDA 1999).

1.2 Agroforestry: History and Concept

Agroforestry (AF) is a new name for an ancient land use and management system (HUXLEY, 1999; KING 1989). Throughout the world trees have been an integral part of the farming systems, and were kept on established farmland to support food production.
This emphasis on food production through AF was replaced through the establishment of the "taungya" system by the end of the 19th century. The taungya system turned out to be a highly cost efficient Teak production system for the British and was spread from Burma throughout the colonial empire.
In return for their forestry tasks the local people were allowed to cultivate the land between the forest tree seedlings. It has to be emphasized that this system had been designed and used toward the optimization of tree yield and went hand in hand with the exploitation of local people. Consequently land scarcity and poverty among the local people became preconditions for the successful establishment of forestry plantations.

Concerning AF research the period from 1856 to the mid 1970s (taunga period) the research goal was to optimize the forest component and yield. The potential of AF for a holistic agricultural development, that is orientated on the needs and livelihood of the peasants was completely ignored (KING 1989). From the beginning of the 1970s onward, the first doubts concerning the actual developing paradigm, policies and approaches were expressed (SCHICHO and NÖST 2006). In terms of forestry policy, it was criticized that the focus had been restricted on the development of the forest industry and the forest itself.

The more important role that forestry could and has played in supporting agricultural production and raising rural welfare has been neglected and ignored. From this late

awareness generation process via the foundation of ICRAF (International Council for Research in Agroforestry) in 1977 up to the nowadays existing view of AF as an important mean of empowerment it was a long way. Today AF is more and more seen as an agricultural production system, especially suitable for small scale farmers (KING 1989).
The fact that small scale farmers around the globe have been practising AF in this sense for centuries until the British reduced it to the tree component is ironically enough and perfectly illustrates the up to now eurocentristic development paradigm (KING 1989; SCHICHO and NÖST 2006)

According to NAIR 1989, the above described debate about the utilization of AF as a land use system either for forestry or agriculture in combination with the changing development cooperation paradigm led to a lot of confusion concerning the definition of AF during the late 1970s and early 1980s. The first edition of Agroforestry Systems (Vol.1, No. 1, pp.7-12; 1982) discussed this confusion and included a selection of definitions in the editorial.
After summarizing these definitions B. LUNDGREN stated that there is a frequent mixing up of definitions, aims and potentials of AF. He stresses two characteristics which are common for all forms of AF and separate them from other forms of land use systems:

"Woody perennials, agricultural crops and/or animals are intentionally grown/raised on the same unit of land, either in forms of spatial mixture or in sequence. There has to be a significant interaction between the woody and non-woody component. This interaction (positive and/ or negative) can be ecological and/or economical" (NAIR 1989 a, p.17) .

From 1982-1987, ICRAF undertook an inventory of AF systems and practices in developing countries in order to evaluate them and develop action plans for their improvement. Based on LUNDGREN´S definition of AF numerous land use systems were analyzed and identified as AF systems (NAIR 1991). NAIR (1989) states that the most commonly used criteria to classify them are:

"Structure of the system (nature and arrangement of components)
Function of the system (role and output of the system)
Agro-ecological zones where the system exists or could exist
Socio-economic scales and management levels of the system." (NAIR 1989 b pp. 48)

Because each of these criteria has its advantages and disadvantages when applied in specific situations, a classification scheme based on a single criterion can't be accepted as universally applicable. Therefore NAIR (1989) argues that the classification of AF systems has to be purpose orientated and should depend on more than one criterion (NAIR 1989 pp. 48-50)

Since there is no AF system with more than three components (trees, crops, animals), it seems reasonable to start a classification based on the component composition and to extend it with the other criteria. e.g.: Silvopastoral system for cattle production in tropical savannas (NAIR 1991).

Thus there are three basic types of agroforestry systems that can be specified according to the particular situation:

"Agrisilviculture (crops and trees)

Silvipastoral (pasture/animals+trees)

Agrosilvipastoral(crop+pasture/animals+trees)

Others (apiculture+trees; aquaculture+trees….)" NAIR 1989 pp. 48).

The above described classification approach of NAIR has been adopted for the nomenclature and classification of AF systems in this thesis.

1.3 The potential of Agroforestry for Ugandan subsistence banana farmers

Through the vertical stratification AF systems are able to provide a microclimate, favourable for crop production. The tree canopy acts as a wind barrier, provides shade and hence reduces evapotranspiration from underlying soil and plants (SCHROEDER, 1995).

SASTRY (1988) states that the morphology of the banana plant with its large leaves and heavy bunches on a tall stem in combination with a very shallow root system make the crop especially susceptible to uprooting due to strong winds. Considering that through poor soil moisture conditions the rooting depth is even more reduced, the positive aspects of the above ground interactions stated by SCHROEDER (1995) can not be highlighted enough.

DOLD et al. (2008) stresses that whether the above ground effect of trees on banana yield and infestation are facilitating, complementary or competing depends on the degree of shading. NORGROVE (1998 p17-18) states that this is true for the tropics, but can not be applied to the subtropics, where shading of bananas decreases yields.

If access to nutrients and water is more constricted than light, facilitating effects of the tree due to reduced evapotranspiration, nitrogen fixation and accumulation of organic matter may outweigh any loss due to light deficiency. Furthermore banana leaves showed an increased radiation use efficiency under shade. Leaf area as well as amounts of chloroplasts showed the same tendency under shade treatment (NORGROVE, 1998 p.18-21).

In the tropics, some upper storey shading can be beneficial as long as other factors than light are more limiting. Bananas grown under shade trees showed a delay in the infection speed of Black Sigatoka and a reduced water stress. If the light availability for bananas is too low the positive effects of shading may turn into negative ones (DOLD et al. 2008)

SCHROEDER (1995) emphasizes that the tree canopy prevents soil compaction and erosion through reducing the kinetic energy of high intensity rainfalls.

In relation to the current short fallow systems, AF systems furthermore have the potential to increase the organic matter input. After a distinct literature research SCHROEDER (1995) concluded that the mean pruning and litter production of all studied examples is 7.4 t ha^{-1} y^{-1}(+-0.8) and hence comparable to the 8 t ha^{-1} y^{-1} dry matter input which YOUNG (1998) modelled as a requirement to maintain soil organic matter levels in the tropics.

Since SCHROEDER (1995) assumed that all the pruning and litter production would be returned to the soil, which especially in silvipastoral and agrosilvipastoral systems won’t be the case, these figures have to be treated with care, but still give a rough orientation. Never the less leaf litter fall and prunnings, used as mulch or incorporated in the soil, will improve physical soil properties as well as soil quality in general.

Beside that prunnings are an important fodder source, whereas trunks provide fuel and construction wood.

Below ground the potential of agroforestry lies within the possibility of tree roots to take up and recycle nutrients from deeper soil layers via litter fall or pruning, and in the case of nitrogen fixing species in the restocking of the nitrogen pool.

Although root turnover may be considered as an important source of organic matter, its actual potential for crop production is due to a lack of information and research hard to quantify (SCHROEDER 1995).

Unfortunately the catching of leached nutrients via deep roots, as well as the recycling of fixed P is only temporary because it depends on the availability of leached and recalcitrant nutrients to the tree roots. Additionally it has to be considered that usually prunnings and litter fall have a higher N:P ratio than the one required by crops (BRIGGS and TWOMLOW 2002, pp.208-209).

Although trees have long been regarded as a key factor in soil fertility improvement and conservation, not every tree species is suitable for sustainable production.:

In Uganda most farmers grow Eucalyptus sp. for its rapid growth rate and high timber value Through the burning of its allelophy leaves, highly needed organic matter is being removed from the system. However there are many other tree species, which combine an equal growth rate and timber quality while providing soil nutrients (BRIGGS and TWOMLOW 2002, pp.208-209).

1.4 Aims of the study

The diploma thesis is embedded in the framework of the present on-going research project: **“Growing bananas with trees and livestock”** which started in 2009 as a collaborative research project between Bioversity International, National Agricultural Research Organisation NARO, Makerere University in Uganda, University of Natural Resources and Life Sciences Vienna and Technical University of Graz in Austria**.**

Other collaborating partners are Luwero District Farmers’ Association, Masaka District Farmers’ Association, Kukolanyo Kulyanyo Village Association, Lwengo Village Association and the NGOs VEDCO and VI Agroforestry.

The overall goal of the project is to improve food security and income of young and resource-poor farmers through banana forests that are linked with animal production and carbon accumulation adapted to changing climates and social conditions by developing banana agro forests with small ruminants as a technology for food security and income *diversification.*

According to the project proposal, the whole project cycle is based on farmer learning processes in combination with a better scientific understanding of biological interactions.

Hence, this study will focus on the farmers' justification and reasoning in selecting a given tree species to be interplanted with bananas as well as on the various interactions between the selected species and bananas.

Within the studied area, there is a certain knowledge gap, concerning the amount of light intercepted through different crown sizes of indigenous trees. As NORGROVE (1998) emphasizes, the majority of studies on the influence of shading on banana yield and growth has been carried out with shade produced through shade cloth. This study will determine the response of bananas to altering shading intensities under the canopy of indigenous trees.

Besides, the belowground interactions in terms of nutrient and water availability for bananas will be investigated at different spatial arrangements.

The main research question is: **"How does above- and belowground interactions between selected indigenous tree species and bananas influence banana growth and yield under subsistence agroforesty systems in Uganda?"**. Based on this main research question, the following objectives were defined:

- To identify indigenous tree species suitable for banana AF production systems while assuring the overall livelihood improvement of the farmers.
- To quantify the influence of height, crown and stem diameter on the light interception characteristics *of A. coria* and *F. thonningii*.
- To carve out the farmers' assessment of shade produced by *A. coria* and *F. thonningii* for intercropping with banana.
- To quantify the response of *Mpologoma* on growth and yield to different shading intensities.
- To identify if *Albizia coria* can contribute to improved soil fertility.
- To show the influence of *Albizia coria* on the water availability for bananas.

2 Study area

2.1 Location

The study was conducted in Nakaseke district in Uganda, East Africa (Fig. 1).

The data has been collected in the south of Nakaseke district in and around the following villages: Bagwa, Busumba, Kakonde, Kasaana and Kayunga. As these villages can not be found on maps, the coordinates of Nakaseke District give the most precise information possible: 00°44´N 32°25É. Fig.1 gives a rough estimation of the location of the above-mentioned villages within Nakaseke district in central Uganda.

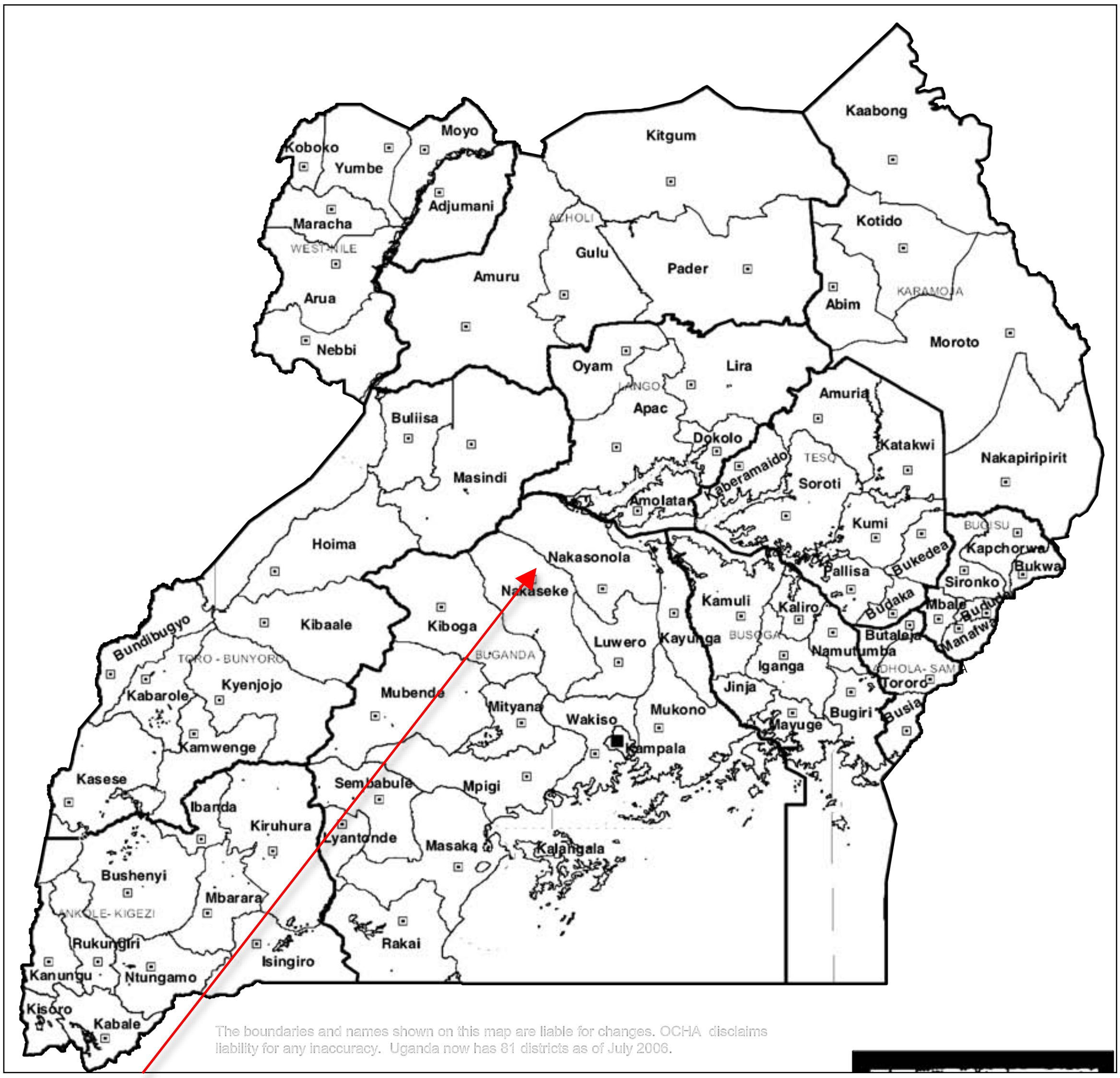


Fig. 1: Location of the villages Bagwa, Busumba, Kakonde, Kasaana and Kayunga in Nakaseke District in central Uganda (INGATECH, 2012).

2.1.1 Research sites

TDR research site

As the research focus was on small scale subsistence agroforestry systems, almost all visited banana plots showed a high diversity in the:

a. Varieties of planted bananas
b. Age of the plantation
c. Interplanted tree species
d. Different intercropping systems
e. Different management systems

Although it was planned to compare at least two sites, this plan had to be skipped due to the above-mentioned circumstances where it took me already one month to find one site where the planned trial design was possible.
Finally, a small banana plantation in Bagwe, a village near Nakaseke, one and a half car hours north from Kampala was chosen. On the 1000 m^2 large area, 101 *Mpologoma* mats are more or less uniformly planted with sporadically interplanted young coffee plants. As the coffee plants were still young and few, this site seemed to be adequate for studying the interactions between *Mpologoma* and *A. coria* which is growing in the middle of the plantation.

The selection of sites for characterizing the light interception of *A. coria* and *F. thonnningii* was based on the baseline data, provided by Bioversity International. The sampling criteria were *A. coria* and *F. thonnniingi* trees of different size and age classes growing in association with bananas that were not too far from the research site Bagwe.

2.2 Climate

As it was not possible to find climate data for Nakaseke district, the data for Kiboga district, bordering Nakaseke in the west was used.
The biomodal tropical climate has two dry seasons from June to July and December to February. The cropping seasons are from March to May and September to November.

During the cropping seasons, heavy and at least in the past well distributed rains with pigs of 1200 mm from March to May and October to November can be expected.

Generally, the annual rainfall pattern varied from 560 mm to 1272 during the last 7 years. In this period of time the average number of rainy days per year ranged from 90 to 130 (INGATECH, 2012; LUWEERO DISTRICT STATE OF ENVIRONMENT REPORT, 2004). The mean daily maximum temperature ranges from 18° to 35°, whereas the minimum daily temperature can be found between 8° and 25° (LUWEERO DISTRICT STATE OF ENVIRONMENT REPORT, 2004).

The above-described climate reflects the climate conditions before climate change took place. Nowadays the situation is different: A recent report by STARK (2011) stated that within the study area droughts are becoming more frequent, temperatures are rising and the rainy season is becoming unpredictable. The rainfall is of higher intensity but less frequent. The interview output of STARK (2011) matches exactly with the statements of the farmers I was working with.

2.3 Geology and Soils

The origins of the soils of Nakaseke District go back to metamorphic rocks of pre-Cambrian age, partly overlaid by successions of sedimentary strata of different age and degree of metamorphosis. Furthermore the geology is characterized by the presence of young intrusive rocks on a mostly acidic basis. The youngest formations are sands, quartz and clays of alluvial or lacustrine origin. In the middle of the tertiary period the present day landscape of Nakaseke district was formed. It can be described as a dissected plateau of 1200m, hosting small hills with flat tops and valleys in between (LUWEERO DISTRICT STATE OF ENVIRONMENT REPORT, 2004).

The soils of Nakaseke district are generally red coloured sandy loam soils in the north and , red coloured clay loam soils in the south (Fig.2). The former is less fertile as compared to the latter (LUWEERO DISTRICT STATE OF ENVIRONMENT REPORT, 2004). In general, more precise information on soil properties was not available, therefore it shall be discussed further in the chapter about soil analyses of the study areas.

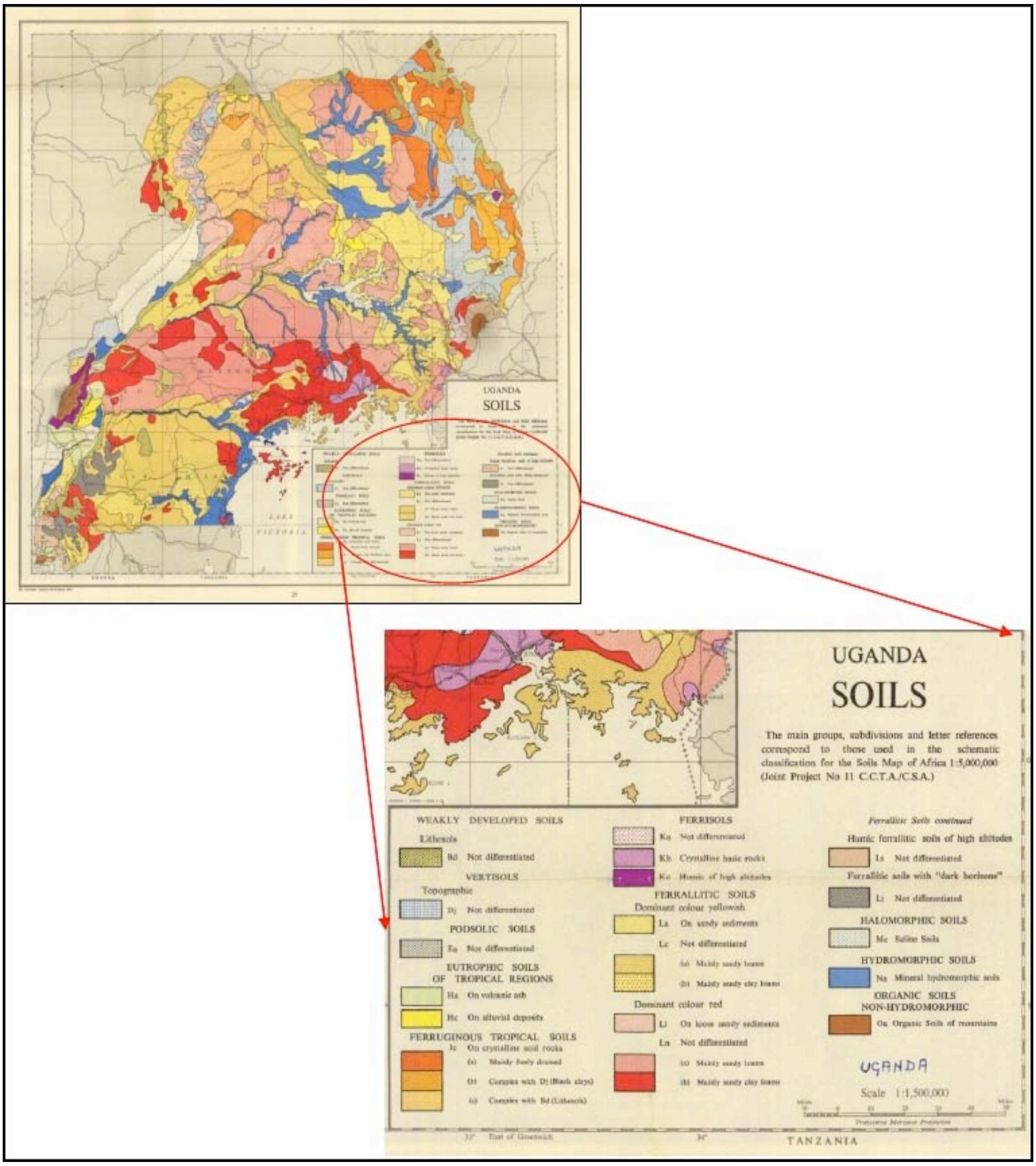


Fig. 2: Soil types of Uganda in particular Nakaseke District (UGANDA GOVERNMENT, 1967)

3 Recording methods

3.1 Selection process of two indigenous trees with the highest importance for the farmers livelihood, particularly with regard to their intercropping abilities with bananas

The selection process was rested upon the baseline survey:” Characterisation of smallholder Banana, Agroforestry and Livestock Households in the districts of Luwero, Kiboga and Sembabule.” The establishment of the baseline data is part of the project **“Growing bananas with trees and livestock”**. Hence it was provided and collected by Bioversity stuff.

It consists of the interview outputs from 208 farmers in Nakaseke, Kiboga and Sembabule District. The interviewed farmers were selected from field partners of Bioversity working in Nakaseke district (VEDCO), Sembabule district (SCC Vi Agroforestry) and in Kiboga district (district administration).

SCC-Vi Agroforestry and VEDCO selected specific sites due to their area of operation, whereas in Kiboga district the selection criteria was an area with a high rate of intercropping between trees and bananas.

Both, SCC-Vi and VEDCO randomly selected 35 farmers from their members and 35 from non members. In Kiboga district, the district administration used the same procedure based on NAADs members. The interviews were performed from May to August 2010.

The selection process of two indigenous trees, suitable for intercropping with bananas was based on descriptive statistical analyses, via PASW Statistics 18, of the above described baseline data, as well as on observations and discussions, at various farmer field meetings, I have attended.

3.2 TDR measurements

Sampling:

Soil moisture was measured during the rainy and the dry season, using a Trase 1 TDR-system from Soilmoisture Equipment with permanently installed waveguides over soil depths of 0-30 and 0-60 cm. The measurements were taken along more or less regular grids of different spacing: a 5 by 5 meter coarse grid to capture the long range variability and three star-shaped fine grids nested within to detect the small scale variability. Two fine grids have been located in the mixed banana *A. coria* stand, and one in the pure banana stand. Whenever there was a danger that the above described position of a measurement point could lead to wrong measurements due to e.g. trenches next to it, the position was changed (Fig.4). In order to capture drying and rewetting cycles, the measurements were taken discontinuously at an interval of 5-12 days, depending on prevailing weather conditions: during drying periods, measurements were taken before upcoming rainy weather, while after rewetting a minimum interval of two days between the last rain event and the next measurement were applied.

In addition to the spatial measurements, soil moisture was also monitored in high resolution over time and depth in two soil pits: buriable wave guides were installed in soil pits over depths of 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm (Fig.3). These wave-guides were measured on a daily basis. One soil pit was located under the tree canopy in the intercropping area, whereas the other one was in the pure banana stand. The above described soil moisture data has been collected and digitized for a time period from the 19th of December 2010 up to the 9th of May 2011. Measuring soil moisture in high resolution over depth and time, reveals different soil properties within the profile. At the same time, it may be used to quantify altering responses of the hydrological balance of the same soil type due to a differing composition of above ground vegetation (SCHUME et al. 2004).

Fig. 3**:** Installation of buriable waveguides at different depths.

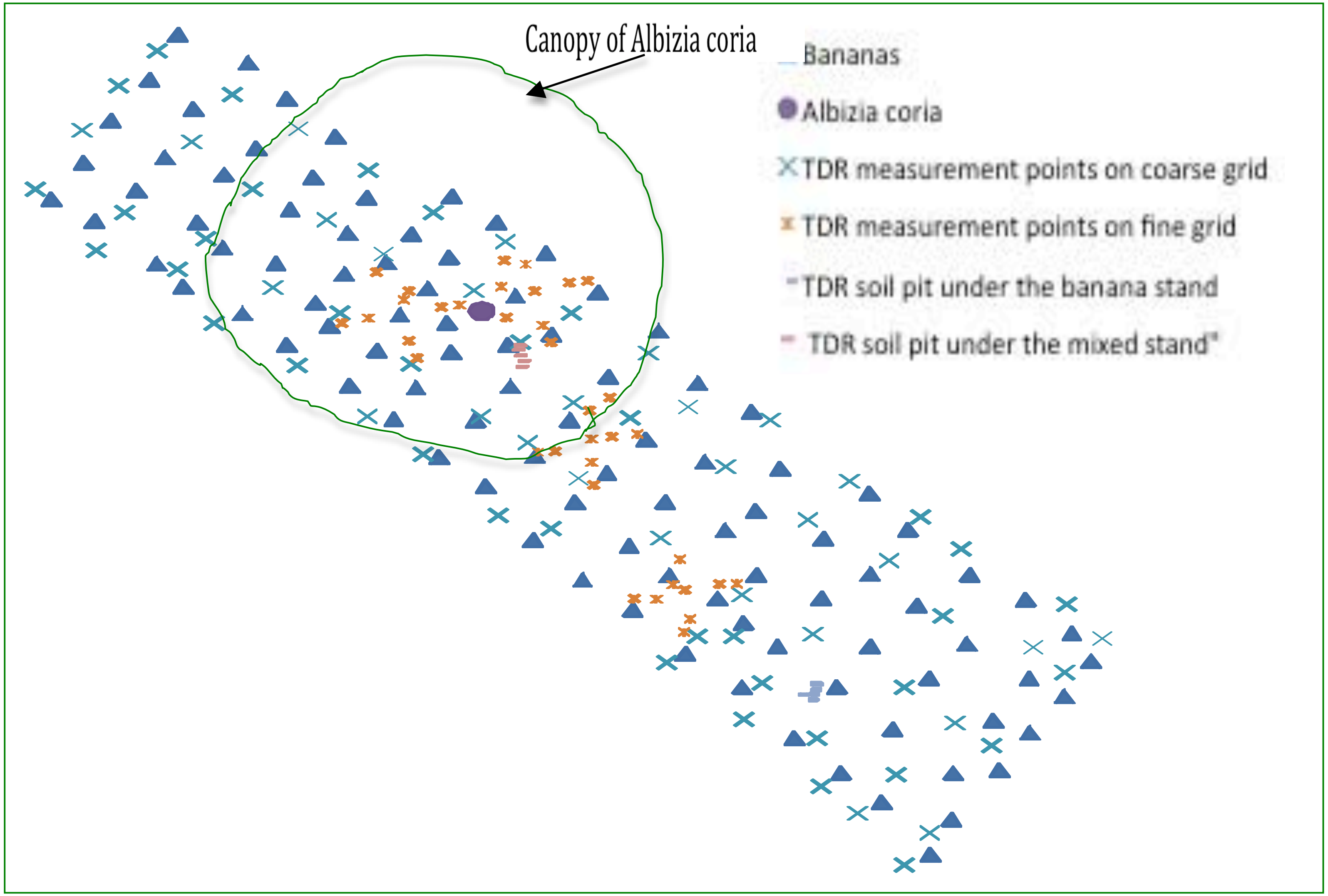


Fig. 4: Arrangement of TDR measurement points in dependency of Albizia coria and bananas

3.3 Collection of growth parameters

From the 102 *Mpologoma* mats at the research site in Nakaseke district, the following growth characteristics and growth stages have been collected every two weeks for a time period of 5 months:

Table 1: Collected growth characteristics and growth stages of *Mpologoma*

Growth characteristics	Growth stages
• Plant height • Circumference of the pseudo stem at soil level • Number of functional leaves, leaf length and max leaf with. Out of these parameters leaf area per mat was calculated, using k = 0.68. • Bunch weight / number of fingers / number of hands per bunch	• Sucker with no functional leaves • Sucker under true leave development • Sucker with large and fully developed leaves • Flowering mother plant and / or development of fruit • Mother plant where the fruits have reached maturity

From *Albizia coria* and *Ficus thonningii* trees, that were photographed for the light interception analyses, trunk diameter at breast height, maximum crown diameter and crown height were measured.

3.4 Characterizing light interception of *Albizia coria and Ficus thonningii*

Light interception was captured with hemispherical canopy photography. Viewing upward, tree canopies were characterized via photographs taken through an extremely wide-angle lens (fish eye). The viewing angle, being almost 180° provides a complete view of the entire sky and produces permanent records of the geometry of canopy openings. Hence the geometric distribution of canopy openings was measured and used to quantify the amount of potential solar radiation penetrating through it (RICHARD, 1990).

During dawn or overcastted sky conditions 4 pictures were taken crosswise at 0°, 90°, 180° and 270° for every analyzed tree with a distance of 1,5 m from the tree trunk.

If underground vegetation was too high, a telescope-monopod in combination with a self levelling mount was used to bring the camera in correct position. Height of the telescope-monopod ranged from 1 m up to 5 m depending on the surrounding ground vegetation.

Additionally the light interception rate that reached the 40 *Mpologoma* mats growing under the canopy of the *A. coria* at the research site Bagwe was captured by taking a hemispherical photograph above each mat.

With an exception of the height of the telescope- monopod that ranged between 3 and 5,5 m, due to the height of bananas, the same method as above described was used

Photo 1: Hemispherical photograph of *Albizia coria*.

4 Evaluation methods

4.1 Statistical Analyses

PASW Statistics 18 was used for descriptive statistical analyses for all gathered data.
In a first step normal distribution was tested with the Kolmogorov-Smirnov test.
Normal distributed data was analyzed with ONEWAY ANOVA, POST-HOC-TESTS for significant differences between the altering classes (BRADE & ZÖLLER, 2009).

4.2 Analyzing light interception

Light interception was analyzed according to CANHAM et al. (1999). Via Gap Light Analyzer (GLA), Version 2.0., the actual shape of each photographed canopy was manually traced to calculate the percentage of visible sky through the crown and hence light transmission (CANHAM et al. 1999).
Monthly insolation data expressed in mean kWh/m²/day, as well as the monthly cloudiness index (Kt) was derived from NASA, (2002).
Based on FRAZER et al., (1999), these parameters were used to calculate monthly mean daily spectral fraction (Rp/Rs) and monthly mean beam fraction (Hb/H) out of the following formulas:

$$Rp/Rs = 1 - \exp(-0.499Kt - 0.219)$$

$$Hb/H = [1 - \exp(-3.044Kt2.436)]$$

FRAZER et al., (1999) state that: "Rp/Rs is the ratio of total daily global PAR to total daily global (total shortwave) radiation, and Kt is the fraction of total daily extraterrestrial radiation received at the ground surface as global radiation. Hb/H is the fraction of total daily global solar radiation incident on a horizontal surface that is in the form of direct solar radiation, and Kt is the daily cloudiness index"

4.3 Analyses of TDR measurements

The continuous measurements of soil moisture of the pure banana stand in comparison to those of the mixed stand, were analyzed and mapped with Surfer 7 software (GOLDEN SOFTWARE INC., 1999) based on (SCHUME et al., 2003) and (SCHUME et al.,2004).
For discontinuous soil measurement data, the mean values of the pure banana stand were tested for significicant differences to those of the pure stand via *t-test*.

4.4 Soil analyses at the trial site Bagwe

According to different distances from the *A. coria,* the whole plantation was divided into 4 different zones. Zone A, B and D was outside the influence of *A. coria* and had a pure banana stand on top, whereas zone C was determined as the area under the canopy of *A. coria, intercropped with bananas*. From each zone 3 subsamples were taken, each at a depth of 0-15 cm, 15-30 cm, and 30-60 cm. After mixing the subsamples of the same zone and depth, 12 composite soil samples were taken to Kawanda Research Institute. They have been analyzed for, pH, P_2O_5, K_2O, MgO, CaO, S Mn, Zn, Cu, B and M (table 7).
Ca, Mg, K, Na, P, Cu, Zn, Mn and Fe were analyzed through Mehlich extraction, whereas S and B was quantified through ashing.
Organic matter was determined by first analyzing organic carbon calorimetrically at 600nm and then multiplying the value by 1.73.
Extractable phosphorus was quantified with Murphy riley solution (ammonium molybdate, potassium antimonyl tartarate and ascobic acid) at 860nm.
All cations are in extractable form, where determined using Mehlich 3 extract (pH 2.5) and quantified via an atomic absorption spectrophotometer. Extractable Boron was determined calorimetrically, based on the Azomethine-H procedure and extracted with Morgan's Extraction solution (sodium acetate).
Soluble sulphates were determined from a 1:5 soil/water extract and quantified turbidimetrically at 600nm.

5 Results

5.1 Selection process of two indigenous trees with the highest importance for the farmers livelihood, particularly with regard to their intercropping abilities with bananas

In order to achieve results in dependency of wealth classes, land size was taken as a proxy of wealth. Depending on the size of land cultivated, households were grouped into four classes.

Table 2 illustrates that almost 70% of the farmers are found in the two lower land possession classes 1 and 2, ranging from 0 to 6 acres. In these two land possession classes the average size of land possessed is 2 and 4.8 acres per farmer, respectively. The remaining 30% of farmers are in land possession classes 3 and 4, ranging from 6 to 300 acres with an average land size of 8.5 and 38.2 acres per household.

Table 2: Distribution of the amount of farmers, land size, and trees over the four land classes.

Land classes	nr. of farmers	land size in acres	total land in acres	mean land/ farmer	trees/ acre	total nr. of trees	percentage of farmers intercropping bananas with trees
land class 1	82	0-3	163.8	2.0	8.9	1452.0	81.7%
land class 2	64	3 - 6	304.0	4.8	11.4	3478.0	79.7%
land class 3	36	6 - 10	306.5	8.5	3.5	1059.0	88.9%
land class 4	27	10 - 300	1030.5	38.2	3.1	3233.0	84.6%

On the land they cultivate, farmers grow various tree species. Table 3 gives an overview of the most frequent combination of tree species at farm level. Table 4 summarizes the percentage of farms with targeted tree species, the sum of trees and the sum of importance scoring for the targeted trees for all land classes as well as for each land class separately.

For each farmer with targeted trees, the importance scoring was calculated by taking the number of tree species on farm plus one, minus the ranking for the targeted tree by the farmer.

Table 3: Percentage of farmers hosting a certain combination of trees on farm

Combination of trees found on farm	Number of farmers	Percentage of farmers
no tree	18	8.6%
none of the top five	23	11.0%
all of the top five	15	7.2%
at least one of the top five	184	88.0%
Artocarpus heterophyllus and *Mangifera indica*	97	46.4%
Artocarpus heterophyllus or *Mangifera indica*	160	76.6%
Artocarpus heterophyllus, Mangifera indica and *Persea americana*	53	25.4%
Artocarpus heterophyllus or *Mangifera indica* or *Persea americana*	165	78.9%
Albizia coria and *Jackfruit*	73	34.9%
Albizia coria or *Jackfruit*	162	77.5%
Ficus thonningii and *Jackfruit*	80	38.3%
Ficus thonningii or *Jackfruit*	172	82.3%
Albizia coria and *Mangifera indica*	59	28.2%
Albizia coria or *Mangifera indica*	157	75.1%
Ficus thonningii and *Mangifera indica*	66	31.6%
Ficus thonningii or *Mangifera indica*	167	79.9%
Albizia coria and *Ficus thonningii*	63	30.1%
Albizia coria or *Ficus thonningii*	148	70.8%

Table 4: Percentage of farms with targeted trees, the sum of trees and the sum of importance scoring for targeted trees

	Farms with targeted trees					Sum of trees					Sum of importance scoring				
	All land cl.	L. cl. 1	L. cl. 2	L. cl. 3	L. cl. 4	All land cl.	L. cl. 1	L. cl. 2	L. cl. 3	L. cl. 4	All land cl.	L. cl. 1	L. cl. 2	L. cl. 3	L. cl. 4
Artocarpus hetero phyllus	66%	57%	73%	44%	59%	1150	264	457	229	200	401	126	149	81	45
Mangifera indica	57%	50%	59%	34%	67%	778	177	281	147	173	278	92	90	54	42
Ficus thonningii	55%	40%	69%	33%	59%	983	174	447	219	143	207	57	85	37	28
Albizia coria	46%	40%	56%	23%	48%	591	115	247	98	131	248	67	102	41	38
Persea americana	40%	28%	50%	27%	41%	1474	98	214	97	1065	221	53	86	50	32
Pachystela msolo	21%	24%	19%	8%	26%	876	222	278	51	325	48	13	25	5	5
Maesopsis eminii	20%	13%	20%	11%	37%	356	60	70	98	128	80	15	22	23	20
Pine	8%	6%	9%	8%	4%	523	127	281	95	20	26	8	13	5	.
Eucalyptus	3%	1%	6%	2%	4%	2420	200	1200	20	1000	21	4	15	2	0
Ficus Sycomorus	3%	1%	3%	5%	4%	11	2	3	4	2	.	.	.	.	.

Benefits and constraints of trees on farm, experienced and evaluated by farmers for each tree species separately, are listed in table 5.

table 5: Benefits and problems associated with trees, based on farmers evaluation

advantages/ disadvantages		*A. hetero phyllus*	*M. indica*	*A. coria*	*F. thon ningii*	*P. ameri cana*	*P. msolo*	*Musizi*	*Pine*	*Eucalyptus*
Good banana neighbour	doesn't know			7%						
	yes	19%		61%	58%	4%		6%		
	no	81%		31%	42%	96%		94%		
positive shading	doesn't know	4%	3%	3%	5%	8%	2%	7%	18%	
	yes	30%	34%	36%	38%	27%	36%	46%	35%	
	no	65%	63%	61%	57%	65%	61%	46%	47%	100%
fodder	doesn't know	5%	4%	4%	6%	7%		7%	6%	
	yes	22%	19%	6%	8%	33%	7%	5%	6%	
	no	73%	76%	90%	86%	60%	93%	88%	88%	100%
mulch	doesn't know	7%	5%	4%	6%	8%		7%	12%	
	yes	8%	3%	12%	7%	5%	2%	5%		
	no	86%	92%	84%	87%	87%	98%	88%	88%	100%
manure	doesn't know	7%	5%	4%	6%	8%		7%	12%	
	yes	3%	8%	34%	18%	4%		2%		
	no	91%	87%	62%	76%	88%	100%	90%	88%	100%
windbreak	doesn't know	7%	4%	4%	5%	8%		7%	6%	
	yes	17%	22%	20%	20%	7%	36%	17%	18%	14%
	no	77%	74%	76%	75%	84%	64%	76%	76%	86%
firewood	doesn't know	4%	5%	3%	4%	5%		5%	12%	
	yes	20%	17%	39%	64%	11%	34%	20%	12%	86%
	no	75%	78%	58%	32%	83%	66%	76%	76%	14%
timber	doesn't know	5%	5%	3%	4%	6%		5%	12%	
	yes	4%	7%	51%	15%	7%	61%	61%	53%	57%
	no	91%	88%	45%	81%	87%	39%	34%	35%	43%
food	doesn't know	3%	3%	3%	4%	1%		5%	12%	
	yes	77%	76%	4%	13%	78%	5%	5%	12%	
	no	20%	20%	91%	83%	20%	95%	90%	76%	100%
competing for nutrients with crops	doesn't know	5%	6%	2%	6%	6%	5%	7%	12%	
	yes	24%	24%	27%	17%	23%	25%	22%	18%	
	no	71%	70%	71%	77%	71%	70%	71%	71%	100%
hosting pests and diseases	doesn't know	6%	7%	4%	7%	7%	5%	7%	12%	
	yes	1%	3%	2%	5%	4%	2%	5%		
	no	93%	91%	94%	88%	89%	93%	88%	88%	100%
negative shading	doesn't know	6%	7%	4%	7%	6%	5%	7%	12%	
	yes	7%	4%	4%	10%	2%		7%	12%	
	no	88%	89%	92%	83%	92%	95%	85%	76%	100%

Based on the farms with targeted trees from table 2, the results from table 3 as well as on the importance scoring from table 4, the high importance of *Artocarpus heterophyllus, Mangifera indica, A. coria, F. thonningii* and *Persea americana* for the livelihood of central Ugandan farmers becomes visible. Due to their high importance *Artocarpus heterophyllus, Mangifera indica,, A. coria, F. thonningii* and *Persea americana* are summarized under the category “top five” in table 3. The irreplaceability of the top five is illustrated by 88 % of farmers, who have at least one of them on their farm. For further comparison, the top five will be separated into fruit trees and soil improving shade trees for bananas.

The value of the fruit trees *Artocarpus heterophyllus*, *Mangifera indica* and *Persea americana* for food security is expressed by 80% of farmers who have at least one of them on farm and 25% who are hosting all three species.

On the other side 70,8% of farmers are having *A. coria or F. thonningii* trees, whereas 30,1% are having both species on farm.
The overall importance of trees for the farmers’ livelihood is stressed through the fact that only 8,6 % have no tree at all on their farm (Table 3)

As explained in the discussion chapter, the following characterization of tree species is a generalization of the views farmers have on advantages and disadvantages of the trees, they are growing, based on to their particular livelihood.

The high importance ranking of *Artocarpus heterophyllus, Mangifera indica* and *Persea americana* is based on their quality of enhancing food and to a minor extend fodder security.
The top priority of *Artocarpus heterophyllus* in the importance scoring might be explained by the fact that *Mangifera indica* and *Persea americana* are only seasonably available, whereas *Artocarpus heterophyllus* can be harvested throughout the year to be used for food and fodder. The high number of *Persea americana* trees in land class 4 may be an indicator for its suitability as cash crop.

Pachystela msolo and *Maesopsis eminii* are both leading with 61% acceptance as the best timber providers. Beside that, *Pachystela msolo* is also regarded as the tree with the best attitude as windbreak and appreciated as firewood resource by 34 % of farmers. On the other hand *Maesopsis eminii* can be regarded as the tree with the best shading qualities (Table 4, Table 5).

The nitrogen fixing ability of *A. coria* is recognised by 34 % of farmers who agree on its value as fertilizer and make *A. coria* to the tree holding the highest percentage for its manuring and mulching qualities. These results also match with the outputs of the farmer field meetings I have attended. Beside its qualities for intercropping, *Albizia coria* is also one of the best timber providers for farmers (Table 5).

Unlike *A. coria*, *F. thonningii* is not a nitrogen fixing species. Despite that, it is the tree holding the second highest scoring for its suitability as manure. 64 % of the interviewed farmers appreciate *F. thonningii* as firewood.
The only tree, holding a higher acceptance than *F. thonningii*, for its quality as firewood is *Eucalyptus* with 86%. However, this output is questionable because only 3% of farmers are growing *Eucalyptus* (Table5).

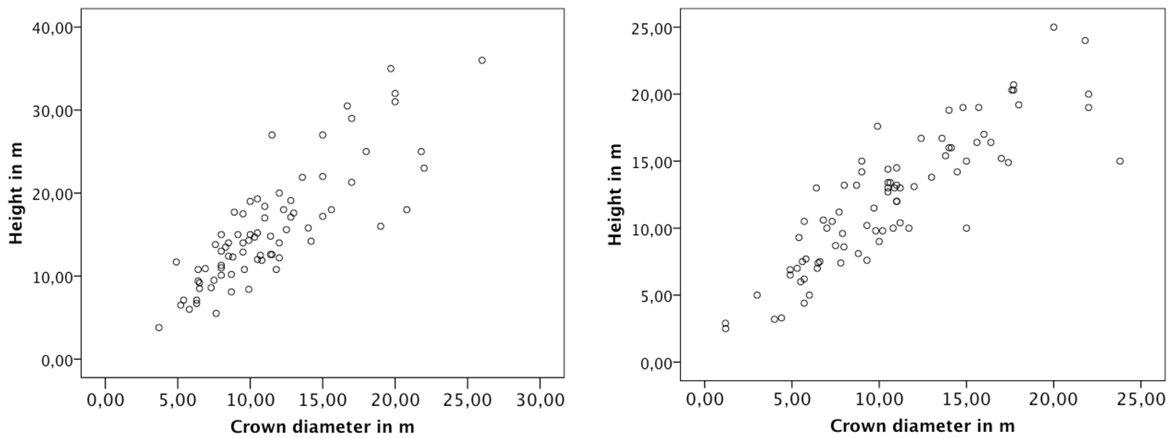
As *A. coria* and *F. thonningii* are regarded as good banana neighbours by almost 60% of interviewed farmers, and can at the same time be found under the top five trees for the overall livelihood of central Ugandan farmers, they were chosen for the characterization of light interception via hemispherical photography. Especially their relatively high ranking concerning positive shading, justifies the need for further research in this direction.

5.2 Analyses of light interception and growth parameters for *Albizia coria* and Ficus *thonningii* trees.

During my last field trip to Uganda the light interception of 96 *A. coria* and 95 *F. thonningii* trees at different size and age classes was captured via hemispherical photography.

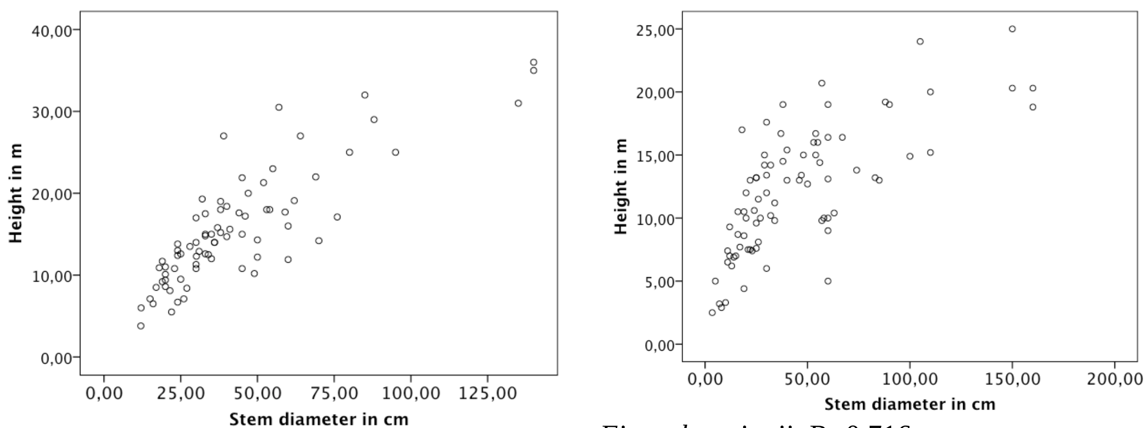
Due to difficult light conditions and overlapping tree crowns, only 79 *A. coria* and 81 *F. thonningii* trees could be used for further analyses.

For both species, a highly significant correlation between the growth parameters height, crown diameter and stem diameter could be demonstrated as shown in Fig. 5-7.



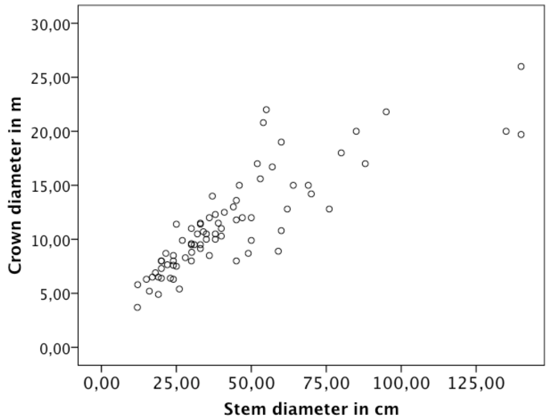
Albizia coria: R=0.837 Ficus thonningii: R=0.868

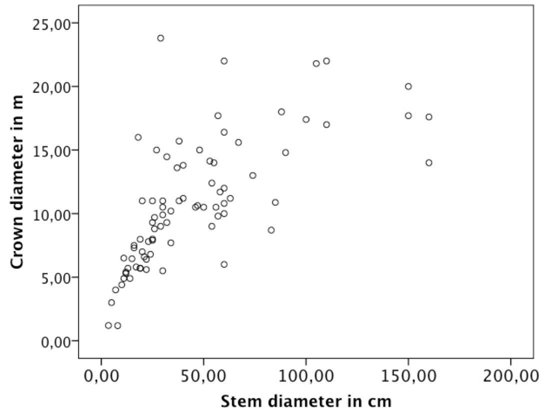
Fig. 5: Height versus crown diameter of *Albizia coria* and *Ficus thonningii*



Albizia coria: R=0.839 *Ficus thonningii*: R=0.716

Fig. 6: Height versus stem diameter of *Albizia coria* and *Ficus thonningii*

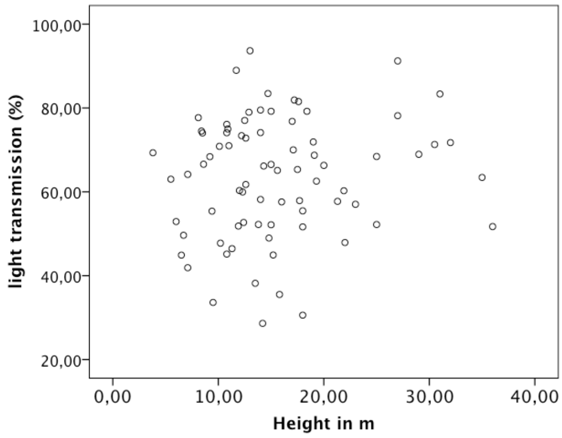


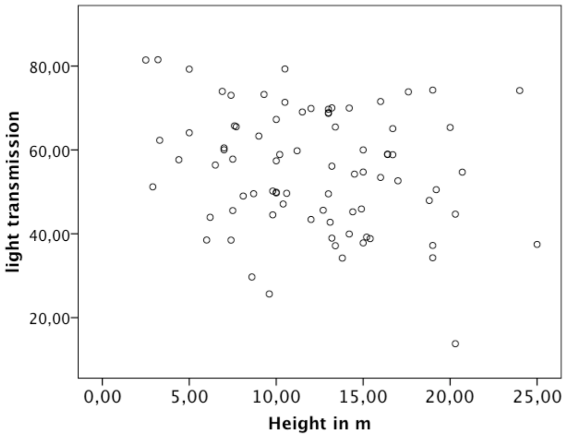


Albizia coria: R=0.838 *Ficus thonningii*: R=0.683

Fig. 7: Crown diameter versus stem diameter of *Albizia coria* and *Ficus thonningii*

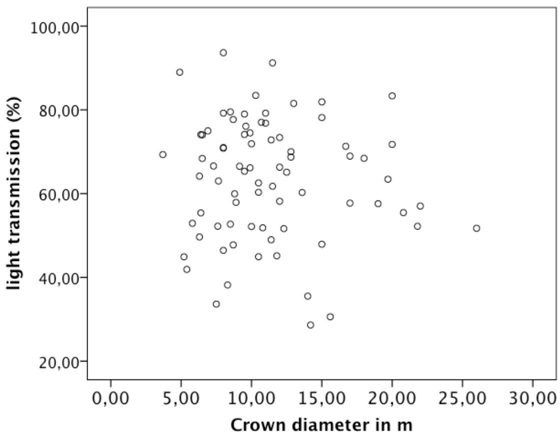
Fig. 8-11 demonstrate that despite the highly significant correlation between the growth parameters, there was no correlation between growth parameters and percentage of light transmission that reaches the area under the canopy.

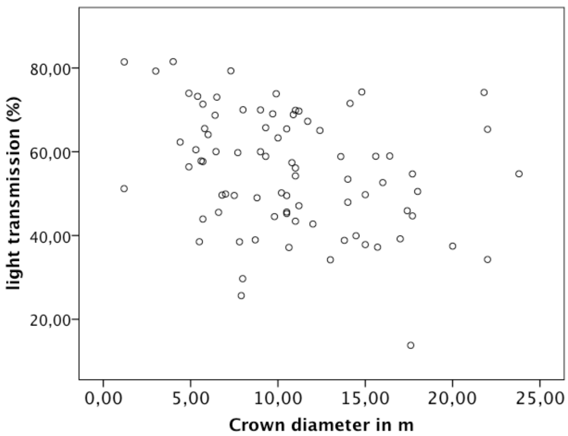




Albizia coria: R=0.126 *Ficus thonningii*: R=-0.227

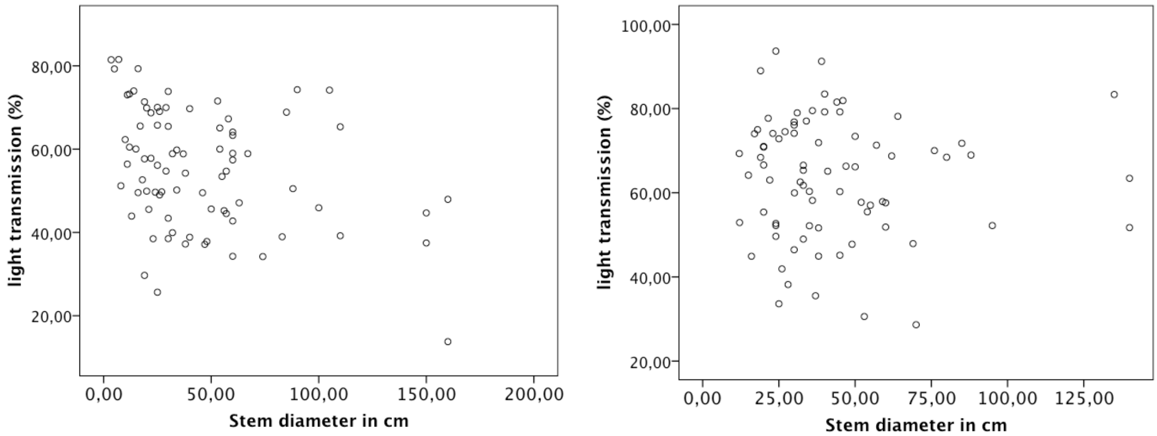
Fig. 8: Light transmission (%) versus height (m) of *Albizia coria* and *Ficus thonningii*





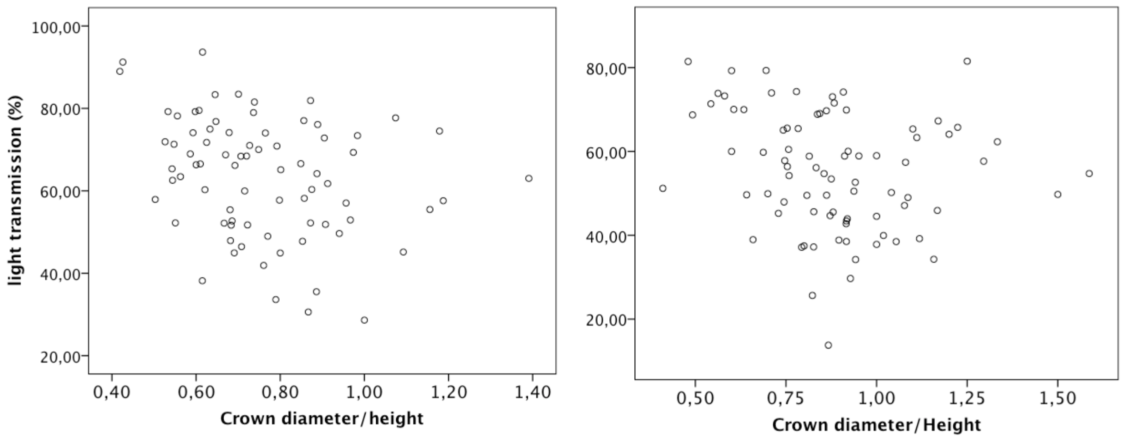
Albizia coria: R=-0.077 *Ficus thonningii*: R=-0.314

Fig. 9: Light transmission (%) versus crown diameter (m) of *Albizia coria* and *Ficus thonningii*



Albizia coria: R=-0.043 *Ficus thonningii*: R=-0.343

Fig. 10: Light transmission (%) versus stem diameter (cm) of *Albizia coria* and *Ficus thonningii*



Albizia coria: R=-0.287 *Ficus thonningii*: R=-0.202

Fig. 11: Light transmission (%) versus crown diameter/height of *Albizia coria* and *Ficus thonningii*

To ease further comparison, the two species were grouped into three light transmission classes (Fig.12-13).

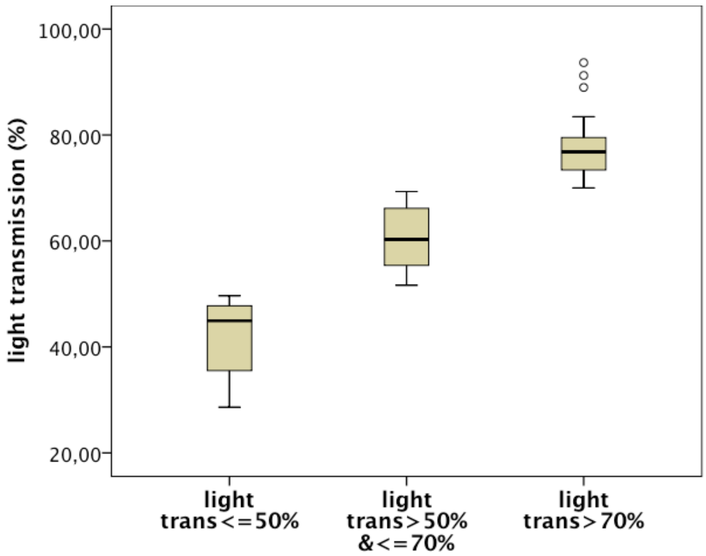


Fig. 12: Light transmission (%) for Albizia coria trees in three different light transmission classes

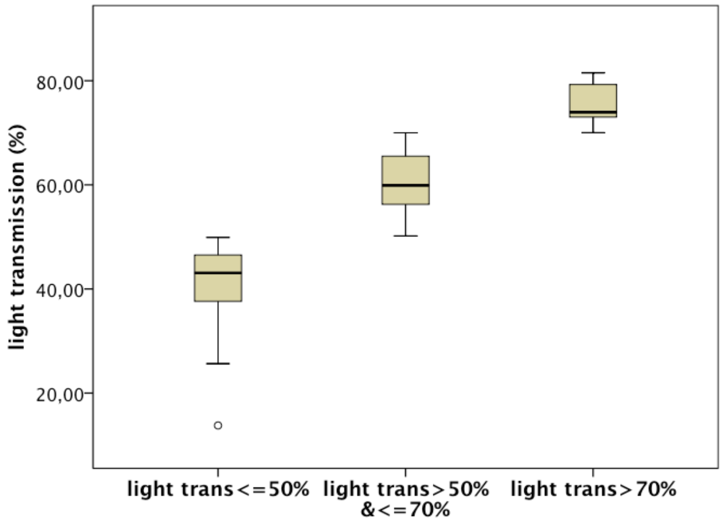


Fig. 13: Light transmission (%) for Ficus thonningii trees in three different light transmission classes.

Although it was not possible to come up with an allometry between growth parameters and the amount of shade produced through them, the collected data stresses the altering intercropping abilities of *A. coria* and *F. thonningii* in terms of light transmission.
With a mean value of 63,3% for light transmission, *A. coria* generally seems to be more adequate for intercropping than *F. thonningii* with a mean of 55,3% (Table 6).

Table 6: Mean calculated light transmission for *Albizia coria* and *Ficus thonningii*.

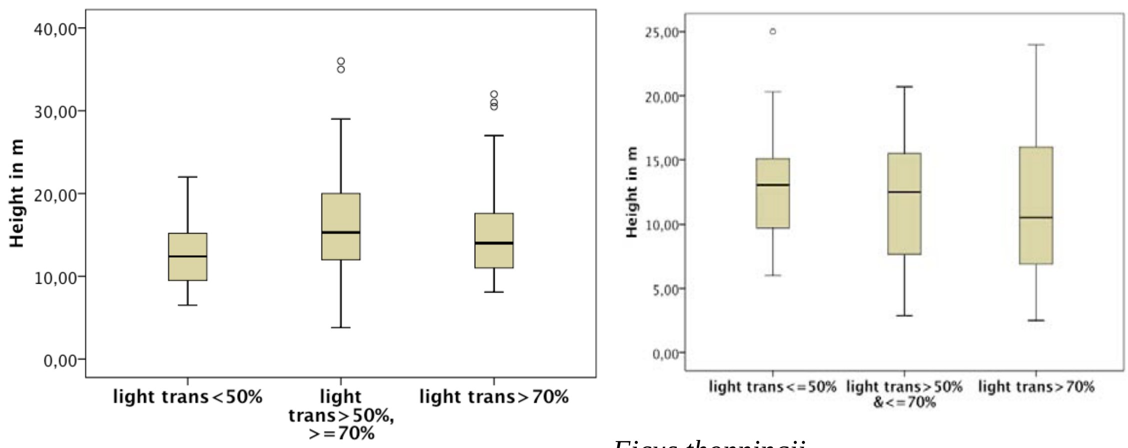
	Albizia coria	*Ficus thonningii*
N	77	81
mean	63,5	55,3
median	65,3	56,1
Standard dev.	14,4	14,1
min	28,6	13,8
max	93,6	81,5

82% of all analyzed *A. coria* was found in the light transmission classes over 50%, whereas only 60% of *F. thonningii* was found in these classes. As the mean and median light transmission percentages are fairly similar, with slightly higher values for *A. coria* in the first and third light transmission class, the strong light transmission rate of *A. coria* becomes apparent (Table 7).

Table 7: Calculated light transmission (%) over the three light transmission classes for *Albizia coria* and *Ficus thonningii*

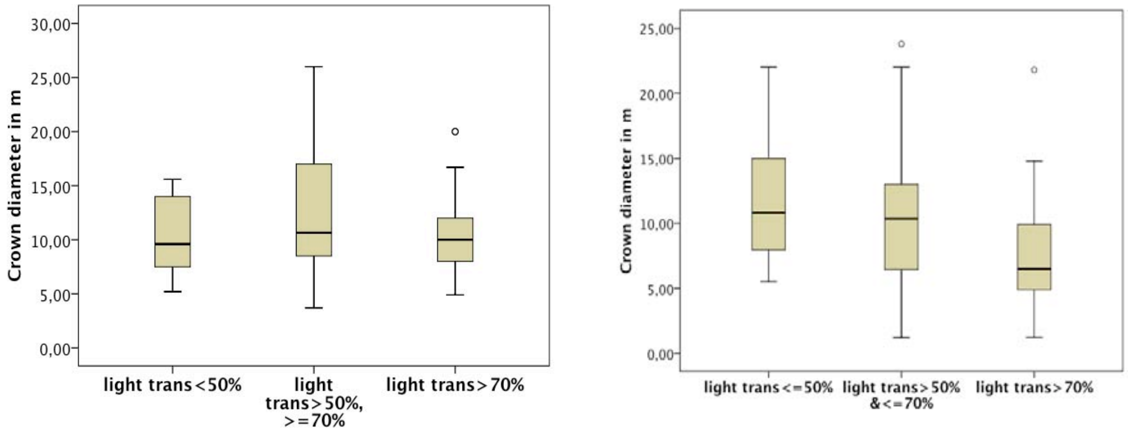
		Albizia coria	*Ficus thonningii*
Light trans <= 50 %	N	14	32
	Mean	41.7 %	41 %
	Median	44.9 %	43 %
	Standard deviation	7.1	7.9
	Min	28.6	13.8
	Max	47.7	49.9
Light transmission >50% &<=70 %	N	34	36
	Mean	60.4 %	60.6 %
	Median	60.3 %	59.9 %
	Standard deviation	6	6
	Min	51.7	50.2
	Max	69.3	70
Light transmission > 70%	N	29	13
	Mean	77.6 %	75.2 %
	Median	76.8 %	74 %
	Standard deviation	6	3.9
	Min	70	70
	Max	93.7	81.5

Fig. 14-17 visualize the effect of differing tree growth parameters of *A. coria* and *F. thonningii* on the above presented light transmission classes.



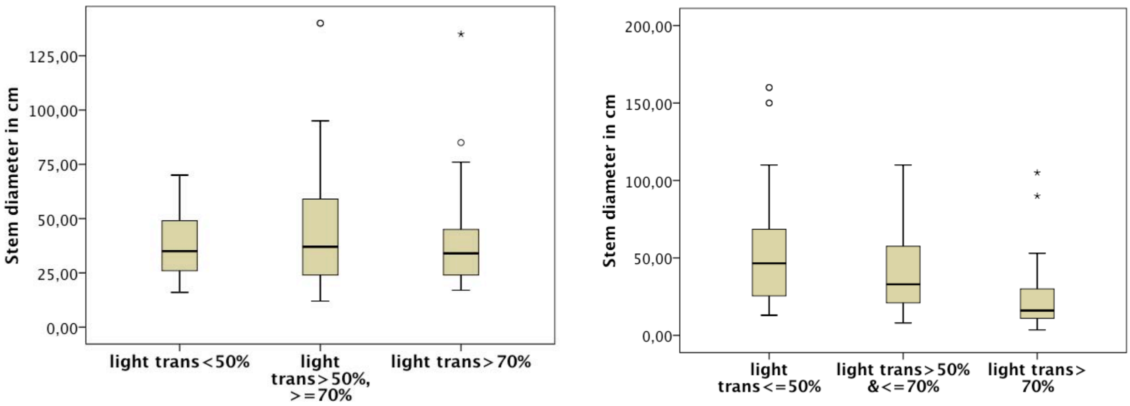
Albizia coria *Ficus thonningii*

Fig. 14: Height of *Albizia coria* and *Ficus thonningii* trees versus light transmission (%)



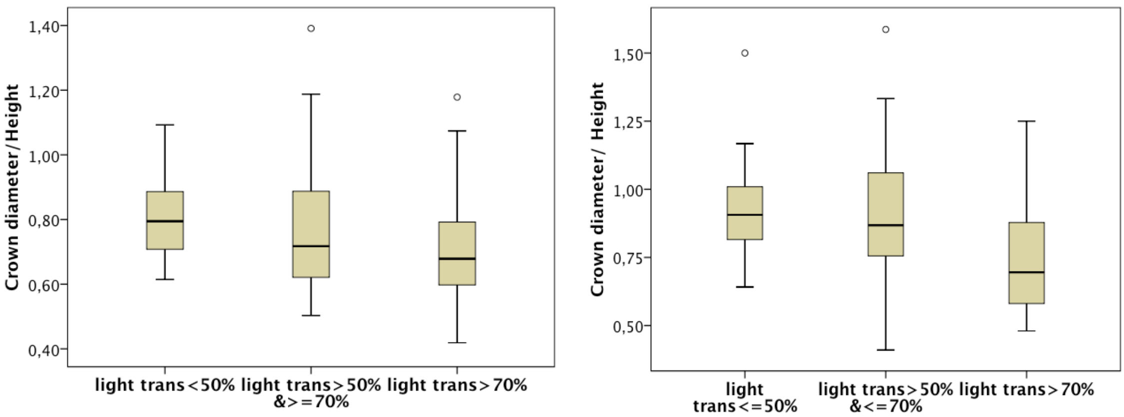
Albizia coria *Ficus thonningii*

Fig. 15: Crown diameter of *Albizia coria* and *Ficus thonningii* trees versus light transmission (%).



Albizia coria *Ficus thonningii*

Fig. 16: Stem diameter of *Albizia coria* and *Ficus thonningii* trees versus light transmission (%).



Albizia coria *Ficus thonningii*

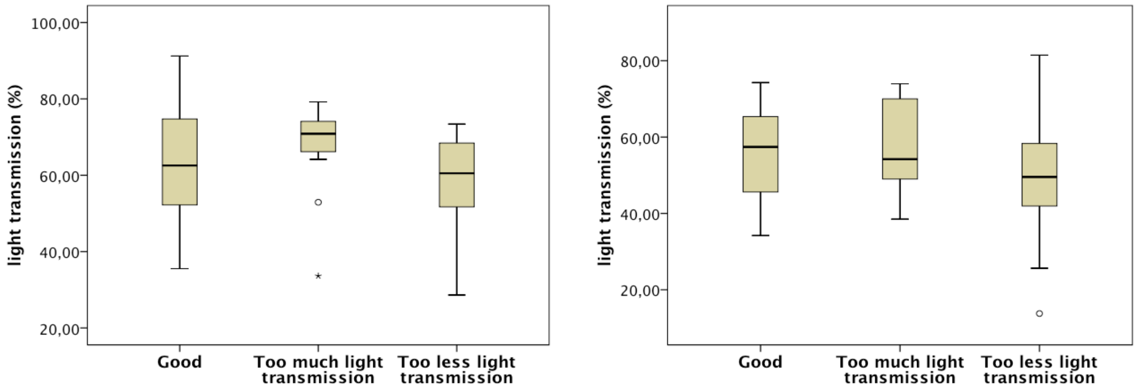
Fig. 17: Crown diameter/ height of *Albizia coria* and *Ficus thonningii* trees versus light transmission.

For *A. coria* no significant difference of the growth parameters height, crown diameter and stem diameter between the particular light transmission classes was identified (Fig.14-16). Fig. 17 indicates a certain relationship between light transmission and the coefficient of tree height divided by crown diameter: The lower this coefficient, the more light will be transmitted through its crown. The differences were not significant, however.

F. thonningii showed a stronger relation between growth parameters and light transmission classes than *A. coria.* Especially class 3 (more than 70 % light transmission) differs from class 1 (less than 50 % light transmission) and 2 (50 % to 70 % light transmission) (Fig.14-16). The coefficient of tree height and crown diameter (H/CD) states this tendency: light transmission class 3 differed significantly from class 1 and 2 ($p<0.05$) (Fig.17).

5.3 The light transmission of *Albizia coria* and *Ficus thonningii* tree canopies versus the shade quality as perceived by farmers*.*

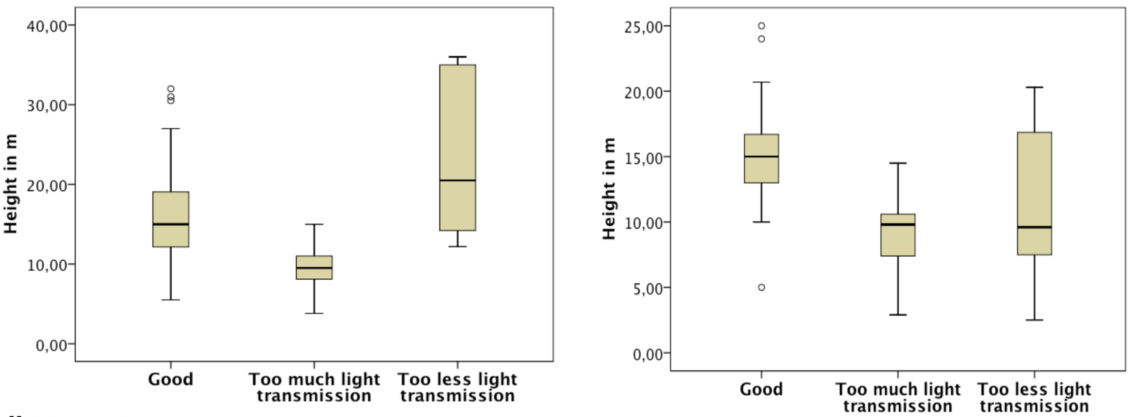
The baseline data drew a picture of farmers who are growing many trees, but do not really know its advantages and disadvantages, in general, and in particular for intercropping them with bananas. In order to find out whether this assumption is really based on the ignorance of farmers, or can be interperated as a result of misunderstandings between farmer and interviewer, the farmers' assessment concerning the suitability of shade produced by their trees for intercropping was captured. Via collaborative documentation and evaluation of existing agroforestry systems on their farms it was planned to find out the farmers criteria for assessing the influence of trees on banana growth. Twenty-three farmers who gave permission to measure light transmission under their trees, were asked to make an evaluation of the shading qualities of their trees. The answers have been classified under three categories: good, too much light transmission and too less light transmission.
Fig. 18 illustrates the farmers evaluation combined with the actually measured light transmission under *A. coriana* and *F. thonningii* trees. Apparently there is no significant difference between the three categories, neither for *A. coria* (ANOVA, F= 1.130, p= .330) nor for *F. thonningii* (ANOVA, F= 1.390, p= .256).



Albizia coria *Ficus thonningii*

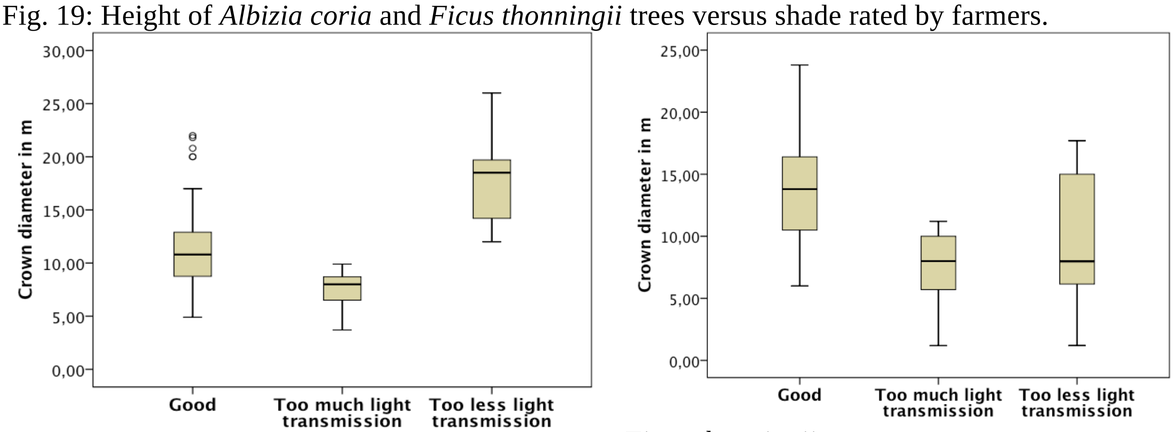
Fig. 18: Measured light transmission under *Albizia coria* and *Ficus thonningii* versus quality of shade rated by farmers.

Obviously the farmers evaluation of the shading quality has not been based on observations of the actually produced shade, at least not in a direct way. To find out the farmers criteria of estimating shade, their evaluation was combined with the measured tree growth parameters



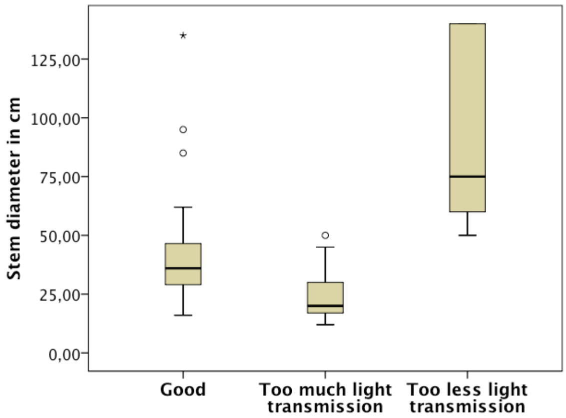
Albizia coria *Ficus thonningii*

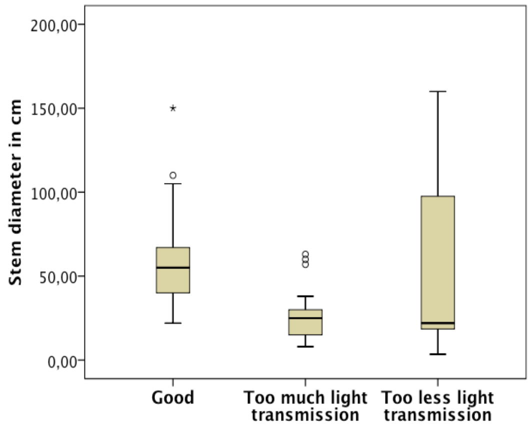
Fig. 19: Height of *Albizia coria* and *Ficus thonningii* trees versus shade rated by farmers.



Albizia coria *Ficus thonningii*

Fig.20: Crown diameter of *Albizia coria* and *Ficus thonningii* versus quality of shade rated by farmers.





Albizia coria *Ficus thonningii*

Fig. 21: Stem diameter of *Albizia coria* and *Ficus thonningii* versus quality of shade rated by farmers.

5.4 The response of Mpologoma to different shading intensities under *Albizia coria*

The analyzed mats are part of the research area in Bagwe. All of them are under the canopy of an *Albizia coria* tree, planted at different distances from the trunk. As the 40 mats were not planted at the same time and are hence not of the same growth stage, 24 mats of the same growth stage were selected for comparison. Leaf area in m^2 per mat, number of fingers per bunch and number of hands per bunch were collected at:

- the beginning of the dry season (11.12. 2010),
- the beginning of rainy season (12.3. 2011) and
- the end of rainy season (14. 5. 2011) for each mat.

For further analyses, the mats were arranged in three light transmission classes according to the amount of light transmission.:

- *class 1: light transmission ≤ 50 %,*
- *class 2: light transmission >50 % & ≤70 %,*
- *class 3: light transmission ≥70 %*

In Fig. 22 the three light transmission classes were set in relation to the actual produced leaf area at the above mentioned measuring dates.

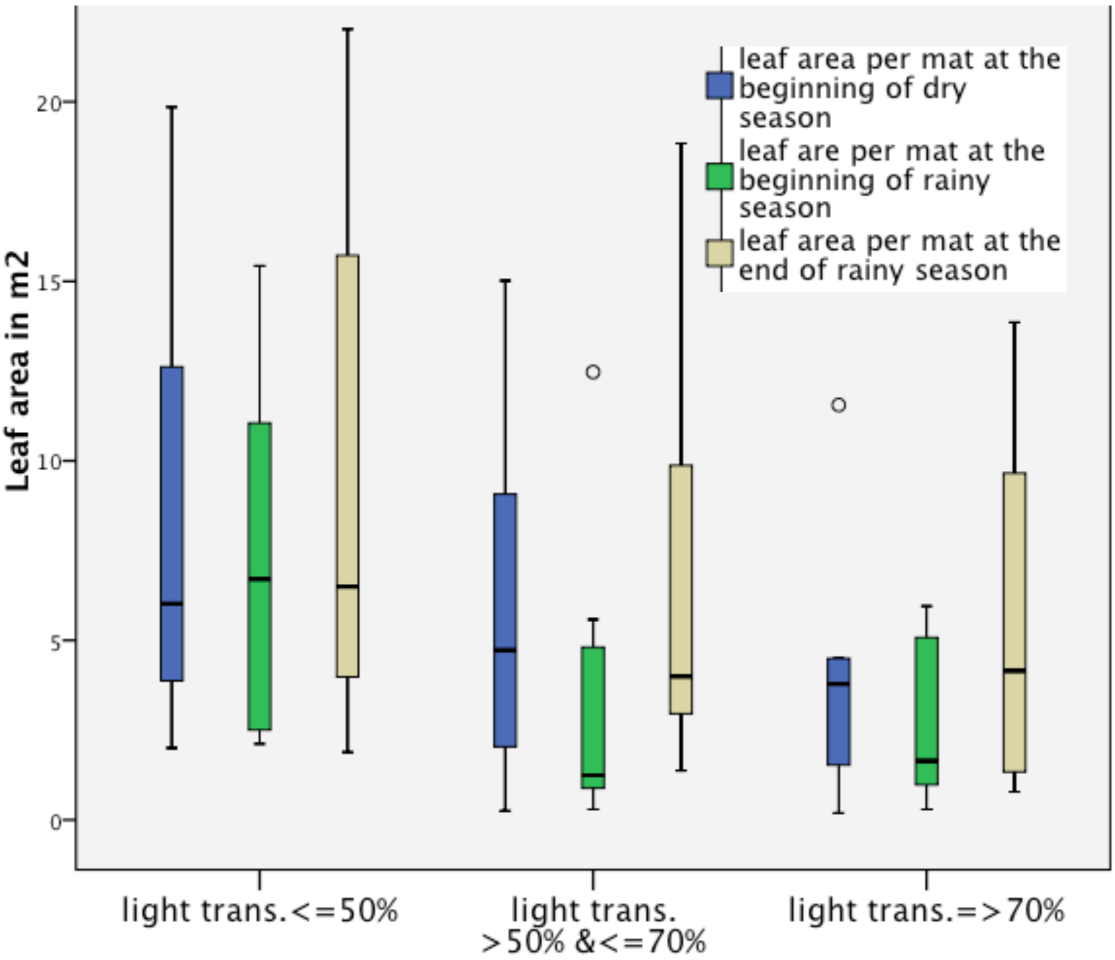
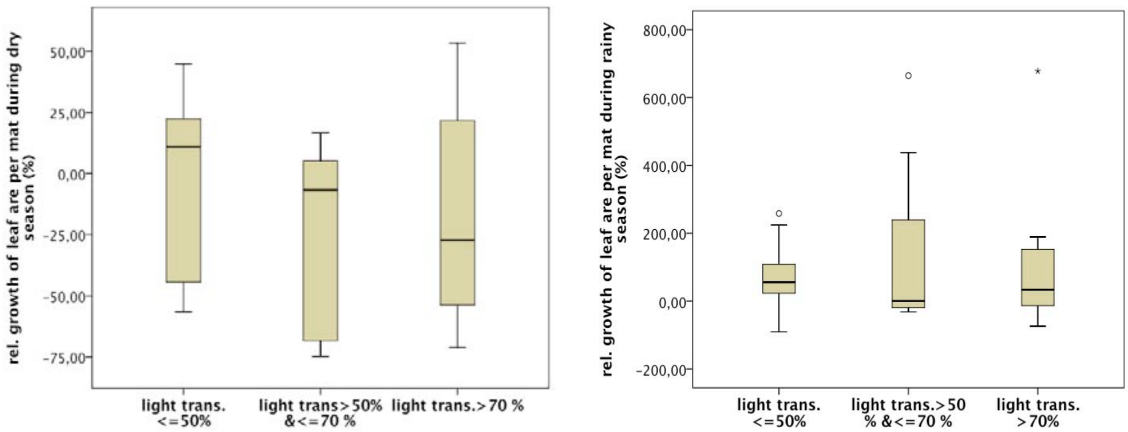


Fig. 22: Measured leaf area of *Mpologoma* over the three light transmission classes at the beginning of dry season, at the beginning of rainy season and at the end of rainy season

Fig. 23 presents the relative leaf area growth in % between the measurement dates.



dry season rainy season

Fig. 23: Mean relative growth of leaf area (%) per mat during dry and rainy season.

Both the actually produced, as well as the relative leaf area growth, do not indicate a significant difference between the light transmission classes. Nevertheless, class 1 is always holding the highest value and shows the lowest leaf area reduction from rainy to dry season (Fig.22-23). The difference in leaf area growth from class 1 (light transmission ≤ 50 %) to class 2 and 3 (both above 50 % light transmission) is much bigger than the difference from class 2 to class 3.

Fig. 24 and Fig. 25 visualize the number of fingers and hands per banana bunch. Although there is again no significant difference between the data of the three classes, it has to be stressed that these are the only parameters where class 1 does not have the highest median.

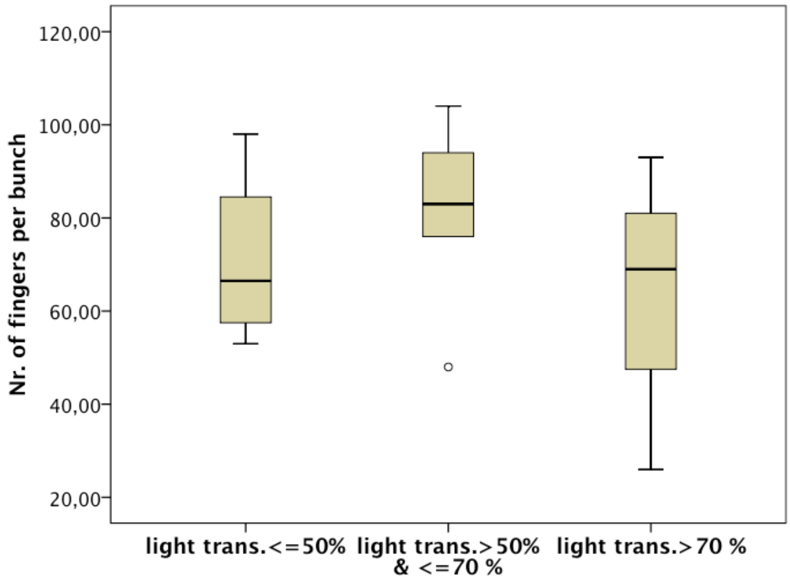


Fig. 24: Mean number of fingers per bunch over the three light transmission classes.

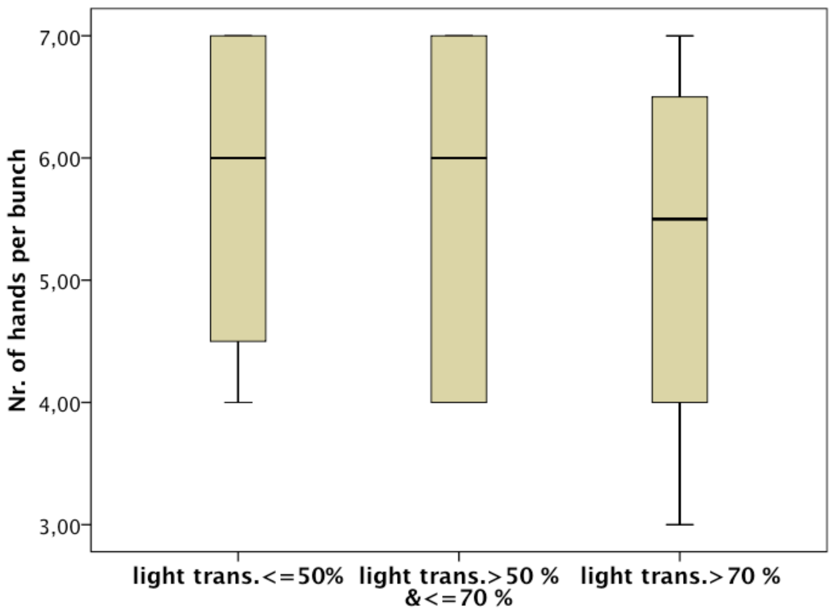


Fig. 25: Mean number of hands per bunch over the three light transmission classes.

Considering that the number of plants with ripe fruits was not enough to allow statistical comparison between the light transmission classes, bunch weight could not be used for further analyses.

Nevertheless, the overall effect of A. coria on banana yield is positive: whereas out of 37 banana mats under the tree, only one plant broke down because of the winds during the rainy season, 24 plants from a total of 66 mats in the pure banana stand were lost.

5.5 Soil analyses at the trial site Bagwe

Table 8: Results of soil analyses at the trial area Bagwe. Zone A, B and D delineate banana plantation areas without trees, C is the area with tree cover and bananas.

ref	depth of sample	pH (H2O)	OM (%)	N (%)	P (ppm)	K (meq/ 100g)	Ca (meq/ 100g)	Mg (meq/ 100g)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)	Boron (ppm)	Soluble sulphat es (ppm)
zone A	0-15 cm	6.1	6.3	0.29	10.4	0.91	15.17	8.61	0.8	7.2	301.8	79.4	0.2	126.4
zone A	15-30 cm	5.4	3.9	0.22	3.9	0.46	9.49	6.78	0.7	4.3	299.9	74.6	0.3	100.2
zone A	30-60 cm	4.9	3.0	0.17	5.2	0.27	8.13	5.19	1,2	6.1	298.1	89.5	0.3	75.5
zone B	0-15 cm	5.6	5.9	0.26	5.2	0.53	13.94	6.90	0.7	5.8	300.9	75.5	0.1	107.0
zone B	15-30 cm	4.9	4.0	0.19	6.0	0.52	8.14	4.19	0.6	3.3	299.6	91.9	0.1	121.1
zone B	30-60 cm	4.8	2.5	0.16	2.1	0.39	10.90	3.28	0.7	2.3	294.7	81.2	0.1	109.7
zone C	0-15 cm	5.9	5.4	0.27	19.8	1.08	27.0	7.07	1.6	7.5	301.4	66.7	0.0	94.4
zone C	15-30 cm	5.5	4.9	0.24	17.6	0.55	20.07	5.17	2.6	5.2	300.0	81.5	0.2	102.4
zone C	30-60 cm	5.3	2.6	0.14	3.3	0.34	11.34	4.38	1.9	0.0	292.5	73.3	0.2	54,5
zone D	0-15 cm	6.3	2.3	0.32	10.1	1.12	29.36	9.87	2.5	6.8	299.3	58.0	0.1	109.5
zone D	15-30 cm	5.5	7.0	0.22	1.7	0.53	19.79	6.78	3.0	4.0	299.7	75.1	0.1	92.8
zone D	30-60 cm	5.0	4.5	0.15	0.9	0.31	10.66	4.28	3.0	0.6	294.9	73.0	0.2	63.7

Ppm = parts per million, meq/100g = Milliequivalent per 100 g soil

In the following section, the results of the soil analyses, summarized in table 8 will be compared to a) worldwide recommended soil requirements for bananas and b) the average composition of top soils in Ugandan banana plots (table 9 in: BLOMME et al. , 2003).

Table 9: Average minimum soil requirements for banana based on worldwide studies versus the average composition of top soils in Ugandan banana plots (VAN ASTEN, et al., 2003)

	pH	**N**	**K**	**Ca**	**Mg**	**P**	**Zn**
		(%)	**(meq/100 g soil)**			**mg/kg**	
Guidelines	5.1	-	0.6	3.0	0.9	8	3.0
Uganda	6.0	0.13	1.3	5.9	2.0	23	-

For all four zones, soil ph was within the recommended levels (table 9). Based on NELSON et al., 2006 who recommend an optimum ph range between 5.5 and 7.5 , the soil layers below 15 cm are slightly too acidic.

Compared to the average of Ugandan soils, Nitrogen levels are relatively high and potassium is below the Ugandan average, but still in line with the guidelines.

Calcium as well as magnesium levels are far above the recommendations for banana and the Ugandan average.

Concerning phosphor, zone A, C and D is above the guidelines, but below the Ugandan average. Only zone B is below the recommended phosphorus level (40 %). Zn levels are with an exception of zone B more than the double amount of the recommendations (table 8).

In table 10 the results of the analyses for all three zones with a pure banana stand are summarized to allow comparison between the impact of a pure banana stand plus extensive manuring on soil fertility versus the impact of bananas growing under the canopy of *Albizia coria* on soil fertility.

Soil fertility was maintained in the following way:

With an exception of the mixed stand, the planting whole of every banana was filled with one big basin of cow and goat dung before planting. After planting, the pure stand was manured once with a small bucket (9 l) of dung between each banana mat.

As pH, organic matter, nitrogen, manganese, iron and boron are fairly similar, the only nutrients that are lower in the mixed stand are magnesium and soluble sulphates. Therefore, the mixed stand is leading for phosphor, potassium, calcium, copper and zinc. It has to be stated that the phosphorus and calcium values of the mixed stand are extremely high compared to those of the pure stand (table 10). These results indicate that the fertilizing effect of *A. coria* is at least as good as the extensive soil improvement via manure.

Table 10: Soil nutrients under the pure banana stand respectively the nutrient status under the mixed stand

	depth of sample	pH H2O	OM (%)	N (%)	P (ppm)	K (meq/ 100g)	Ca (meq/ 100g)	Mg (meq/ 100g)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)	Boron (ppm)	Soluble sulphates (ppm)
Pure banana stand	**0-15 cm**	**6**	**4.84**	**0.3**	**8.57**	**0.85**	**19.5**	**8.46**	**1.35**	**6.58**	**300.7**	**70.95**	**0.13**	**114.308**
	15-30 cm	**5.27**	**5.0**	**0.2**	**3.88**	**0.5**	**12.5**	**5.92**	**1.42**	**3.89**	**299.7**	**80.52**	**0.17**	**104.7**
	30-60 cm	**4.9**	**3.31**	**0.2**	**2.74**	**0.32**	**9.89**	**4.25**	**1.63**	**3.01**	**295.9**	**81.25**	**0.18**	**82.97**
Mixed stand	**0-15 cm**	**5.9**	**5.4**	**0.3**	**19.8**	**1.08**	**27**	**7.07**	**1.63**	**7.47**	**301.4**	**66.66**	**0.03**	**94.90**
	15-30 cm	**5.5**	**4.91**	**0.2**	**17.6**	**0.55**	**20.1**	**5.17**	**2,6**	**5.23**	**300,0**	**81.5**	**0.24**	**102.42**
	30-60 cm	**5.3**	**2.60**	**0.1**	**3.26**	**0.34**	**11.3**	**4.38**	**1.94**	**0.0**	**292.5**	**73.3**	**0.18**	**54.51**

Soil profiles within the four zones revealed a slightly higher mean fort the A and AB-horizon under the mixed stand with 23.5 cm and 20 cm versus 21.3 cm and 17.3 cm under the pure stand. Consequently the mean for the B- horizon was a bit smaller (19.5 cm) under the mixed stand compared to 21.3 under the pure banana stand (Fig. 26).

Fig. 26: Soil profile under the mixed stand on the left in comparison to the pure stand on the right.

5.6 Soil moisture measurements at Bagwe

5.6.1 Spatially distributed discontinuous measurements

The discontinuous TDR measurements were analyzed by comparing the mean volumetric water content (VWC) of the soil under the pure banana stand to the values under the mixed stand (trees plus banana). The differences between the stands were tested for statistical significance by t-tests for all soil layers.

VWC of soil layer 1 (0-30cm) was significantly lower under the mixed stand for all measurement dates except February 24 and March 24 (Fig.30). This finding is in accordance with the results of the permanent measurements performed in the soil pits (Fig.31).

By the end of February, after 23 days without rain and 20 days with air temperatures above 35°C, in both stands the topsoil was almost equally depleted and both stands had to reduce evapotranspiration, resulting in non-significant t-test results for February 24.

The heavy rainfalls on March 19 and 20 (45 mm) on the other hand, led to similar VWC levels at the other end of the scale in both stands (Fig.30), also causing non-significant t-test results for March 24. Generally, severe drought or heavy rain events tend to level out differences in soil moisture patterns between differently stocked stands (SCHUME et al., 2003). As long as there were no extreme whether events (Fig.28) in terms of persistent dry spells or heavy rainfall, the observed effect of rewetting was stronger under the pure stand than under the mixed stand, probably due to the higher canopy interception of the mixed stand, as can be deduced from the light measurements. Overall, the combination of reduced soil evaporation and higher interception rates of the combined tree/banana canopy might be jointly responsible for the lower VWC in soil layer 1 observed under the mixed stand.

Quite opposite to soil layer 1, the VWC of soil layer 2 (30-60 cm) was on average 2% lower under the pure stand during the dry season (Fig. 29, Fig.30). Statistically significant differences could be observed only during the dry season, i.e. on December 28, January 18, February 5 and 14 as well as on March 10.

5.6.2 Soil pits - permanent measurements in high time resolution

The soil pits served to obtain soil moisture values in higher resolution over depth and in time. From the spatial point of view they have the representativeness of a spot measurement. For the first 60 cm soil depth the results are in line with the above stated findings of the spatially distributed discontinuous measurements.

In 80 cm soil depth the VWC was constantly app. 4% lower in the mixed than in the pure stand. In 100 cm depth both soils started at about the same moisture level, but the decrease in the mixed stand was much more pronounced (Fig. 27).

Altogether higher water extraction rates from the subsoil (deeper than 60 cm) were indicated by the combination of trees and bananas.

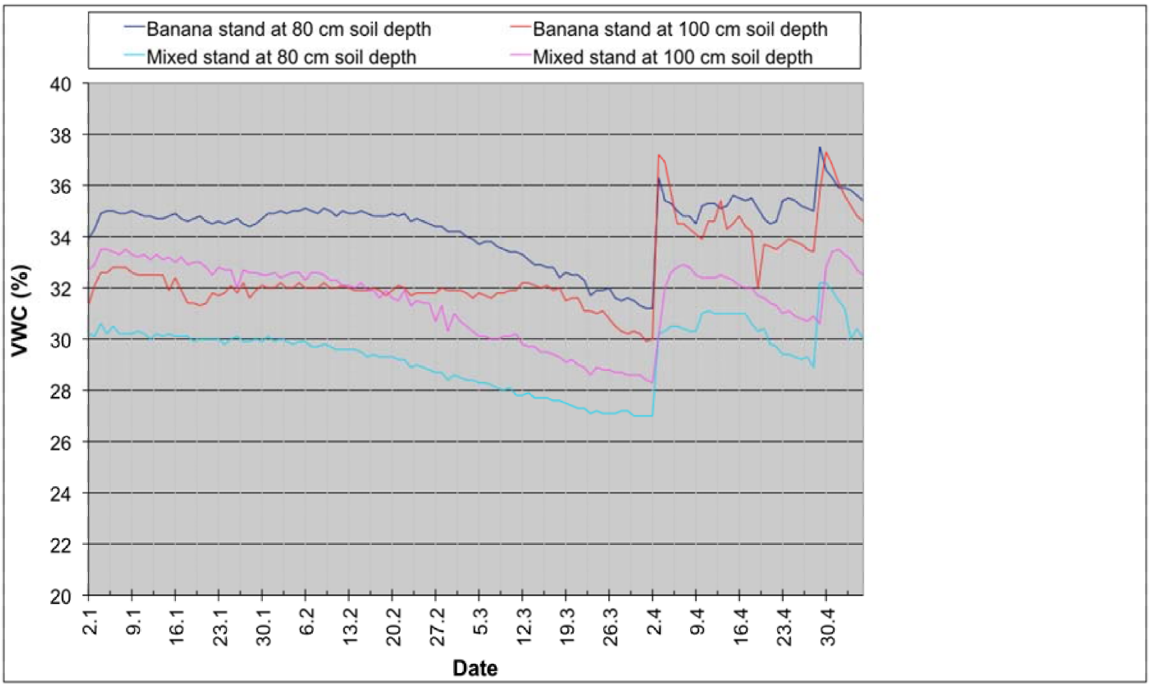


Fig. 27: Daily soil water measurements, comparing the pure banana stand to the mixed at soil depths of 80 versus 100 cm (daily measurements in the soil pits).

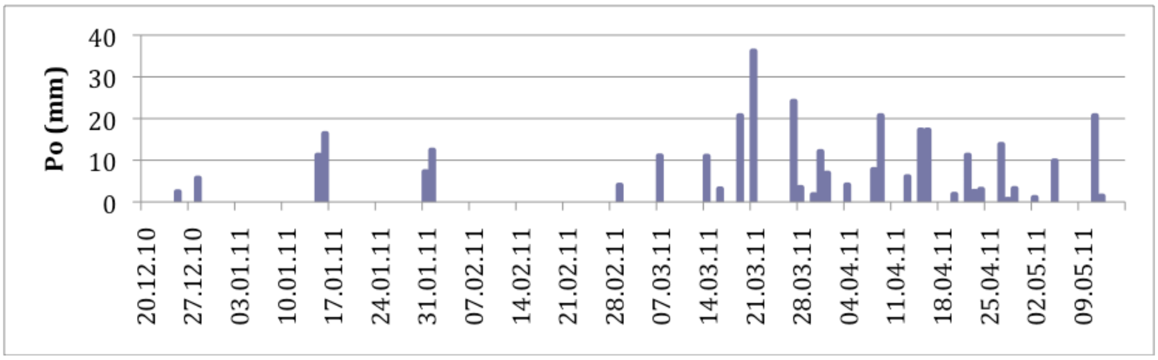


Fig. 28: Daily open field precipitation (*P*o) at the research site.

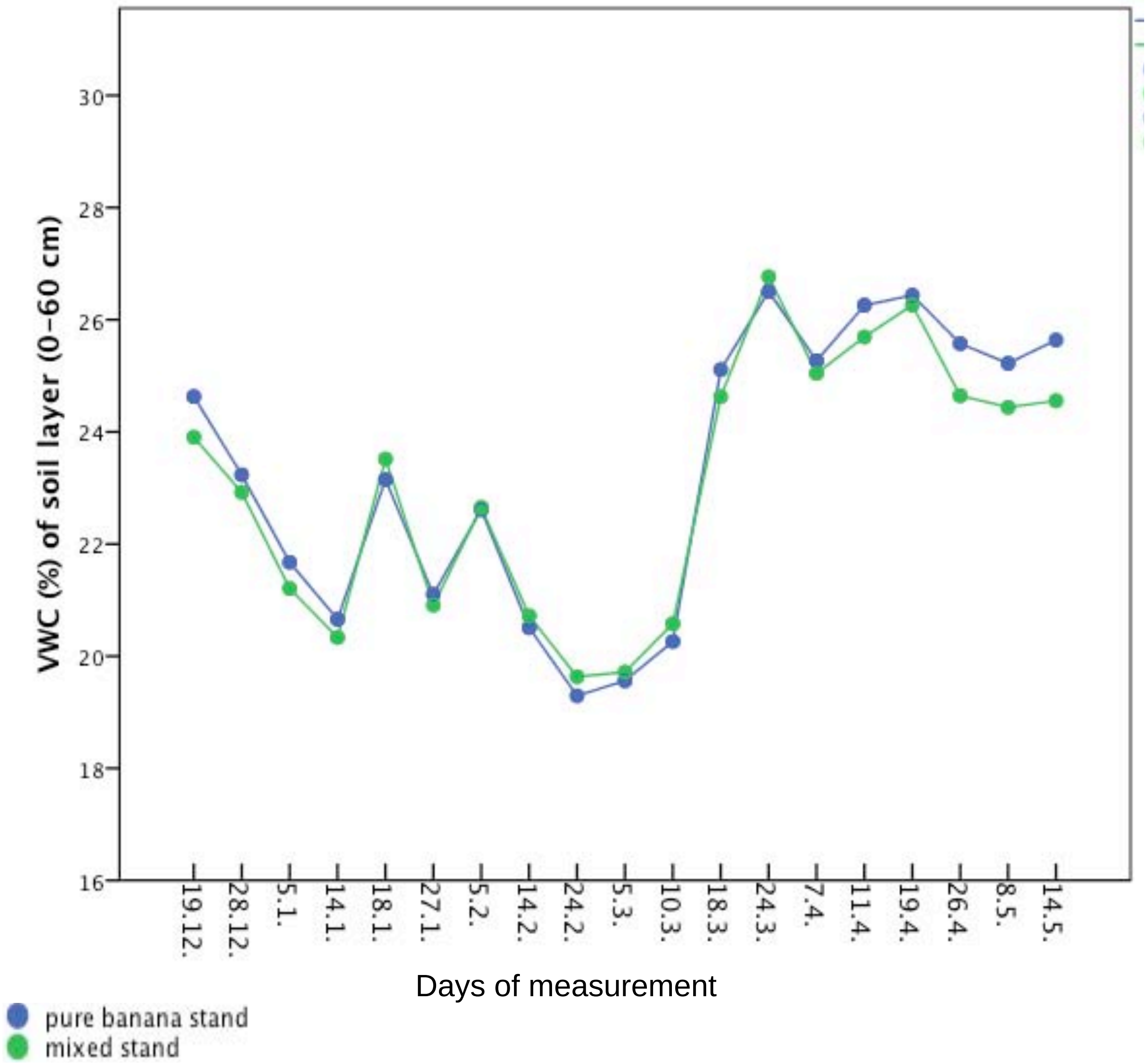


Fig. 29: Mean volumetric soil water content (VWC) by stands in the first 60 cm

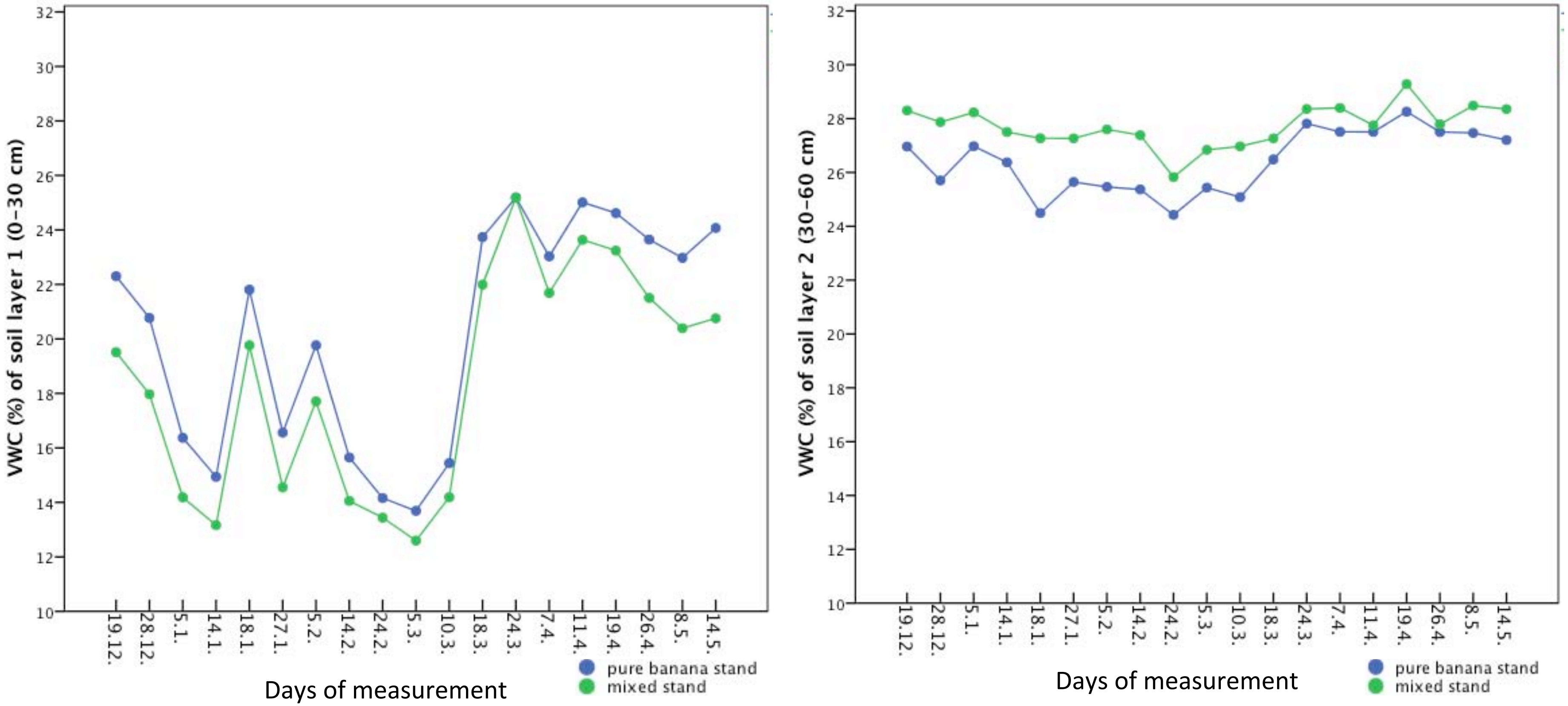


Fig. 30: Mean volumetric soil water content (VWC) by stands and soil layers

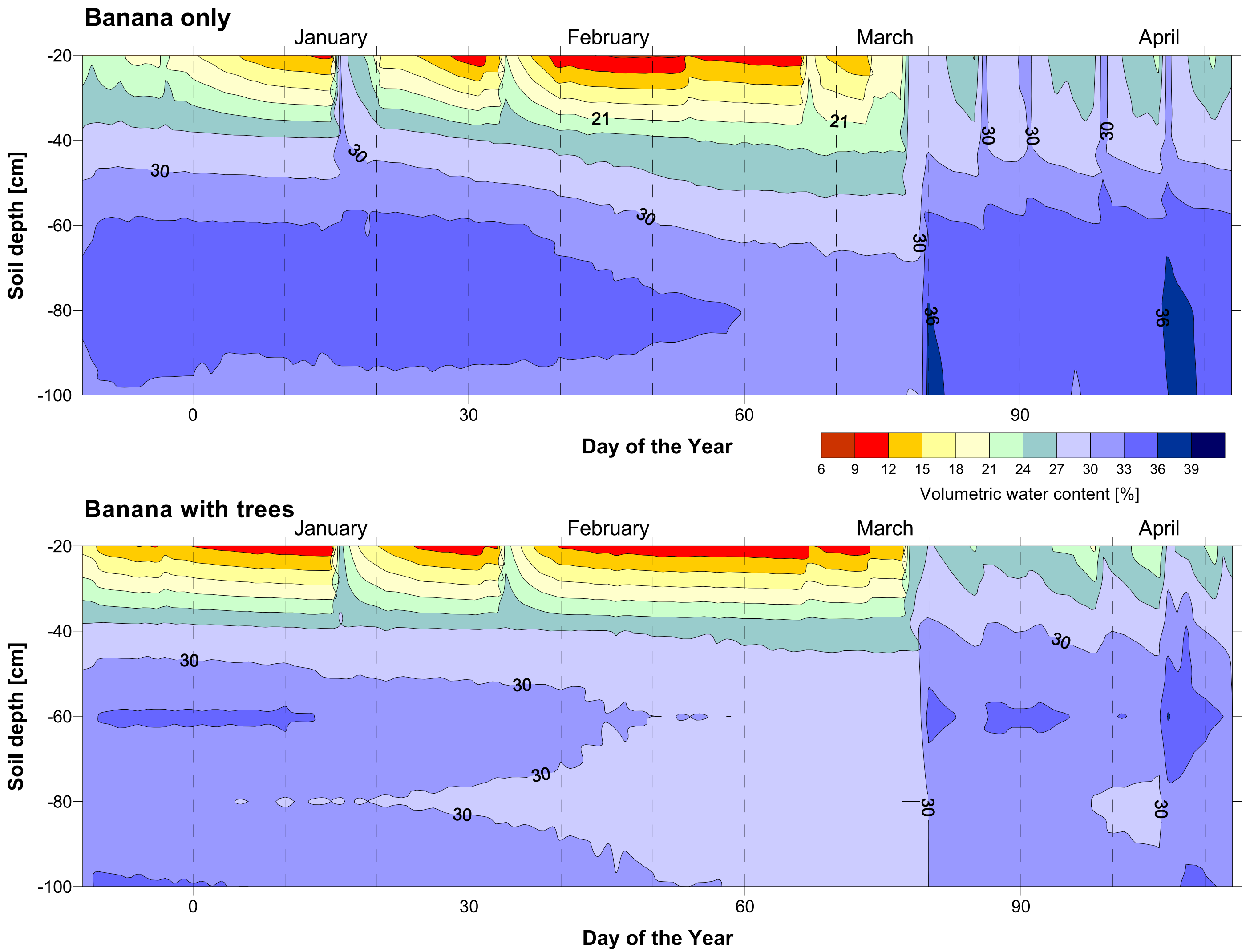


Fig. 31: Volumetric soil water content in the mixed and pure banana (daily measurements in the soil pits).

6 Discussion

6.1 Selection process of two indigenous trees with the highest importance for the farmers livelihood, particularly with regard to their intercropping abilities with bananas

Taking into account that land scarcity normally leads to deforestation, 8,9 and 11,4 trees per acre in land class one and two compared to 3,5 and 3,1 trees per acre in land class 3 and 4 are surprising results, which justify further assumptions (Table 2).:

If small scale farmers have that many trees on their land, they can be expected to see positive effects from the trees thus compensating the loss of potential land for crop production. This is in line with the findings of NIELSEN, et al., (1995), who concluded that resource poor farmers, like female headed households had a high frequency of fruit trees to ensure food security for children although they were aware of the reduced yield of annual crops due to the presence of competing fruit trees.

The next wealth group after female headed households are small scale farmers who are holding enough resources for sustainable long term nutrition and hence are able to plan on a longer scale. The majority of them are still experiencing land scarcity, especially if parts of the land have to remain fallow to replenish soil fertility. For this group, soil improvement via AF is a commonly practiced alternative to the fallow system of the past in a situation of unaffordable mineral fertilizers.

As the majority of these farmers are holding a form of land title that forbids them to make use of the trees growing on their compound in terms of selling timber, their goal is rather on providing shade and soil improving trees for their crops than on generating direct financial benefit from selling timber (NIELSEN, et al., 1995).

As mentioned earlier, the selection of suitable indigenous trees was based on an analyses of the baseline data provided by the project, and to a minor extent on my own observations and discussions during farmer field meetings. For a consistent understanding and interpretation of the results presented in chapter 5.1., some points on the way the data was collected, need further clarification.

- 98 to 100% of the interviewed farmers, who do not have the targeted tree species on their farm, made no comment on the advantages or disadvantages of those trees. This might be due to the questionnaire, the way the interview was conducted, or because the knowledge on trees disappeared with their absence from the farm.

  Therefore the calculations of table 3 are always based on the answers of farmers who are growing the particular trees and not on the total number of interviewed farmers. Like that only the knowledge of farmers who are growing the particular trees is captured and analysed.

- In most of the cases where the interviewed farmers had the targeted trees on their farms, the percentage of farmers who made no comment on advantages and disadvantages remained below 10%. This figure shows that the majority of farmers who are growing trees have opinions on the advantages and disadvantages of a certain tree in their particular case.

  Still this doesn't mean that there is a common understanding of benefits and problems associated with trees.

- Table 5 indicates that firewood, food and timber are the only benefits where more than 50% of the farmers confirm that this is true for at least one of the targeted trees. The other benefits are not mentioned with a mean of 80% of the interviewed farmers.

  This phenomenon might be explicable through the difference between the farms:

  The interviewed farmers own small subsistence farms with 0.25 acres up to farms with 300 acres.

  Other factors that might cause a diversification of interest, concerning the utilization of trees, are farmers with and without animals, the kind and number of animals as well as the household composition and cropping system.

  Another explanation for the high number of neglected benefits of trees might be that interview questions contained a double negation.

The above-highlighted points state that the following discussion of tree species is a generalization of the views farmers have on advantages and disadvantages of the trees, they are growing, based on to their particular livelihood.

The results of table 3 and 4 give further evidence, that farmers in different wealth categories judge the importance of the soil improving trees, *A. coria* and *F. thonningii* differently to the importance of the fruit trees, *Artocarpus heterophyllus, Mangifera indica* and *Persea americana*.:

In the case of *F. thonningii,* the highest importance scores can be found in land class 2 (85 points), followed by land class 1 (57 points), land class 3 (37 points) and land class 4 (28 points). The importance scoring of *A. coria* shows the same tendency: 102 points in land class 2, 67 points in land class 1, 41 points in land class 3 and 38 points in land class 4. Farmers in land class 2 seem to have the resources and awareness to plant soil improving trees.

Given that the sum of soil improving trees (calculated individually for *A. coria* and *F. thonningii*) in land class 1 is less than half of the sum of trees from land class 3 and 4 together, the fact that the importance scoring of class 1 is almost the same as the sum of importance scoring from land class 3 and 4, highlights, a) the awareness of farmers from land class 1 concerning the need for soil improving trees, and b) the limited resources to grow soil improving trees in land class 1. As land class 2 shows a similar tendency, it can be stated that in both land classes a strong potential to work with soil improving trees can be found, provided that the resource problem of land class 1 is solved first.

In summary, farmers from land class 1 and 2 show a stronger awareness concerning the soil improving trees *A. coria* and *F. thonningii* than farmers from land class 3 and 4 (table3).

For the fruit trees, *Artocarpus heterophyllus, Mangifera indica* and *Persea americana*., a ranking according to the importance scoring indicates the same tendency as described for *A. coria* and *F. thonningii:*

Land class 2 is leading, followed by land class 1, 3 and 4, indicating that again, farmers in land classes 1 and 2 are holding a higher potential for possible interventions towards improved agroforestry practices.

However, a comparison of the importance scoring between land class 1 and 2 confirms the above made assumption that the presence of soil improving trees on farm indicate a shift from the short-term planning of how to survive to the long-term planning mode and hence goes hand in hand with increased availability of resources.: in land class one, Jackfruit is followed by Mango and then, with much lower values, by *A. coria* and *F. thonningii*.

In land class two, Jackfruit is followed by *A. coria* on place 2 and *Mangifera indica* and *Persea americana* and *F. thonningii* almost equally on place 3, indicating that any intervention focusing on soil improving tree has to bear in mind that fruit trees, especially *Artocarpus heterophyllus*, need to be an inherent part of the overall program.

Another figure expressing the need for incorporating fruit trees in the research and extension agenda is that 80% of farmers are having at least one of the fruit trees *Artocarpus heterophyllus, Mangifera indica* and *Persea americana* on farm, compared to 71% of farmers having *A. coria* or *F. thonningii* trees.

My research assignment was to find indigenous trees suitable for intercropping with banana and to asses their impact on banana growth and yield. Nevertheless one has to be aware that without integrating fruit trees, especially *Artocarpus heterophyllus* in the overall farming system and hence research agenda, implementations of findings, will have a low impact, in particular for the poorest group of farmers. According to NIELSEN, (1995), the following agroforestry interventions are proposed for the poorest group of farmers, namely female headed households: (1) support micro nurseries that can produce improved (i.e. grafted) fruit trees cheaply; (2) support the selection of fruit trees with positive side effects and multipurpose use and (3) improve existing fruit tree agroforestry systems to increase benefits and reduce the yield suppressing effect of many fruit trees“(NIELSEN, 1995 p:91).

In the following, the selection criteria of *A. coria* and *F. thonningii* will be highlighted and discussed.

More than 80% of the farmers are intercropping bananas with trees (Table 2). As almost 60% of interviewed farmers regarded *F. thonningii* and *A. coria* as good banana neighbours, and at the same time both of them can be found under the top five trees for the overall livelihood of central Ugandan farmers, they were chosen for the characterization of light interception via hemispherical photography. Especially their high ranking concerning

positive shading, justifies the need for further research in this direction (Table 3, Table 4, Table 5). The high ranking of *A. coria* and *F. thonningii* is also confirmed by a study of NIELSEN, (1994a) who found that out of 338 trees on 11 farms, the tree species with the highest frequency were *A. coria* and *F. thonningii* with 21,6% and 31,4%.
Although 62% of the farmers deny the suitability of *A. coria* as manure, the 34% who agree on its suitability still show a strong tendency and make *A. coria* to the tree holding the highest percentage for its manuring and mulching qualities (Table 5). These results also match with the outputs of the farmer field meetings I have attended. As Uganda is hosting several species of *Albizia.* and not all of them are N-fixing, this could explain why many farmers do not consider it as a manuring tree species.

Unlike *A. coria, F. thonningii* is not a nitrogen fixing species. The fact that the number of *F. thonningii* is almost double than that of *Albizia* might be explained through its high cultural value for burial ceremonies as well as through its suitability for firewood, which was confirmed by 64% of the farmers. Furthermore *F. thonningii* is having a high value as animal fodder. (Table 5, Roothaert and Franzel 2001).

6.2 Light interception and growth parameters for *Albizia coria* and *Ficus thonningii* trees

As stated in chapter 5.2, there was no correlation between growth parameters and percentage of light transmission that reaches the area under the canopy (Fig. 8-11).
Reasons for this could be the following:

- The light transmission of the two tree species does not show strong ontogenetic changes. Small trees can already show high light interception. The same can be true for older trees.

- Farmers reported that *A. coria* and *F. thonningii* show a very strong response to different nutrient and water levels. Two trees of the same size can differ a lot in age and leaf area just because of different nutrient and water ability.

- The easily measurable parameters height, crown- and stem-diameter do not describe crown architecture precisely enough to make conclusions concerning the amount of shade produced by a certain tree. Other parameters like crown depth and tree age would be needed.

- The way of managing trees alters from farm to farm: Some farmers prune the trees only when they are small, others only when they feel the shade is becoming too strong. Many farmers do not prune at all because they are not used to climbing trees.

Although it was not possible to come up with a simple allometry between growth parameters and the amount of shade produced through them, the collected data presents useful information on the intercropping abilities of *A. coria* and *F. thonningii.*:

With a mean value of 63,3% for light transmission, *A. coria* generally seems to be more adequate for intercropping than *F. thonningii* with a mean of 55,3% of transmitted light (Table 6). After grouping the two tree species into three light transmission classes (Fig.12-13), 82% of all analyzed *A. coria* was found in the light transmission classes over 50%, whereas only 60% of *F. thonningii* was found in these classes. Considering that the mean light transmission percentages are fairly similar with slightly higher values for *A. coria* in the first and third transmission class (table 7), these results stress the higher light transmission rate of *A. coria*.

Up to which amount the light transmission rate is a direct function of ontogenetic changes needs further research and studies where the different factors influencing the light transmission rate can be separated, which was not possible in the present on farm trial.
In order to give a consistent answer to this question, a long term trial set up would be needed to study the influence of tree age, growth parameters, management practices, irrigation and nutritional status on canopy light transmission rate separately, and in a next step the way they interact with each other.
However, before going into more detailed research on the factors influencing light transmission, it has to be ensured that light is really the main limiting factor in small scale AF banana production, which, based on the results of the present study, can not be confirmed.

If it is the main limiting factor, it still has to be considered that in the studied area, the management of trees is limited to choice of species and planting distance, whereas pruning is rarely practiced (NIELSEN, 1994b).

Consequently, well grounded research outputs on these two aspects have high chances to be adapted by farmers and hence can contribute to an improvement of the cropping system. If on the other hand, research is ignoring aspects, farmers are already familiar with and puts the focus on more or less unknown management strategies like pruning to improve light transmission, it is questionable if farmers will make use of this research output. This assumption is in line with the findings of NIELSEN, (1994b) who states that management practices, already practiced by farmers, have proved to be compatible with the production system whereas management recommendations focusing on aspects that are not considered by farmers, are often not applicable due to some overlooked constraints in the production system (NIELSEN, 1994b).

6.3 Measured light transmission under Albizia coria and Ficus thonningii trees versus quality of shade rated by farmers.

The farmers' evaluation of the shade, produced by *A. coria*, is not based on the actually produced shade, but rather depends on height, crown diameter and stem diameter of the trees (Fig.19-21). For *Ficus thonningii* the picture is similar, but less distinct (Fig.19-21).

According to the ranking of farmers, the ideal growth parameters of *A. coria* and *F. thonningii* are the following:

With an exception of tree height, where both species are sharing the same median of 15 m, the farmers opinion about the ideal crown and stem diameter for intercropping with banana differs between *A. coria* and *F. thonningii*.:

With 10,8 m, *A. coria* is having a smaller median for crown diameter than *F. thonningii* with 13,8 m. For stem diameter, the data is similar with a median of 36 cm for *A. coria*, compared to 55 for *F. thonningii*. Taking into account that the crown of *A. coria* is generally less dense than the one of *F. thonningii* this figures stress the awareness of farmers concerning suitable crown forms for agroforestry.

Obviously farmers observe growth parameters, but do not prioritise the linkage between growth parameters and the amount of shade produced, at least not in a direct way. Based on the findings of the present study, this makes sense:

- The measured growth parameters do not correlate with the amount of shade produced through them.
- Yield responses of Mologoma did not show significant differences between the three light transmission classes

Based on the interview output of individual farmers, farmers do use growth parameters to estimate the influence of the tree component on the overall cropping system. As they are not used to pruning, growth parameters, especially tree height and crown, define the area that can be used for intercropping in the following way:

- Height: On one hand trees should be high enough to ensure that the lowest branches do not touch the banana leaves; on the other hand the distance from the lowest to the highest branch should be as small as possible. For the farmers this distance is a way of classifying the shape of the canopy and hence the density of the produced shade. The smaller the distance from the lowest to the highest branch, the smaller and denser is the shade.
- Crown diameter: The crown should be wide enough to shade a reasonable amount of bananas. In order to enlarge the shaded area, farmers accept higher shading intensities.

Up to which amount the shade produced by a certain tree, is put in the category good, depends on the limiting production factors farmers are experiencing.

Their priority is rather to ensure harvest during unpredictable times of draught than to optimize yields.

As crown size usually correlates with the size of the root system, the amount of land achieving soil improvement via the tree may also be a function of crown size. However, NIELSEN (1994) states that whether the active area of *F. thonningii* and *A. coria* is a function of tree size or age needs further research. Nevertheless the active area of *F. thonningii* seems to be a bit smaller compared to the one of *A. coria* (NIELSEN, 1994).

Due to diverse micro-environments of the farms, farmers experience variable factors as limiting and hence rank the same amount of shade differently.:

- In a generally dry farm environment, higher amounts of shade are regarded as useful to ensure survival of bananas during draught. Consequently, on farms with good soil water balance, the same amount of shade might be seen as too much.
- Farmers with limited access to manure might judge high amounts of shade as good, because they are in need of the soil improving effect of *F. thonningii* and *A. coria*, whereas farmers, who are not experiencing soil depletion, might see light as limited resource for plant growth.

Water balance and plant available nutrients, are just two examples of factors determining the farm micro-environment. However, there are many more, e.g. disease pressure, inclination, location of the farm in dependency of forest, exposure to wind and so on.
As each of these factors can differ from farm to farm and is interacting with the others, it becomes obvious that the farmer's evaluation of shade does not coincide with the actually measured light extinction.

6.4 Interpretation of the interview process and output

The first part of this section is meant to give a qualitative insight in the livelihood of central Ugandan subsistence farmers, based on the interview results. In the second section, the way farmers experience and response to on farm research, as well as the interview process and the way this process influences the output, is analyzed.

The biggest challenge concerning livelihood is that most of the farmers are still subsistence farmers, selling the surplus of production for very low prices, while at the same time all of them have to come up for the high educational expanses of their children. Given that there is limited support for the educational and agricultural sector, people have no means to change their situation and feel ignored.
Field visits with the farmers revealed that more and more of them started spraying Weedmaster (a herbicide with dimethylamine salt of dicamba and dimethylamine salt of

2,4 dichlorophenoxyacetic acid as active substances), without any awareness concerning its threat for mankind and the environment. Spraying with a knapsack in the presence of children is a common practice.
As Weedmaster is an affordable herbicide for farmers, they rather spray than spending days with weeding. The consequence is a hard and dried out soil with low and decreasing amounts of organic matter. Taking into account that banana roots need a soft soil that is rich in organic matter, this development could be a serious threat for the banana production of central Uganda.
Besides declining soil fertility, the biggest challenge for banana production, mentioned by the majority of farmers, is bacterial wilt. Although some know how to deal with it, disseminating the disease through pruning the whole plantation without disinfecting the working tool is still common practice.

Although the focus of the interviews was on the farmers' valuation of the shade produced by their trees as well as on the ability to use these shade for banana production it was very hard and rare to get precise information on these points. Sometimes, the analyses even revealed contradicting results where trees with high light transmission rates were put in the category of too less light transmission and the other way round.

Explanations for this phenomenon could be:

- Given that subsistence farmers usually have no means for irrigation, their focus is on avoiding direct sunshine in order to minimize the plants water demand and to protect the banana roots from drying out. As pruning of big trees is not a familiar practice for them, they rather plant under too much shade and take a yield reduction into account than planting in direct sunlight with the threat of loosing the whole plant. Especially draught susceptible varieties like *Mpologoma* will loose most of their roots during draught and easily break down during the storms of the rainy season. Consequently shade is experienced as drought insurance and not questioned in terms of quantity.

- Under the present situation of land scarcity, the only way to ensure and improve soil fertility is via manure or soil improving trees. If farmers loose soil fertility, and they are already experiencing this process, the whole production capital is lost. So from the farmer's point of view it is somehow irrational that somebody comes and starts thinking about reducing soil fertility in order to optimize shade management, especially if shade is not considered as a problem, but rather as a chance. Consequently, farmers might have understood shade produced by a certain tree as a synonym for the micro environment under the canopy of a tree, including the soil improving effect via litterfall and N-fixation as well as enhanced soil porosity through decomposing roots.

- The idea of pruning grown up trees is new to farmers of this area. In the past, it was common practice to prune young trees in order to give them a suitable shape for crop production. However, this practice and knowledge was more or less lost in the political instabilities and wars during the last decades. As people were forced to leave their homeland and hide in the bush for several years, repatriating farmers came across grown up trees that have not been pruned according to intercropping needs. Given that farmers have no means and experience to prune a tree of 20 m height, they do not invest time and effort in thinking about an optimum shading intensity.

- Most of the farmers speak rather Luganda than English. Therefore I was forced to work with a translator, -which is another source of misunderstandings and a source for imprecise answers.

- Taking into account, that farmers are used to researchers that come, exploit their knowledge and use the results for their own benefit and publications instead of closing the research cycle by sharing findings with the farmers, they were extremely sceptical about what I was doing. For them, it was a new situation that somebody was coming in order to cooperate with them for their own benefit. Hence, I seriously doubt that it was possible to ease mistrust in all of them. Consequently, imprecise answers must not only be interpreted as ignorance and lack of interest but rather as a way of passive resistance against potential scientific exploitation.

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Interview session with Mulyake Ayub after a field visit

Hard and dried out soil, two weeks after spraying with Weedmaster.

6.5 The response of *Mpologoma* to different shading intensities under *Albizia coria*

Both, the actually produced as well as the relative leaf area growth do not indicate a significant difference between the light transmission classes.

Nevertheless, class 1, the class with the highest light interception, is always holding the highest value and shows the lowest leaf area reduction from rainy to dry season (Fig. 22-23). The difference in leaf area growth from class 1 (light transmission<= 50 %) to class 2 and 3 (both above 50 % light transmission) is much bigger than the difference from class 2 to class 3, confirming the results of ISRAELI et al. (1995) that 20% and 40% of shade had no effect on leaf area growth. If, on the other hand, shade was increased to 70% of full sunlight, a significant decrease on leaf area was observed (ISRAELI et al. 1995). Consequently the difference in leaf area growth from light transmission class 1 to class 2 and 3 might become significant if light transmission of class 1 is reduced to 30 %. However this assumption has to be treated with care as the study of ISRAELI et al. (1995) was conducted in the subtropics, while the present study is located in the tropics.

Fig. 24 and Fig. 25 visualize the number of fingers and hands per bunch. Although there is no significant difference between the data of the three classes, it has to be stressed that these are the only parameters where class 1 does not have the highest median.

As the number of plants with ripe fruits was not enough to allow statistical comparison between the light transmission classes, bunch weight could not be used for further analyses.

Therefore the figures for number of fingers per bunch /number of hands per bunch shall be used to discuss the yield response on shade. According to NORGROVE (1998) who analysed and discussed several studies on the response of bananas on shade, among those: Murray (1961), VINCENTE-CHANDLER et al.(1966) and TORQUEBIAU and AKYEAMPONG (1994), all studies showed a positive effect of shade on yield. NORGROVE, (1998) points out that the studies of MURRAY (1961), TORQUEBIAU and AKYEAMPONG (1994), conclude that bunch mass was greatest at 50% shading (NORGROVE, 1998).

In the experiment of Murray, (1961) bananas were grown under three different shade levels, reducing incident light to 70%, 50% and 20% of full sunlight (100%). Even at the heaviest shading, bunch weight was not affected, but rate of plant development, from planting to harvest was slower, which could not be confirmed for plants grown at less than 50% shade (ISRAELI et al., 1995). However the fact that in the present study none of the measured parameters showed a significant difference between the three light transmission classes may have the following reasons

- Although the compared mats were all off the same growth stage, they were not uniform enough. As the experiment was not performed on station, the process of classifying the mats in order to compare classes was always a compromise between defining the class/growth stage in a way that the differences within the class are as small as possible, and on the other side according to the need of statistical representativeness.

- There might have been other factors, eg. water, nutrients, management practices, that under the present situation of small scale subsistence agriculture, were more limiting than light and hence caused altering reactions from the plants. As the whole family in a farm is involved in the management of the banana plantation, standardized management practices do not exist, resulting in different growth conditions. Especially in the case of water, where recommendations range from an average amount of 25 mm/week (SASTRY, 1988) to 45 mm/week (UGANDA NATIONAL COUNCIL FOR SCIENCE AND TECHNOLOGY (UNCST), 2007) the measured amount of water was with an average of 12 mm/week less than half of the lowest recommendation. The long-term precipitation data from the district ranges from 11,7 mm/week to 27 mm/week (INGATECH, 2012), indicating that the measured precipitation is at the lower end of the normal range. Hence it may be reasonable to assume that water was a stronger limiting factor than available light, resulting in non-significant differences between the three different light treatments.

6.6 Soil moisture measurements at Bagwe

Overall, the combination of reduced soil evaporation and higher interception rates of the combined tree/banana canopy might be jointly responsible for the lower VWC in soil layer 1 observed under the mixed stand. SCHUME et al. (2003) states that generally, severe drought or heavy rain events tend to level out differences in soil moisture patterns between differently stocked stands. This is line with findings of the present study, where as long as there were no extreme weather events in terms of persistent dry spells or heavy rainfall, the observed effect of rewetting was stronger under the pure stand than under the mixed stand, probably due to the higher canopy interception of the mixed stand, as can be deduced from the light measurements.

Quite opposite to soil layer 1, the VWC of soil layer 2 (30-60 cm) was on average 2% lower under the pure stand during the dry season (Fig.30). Statistically significant differences could be observed only during the dry season, i.e. on December 28, January 18, February 5 and 14 as well as on March 10.

In 80 cm soil depth, the VWC was constantly app. 4% lower in the mixed than in the pure stand. In 100 cm depth both soils started at about the same moisture level, but the decrease in the mixed stand was much more pronounced (Fig. 27).

Altogether, higher water extraction rates from the subsoil (deeper than 60 cm) were indicated by the combination of trees and bananas.

This enhanced water extraction might be attributed to the presence of tree roots in the subsoil. If banana roots contributed to the water extraction from that depth remains unclear and needs further research. However banana roots were found in high concentration in soil layer 1, as indicated by TURNER et al.,(2007) who point out that the effective irrigation depth for bananas ranges from 0,3-0,4m, though there are cases where bananas derived water from much deeper layers. The rooting depth of bananas is strongly influenced by physical soil properties (TURNER et al., 2007).

The bottom of this banana root network coincided with the beginning of a dense, clayey layer at app. 30 cm depth, implying that soil layer 2 was hardly rooted by banana in the pure stand. So from this point of view, the above finding that soil layer 2 was stronger depleted under the pure banana stand is somewhat contradictory.

Given that a banana mat has a daily water uptake of 25 l on a clear day, 18 l on a cloudy day and 9,5 l on an overcast day (NORGROVE, 1998), an explanation of the above finding that soil layer 2 (30-60 cm), was stronger depleted under the pure banana stand, could be the high water demand of the unshaded pure banana stand. Furthermore, precipitation water is used by the bananas in the first soil layer, before it could drain into the dense clay of soil layer 2.

In mixture with tree roots, banana roots seemed to benefit from the fragmenting and loosening effect of the penetrating *A. coria* roots, as was observed during the excavation works of the soil pits at the research site: below soil layer 1, tree roots were usually accompanied by a large number of banana roots growing in the immediate contact zone between tree root and soil. So in association with *A. coria,* banana roots could penetrate into deeper, harder soil layers than when grown in pure stands. Though this fact could also be interpreted as competition for water and nutrients, it has to be stressed that without this facilitating effect of *A. coria* roots, banana roots would not have the chance to utilize these soil layers at all.

The growth of especially coarse roots does not only fragment the soil and thereby create soil structure. After their decay, roots leave pathways for preferential flow, facilitating infiltration through vertical macropores. Absent macropores in soil layer 2 of the banana stand, and thus insufficient infiltration offers a possible explanation for the lower VWC observed in layer 2 under the pure banana stand. Higher VWCs in the subsoil of the pure banana stand (Fig.30 and Fig. 31) and fast rewetting after rain events may be caused by quick flows.

Given that the results of Fig. 30 and Fig. 31 are derived from soil pits, that from the spatial point of view have the representativeness of a spot measurement, the above described drainage effect of macropores can not be condemned. Analyses of root distribution and soil physical parameters like bulk densit, soil texture and saturated hydraulic conductivity would be needed for a consistent interpretation of these preliminary findings.

7 Conclusions

The above ground effect of *A. coria* in terms of shading did not show a statistically relevant decrease in yield for none of the different shading intensities. However, a yield increasing effect due to shading could not be demonstrated neither.

The effect of *A. coria* on the water household of bananas is due to a shortage of representative field data, especially root distribution in dependency of soil moisture content, hard to quantify. Based on banana growth parameters, there was no significant difference in the performing of the bananas under the canopy and those outside.

Nevertheless, the soil improving effect of *A. coria* has to be stressed, especially in the case of Uganda, which is amongst the leading countries in Sub Saharan Africa concerning soil degradation (NKONYA et al., 2008).

Considering that the area outside the canopy was manured and soil analyses did not show significant differences in the nutrient availability between the manured and unmanured sites, the soil improving effect of *A. coria* was as strong as the manure, applied to the plantation.

Usually the perennial banana system is, because of to its high nutrient demand, close to the homestead and receives the majority of organic waste and residues from kitchen, fields and animals on the expense of the soil fertility of other fields (BRIGGS & TWOMLOW, 2002).

Bearing that in mind, the soil improving effect of *A. coria* without a negative effect on banana yield through shading, can not be highlighted enough: Through its presence in the banana plantation, plants and soils remain healthy and productive without additional input and at the same time, soil fertility of the other fields do not suffer a negative nutrient balance due to the removal of organic matter towards the banana plantation.

According to NIELSEN (1994), the effect of *F. thonningii* on banana growth and soil fertility is similar to *A. coria*. Hence, *A. coria* and *F. thonningii* have a strong potential to contribute not only to improved soil fertility on banana plantations but also on the whole farm level. Considering that, at least parts of the mulching material as well as firewood, that is usually collected in the bush and forest, can be provided by those trees too, their positive impact goes beyond farm level.

Both *A. coria* and *F. thonningii* have an old and strong tradition in indigenous AF systems of central Uganda, as can be detected from farm visits, analyses of the baseline data and a study of NIELSEN (1994).

According to the farmers experience, *A. coria* and *F. thonningii* have the same net effect on bananas (NIELSEN, 1994), which is in line with the findings presented in this study.

However, on one side *A. coria* and *F. thonningii* are both appreciated for the same soil improving and shading effect, on the other side they show strong differences: *F. thonningii* is a fast growing tree with a short live span, shallow roots and slowly decomposing leaves, whereas *A. coria* is growing slowly, has a strong tap root, easily decomposting leaves, a long live span and is N-fixing. (NIELSEN, 1994).

The fact that farmers are using two species with almost contrary characteristics, to achieve the same net result, might mean that *A. coria* and *F. thonningii* react in different ways to altering (micro) environmental conditions and interact with bananas through different components and interaction patterns. For a consistent understanding of these processes answers to the below stated question are highly needed:

In which way is the net result of the interaction between the two tree species and banana influenced by:

- the micro environment of the plantation (surrounding vegetation, depth of ground water table, soil properties, inclination...)?
- different management practices?
- the selected banana cultivar?

Derived from the experience gained in the present study and the way the study was embedded in the overall project, it has to be stressed that further research on the question stated above needs to be based on the net result of the interaction between bananas and *A. coria* /*F. thonningii* evaluated by farmers. Well grounded participatory evaluation and cooperation methods, focusing the farmers experience and constrains in a holistic way, are needed before going into detailed scientific analyses of individual factors, influencing the interaction. Furthermore it has to be stated that the scientific way of regarding farmers as homogeneous, is an abridged perception, ignoring the fact that different farmers are confronted with different constrains, and are hence looking for diverse solutions.

With a purely non-qualitative research agenda, there is a big threat that this pluralism of constrains and solutions is neglected. As soon as this pluralism is ignored, participation of farmers and hence a cyclic research process is being reduced to political correctness, but far away from sustainable research with an impact for farmers.

With a stronger focus on qualitative social science, the existing knowledge of farmers, based on their overall livelihood, could be taken as a basis for a cyclic research process, where biophysical research can play an important part in deepening the understanding of the way and degree specific factors are interacting.

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