Soil Analysis for
FERTILITY DECLINE ASSESSMENT
AND ITS RECOVERING FOR SUSTAINABLE & PERMANENT FOOD CROPS PRODUCTION IN MBAMBA

Prepared for:
Niassa CARNIVORE Project

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Table of Contents

ANNEXES

FIGURES

TABLES

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EXECUTIVE SUMMARY

The objective of this study was to find out sustainable and permanent productive land uses in active and abandoned mashambas in Mbamba, Nkuti villages and the surrounding areas including identification of missing nutrients in the soils, recovering the soil fertility status throughout the natural fertilisers applications, identification and list the alternative crops that can sustainably produce food or income for the local communities.

The current situation shows an increasing wildlife habitat conversion through slash-and-burn for agriculture which represent a major risk to the protected areas as the human population grows particularly within L4-East and L5-South concession units, and Niassa National Reserve in general. This is even exacerbated by the fact that the current cropping systems practiced mainly dominated by crops that are high nutrient extracting demand from the soils. The area covered by active and abandoned mashambas in Mbamba village, for example, had grown dramatically from 1,084 ha in 2006 to more than 2,215 ha cumulatively in 2016, and the abandoned areas had never been reused.

Two field visits were carried out covering the dry (December 2016) and wet (March, 2017) seasons, a total of fourteen (14) soil samples for fertility assessment were taken at two soil depths (0-20*cm* and 40-60*cm*) from seven (7) sites where soil auger holes were also described. In each site, the soil samples were bulked and sub-sampled from five points surrounding the auger hole site. The soil sampling covered the active and abandoned mashambas, and bushland. In addition five (5) soil profiles were full described and sampled for soil characterisation and classification. And four (4) manure and one (1) ash samples were also collected for chemical analysis.

The dry season visit evidenced non or very little existence of crop residues left on the soil surface, slight to moderate wind erosion, and flesh signs of burning of the crop residues in the mashambas as well as in bushland. While the wet season in the active mashambas the cropping pattern was dominated by a poor crop combination not providing enough soil cover to guarantee moisture and nutrient retention that enable a good environment for biological activity most responsible for much organic matter incorporation into the soil. Most crops grown are nutrient extracting rather than nutrient-fixing ones and worsened by the critical "*threat*" for cereals - the *incidence* (and infestation) of *Striga* (*asiatica* and *hermonthica*) common known as '*witchweeds*' which becomes very severe after 2-3 years of consecutive production of crops attacking the main staple food crops - maize, sorghum and millet.

Farmers in the region usually cultivate a range of food crops, cereals (maize, sorghum and millet) roots (cassava, sweet potato), groundnut, bambara beans, cowpea, pigeon peas, and fruits, etc., for domestic consumption and sale. But their definition of food security is usually framed around grain, the staple food. A farm family will say they are food secure if they can grow enough maize, sorghum or millet to feed themselves from one cropping season to the following one.

The area has two distinct climatic seasons a wet season from the end of November to April of the following year (heavy rains start in December) and a dry season from May to October, and has an annual average temperature of 24.5^{o}C. The annual rainfall within the region is

1,418.4mm, potential evapotranspiration of about 1,345.3mm, and the mean relative humidity of 69.6%. These climatic conditions are rated as highly suitable for most of annual crops.

The soil sample analysis had shown low fertility status evidenced by their poor chemical properties. While the soil profile descriptions had shown good physical conditions observed throughout the soil structure, internal drainage, permeability, and porosity but very little evidence of biological activities in the abandoned field and relative high in the bush land; the soil texture varied from sandy to loamy-sand at 0-20*cm* soil depth and sand-loam to sandy-clay below 60*cm* soil depth; the organic matter, total nitrogen, available phosphorus and exchangeable potassium are the most critical nutrients missing being *low* throughout the soil profile; but the exchangeable calcium and magnesium are *moderately high* to *very high* in the topsoil in the active mashambas and bushland but *low* in abandoned mashamba.

On the manures and ash chemical analysis, "bat guano" had shown *high* content of nitrogen (16.55%), phosphate (34.20 ppm) and potassium (27.14 mg kg^{-1}), these three nutrients (N-P-K) are the most essential for plant growth; the ash from the black wood tree species is also very rich in exchangeable calcium with 39.54 mg kg^{-1} (*very high*) and magnesium with 47.86 mg kg^{-1} (*very high*); the nitrogen content in elephant (1.08%), rock hyrax (2.49%) and buffalo (1.54%) manures are rated as *very low* compared to guano (16.55%); the available phosphorous content is *high* in the elephant (19.12 ppm), rock hyrax (17.37 ppm), and buffalo (18.52 ppm) manures despite being low when compared to guano; and the exchangeable calcium content (average of 5.64 mg kg^{-1}) and magnesium (average of 7.83 mg kg^{-1}) content are best found on the elephant, buffalo and rock hyrax manures rather than in guano.

Chapter 4, describes the nitrogen-fixing-plants (NFTs), and the land suitability assessment for selecting alternatives crops that best suit according to the biophysical conditions (climate and soils requirements) in region. The land suitability assessment came out with seven (7) crops and one (1) tree species, these crops are described in details (in Annex 3). Some of these crops are already being grown in the region and are less or not affected by the *striga* and stemborer.

The crucial and most critical "threat" that drives farmers to abandon their mashambas, a part from the soil fertility decline is the incidence (infestation) of "*Striga*" or '<u>witchweeds</u>' which becomes very severe after 2-3 years of consecutive cropping of cereals (maize, sorghum and millet). The chapter 5, gives a description of an effective, low-cost and environmentally friend technology known as *'push-pull'* for the control of stemborers and suppression of *striga* weeds in cereals. Planting rows of *Desmodium* between rows of cereal crops can effectively reverse declining crop yields by controlling *striga* and improving soil fertility, at the same time as providing farmers with a year-round supply of fodder.

Chapter 6, gives a summary of the most salient conclusions and recommendations. Detailed soil auger holes and profile descriptions including chemical and physical analytical data of the visited sites are presented in Annex1.

Sumário Executivo

Este estudo teve por objectivo encontrar as formas de uso de terra mais adequadas para uma agricultura sustentável e permanente, quer nas mashambas activas, quer em aquelas já abandonadas devido ao declínio da fertilidade dos solos. Mais ainda, identificar os nutrientes em falta nos solos, e a forma de recuperação destes (solos) através de aplicação de adubos naturais de origem animal ou vegetal. A identificação e listagem de culturas alternativas que potencialmente podem produzir comida, de forma sustentável, e gerar rendimento para as comunidades locais de Mbamba e Nkuti foi o outro objectivo definido no estudo.

A situação corrente mostra uma conversão acelerada do habitat da flora para uma agricultura de tipo corte-e-queima, facto que representa um grande risco nas áreas protegidas devido a crescente população humana nas concessões L4-Este e L5-Sul dentro da Reserva Nacional do Niassa. Esta situação é ainda exacerbada pelos actuais sistemas de produção não adequados dominados por culturas mais exigentes quanto a nutrientes nos solos. As áreas cobertas por machambas activas e as já abandonadas na região de Mbamba cresceram drasticamente passando de 1.084 ha em 2006 para mais de 2.215 ha em 2016, sendo de realçar que as machambas uma vez abandonadas nunca voltaram a ser cultivadas.

Duas vistas de campo foram efectuadas na região, sendo uma na época seca (Dezembro 2016) e outra na época chuvosa (Março 2017), nestas visitas foram colhidas cerca de 14 amostras de solos para a avaliação o nível de fertilidade destes, as amostras foram colhidas em duas profundidades (0-20*cm* e 40-60*cm*) em 7 locais onde foram descritas igual número de sondagens. Em cada local várias sub-amostras, no mínimo 5 foram colhidas e misturadas perfazendo uma amostra composta em cada profundidade. A amostragem cobriu as machambas activas, as já abandonadas e matas virgens. Em adição, 5 perfis de solos foram descritos e amostrados em função dos horizontes identificados para a classificação taxonómica. Quatro amostras de estrume foram igualmente colhidas sendo guano de morcego, de elefante, búfalo e marmota e uma amostra de cinza do pau preto, colhida na cozinha local. Estas amostras, foram submetidas para análises laboratoriais.

A visita feita durante a época seca, permitiu observar e registar a não existência ou pouco restolho presente na superfície do solo, sinais de erosão eólica ligeira a moderada do solo, e vestígios de queimadas recentes em algumas machambas activas e nas matas virgens. E na época chuvosa, em particular nas machambas activas o padrão das consociações de culturas mostrou uma fraca cobertura vegetal, facto que contribui para uma baixa capacidade de manutenção da humidade e de nutrientes no solo superficial, condições essenciais para a actividade biológica que facilita a incorporação da matéria orgânica no solo.

A maior parte das culturas em campo não tem propriedades de fixar nutrientes (por exemplo: o nitrogênio), esta situação é ainda agravada pela presença de uma ameaça crítica - a ocorrência da *Striga* (*asiatica e hermonthica*) uma erva daninha mais conhecida por "*infestante feiticeira*" e na óptica dos produtores, esta (striga) se torna muito severa nas machambas depois dos 2-3 anos de cultivos consecutivos de cereais e ataca basicamente culturas mais importantes na dieta familiar, nomeadamente milho, mapira e mexoeira.

Na região, os produtores produzem diversas culturas, desde cereais (milho, mapira e mexoeira), raízes e tubérculos (mandioca e batata doce), amendoim, feijão jugo, feijão boer e até algumas fruteiras para o autoconsumo e venda do excedente. A definição de segurança alimentar pelos produtores na região, é em geral, a volta de cereais - milho, mapira e mexoeira. Uma família só se sente em segurança alimentar se produzir milho, mapira e mexoeira em quntidades suficientes para o seu consumo durante uma campanha até a campanha agrícola seguinte.

O clima da região apresenta duas estações bem distintas, a época quente e chuvosa que começa nos finais de Novembro e se estende até o mês de Abril do ano seguinte (chuvas fortes começam em Dezembro), e época fresca e seca ocorre de Maio a Outubro, a temperatura média anual é de 24,5^{o}C. A precipitação anual acumulada na região é de 1.418,4*mm*, a evapotranspiração potencial é de 1.345,3*mm* e a humidade relativa está em média na ordem dos 69,9%. A combinação destes parâmetros providencia condições climáticas ideais para um maior leque de culturas anuais.

As análises laboratoriais do solo mostraram qualidades químicas muito pobres em nutrientes. Contudo, as condições físicas são óptimas evidenciadas pela estrutura do solo, drenagem interna, permeabilidade e a proposidade; pouca actividade biológica no solo superficial foi observada em particular nas machambas abandonadas quando comparada na mata virgem e nas machambas activas. A textura do solo variou de arenosa a areia-franca na profundidade 0-20*cm* para franco-arenosa a argilo-arenosa abaixo do 60*cm* de profundidade; os teores de matéria orgânica, nitrogênio e fósforo disponível e potássio trocável (nutrientes essenciais para as plantas) estão em níveis muito críticos, ou seja menos presentes ao longo do perfil dos solos nas machambas activas e abandonadas. Entretanto, os teores de cálcio e magnésio são classificados como moderadamente elevados a muito elevados no solo superficial nas machambas activas e na mata virgem.

Das análises químicas dos estrumes (de elefante, búfalo, marmota e o guano de morcego), e a cinza, o guano de morcego mostrou teores *elevados a muito elevados* de nitrogênio (16.55%), fósforo (34,20ppm) e potássio (27,14 mg kg^{-1}), estes três elementos (N-P-K) providenciam nutrientes essenciais para o crescimento das plantas. A cinza proveniente da lenha da espécie "pau preto" é também muito rica em cálcio (39,54 mg kg^{-1}) e magnésio (47,86 mg kg^{-1}); os teores em nitrogênio nos estrumes do elefante (1,08%), marmota (2,49%), e búfalo (1,54%) são relativamente *baixos* quando comparados com o guano de morcego; a concentração do fósforo disponível é *elevada* nos estrumes do elefante (19,12ppm), marmota (17,37ppm), e búfalo (18,52ppm), contudo, classificados como *baixos* no guano; o cálcio e o magnesio mostram-se bem concentrados nos estrumes do elefante, búfalo e marmota do que no guano.

Uma breve avaliação de aptidão para a selecção de plantas fixadoras de nutrientes, em particular o nitrogênio no solo foi feita observando os critérios biofísicos dos solos e o clima da região. Esta avaliação resultou na selecção de 7 culturas e uma espécie arbórea, esta com uma história secular de salvar milhares de produtores no meio rural onde agricultura em sequeiro é a base de sustento; as culturas seleccionadas estão descritas com maior detalhe no Anexo 3. Algumas das culturas seleccionadas são do domínio local na região sendo estas pouco ou mesmo não afectadas pela maliciosa erva daninha - a *striga spp*.

A maior ameaça e conductora na tomada de decisão em continuar ou abandonar uma machamba em uso, para além do declínio da fertilidade natural, é a eclosão da "*Striga*" - a "*infestante feiticeira*" que se torna muito severa e devastadora depois de 2-3 anos de cultivos consecutivos de cereais consociados com outras culturas.

Uma tecnologia efectiva de baixo custo e amiga do ambiente, vulgarmente conhecida como *'push-pull'* para o controle da striga nos cultivos de milho, mapira e mexoeira é devidamente descrita e apresentada no capítulo 5 do relatório. E esta tecnologia consiste na sementeira em linhas de "*Desmodium*" entre as linhas de cereais (milho, mapira, mexoeira) facto que permite o controle da *striga* e ao mesmo tempo melhora a fertilidade do solo e providencia ração para alimentação animal.

1. INTRODUCTION

Mbamba village is one of the large community (with more than 2,000 people) located within the L5-South concession unit in south eastern Niassa National Reserve. The peoples' main activities are subsistence slash-and-burn agriculture, hunting and fishing. Food security is a constraint and few alternatives are available for local community livelihoods. One and the most limiting factor on the rainfed agriculture in the region is the low soil fertility worsened by the poor cropping systems practiced.

The current situation shows an increasing wildlife habitat conversion through slash-and-burn for agriculture being a major risk to the protected areas as the human population grows particularly inside L4S and L5S concession units, and Niassa National Reserve in general. This is even exacerbated by the cropping system practiced which is dominated by the crops with high demand on nutrient extraction from the soils rather than nutrient fixing ones. The area covered by the mashambas (active and abandoned fields) in Mbamba Village had grown dramatically in the past 15 years (1,084 Ha in 2006 and cumulatively 2,215 Ha in 2012), and the abandoned area including that inside the electric fence that had never been reused.

The reclamation of the abandoned fields included (i) identification of missing nutrients in the soils, as well as, in the fallow fields compared with the bush lands nearby the villages; (ii) recovering the soil fertility status through natural fertilisers (plant and/or animal manure) applications; (iii) identification and list of alternative crops (fruits, medicinal, food, oil, essential, nuts, etc) that can sustainably produce food and/or income for the community.

The use of chemical fertilisers was out of concern since the area is within the conservation wildlife habitats. Some experiences working with Village through a farmer field school (FFS), such as mixed cropping, minimum or low tillage, mulching were already been implemented to increase the time active of fields to remain fertile and productive increasing production and food security.

1.1 Objectives

On the attempt to find sustainable and permanent productive use of the abandoned fields, in line with ToRs (see Annex 8), the following objectives were established:

- Identify nutrients missing in abandoned, fallow fields and bush land nearby Mbamba and Nkuti Villages;
- Recover the soil fertility status thorough natural fertilisers (plants and animal manure) origin; and
- List the alternative crops that can best suit to the biophysical conditions and produce food or income for Mbamba and Nkuti communities.

1.2 Methods and Materials

Two stages of fieldwork were planned to visit the area: (i) dry season (December, 2016) and (ii) Wet season (March, 2017).

(i) Dry season (December - 2016):
In the dry season, three sampling sites were established, two in Nkuti and one on halfway between Mbamba and Nkuti villages covering the areas of:

a) active fields (mashambas) opened in year 2014;
b) abandoned fields (machambas) in year 2010; and
c) bush land - halfway between Mbamba and Nkuti Villages.

At each soil sampling site an auger hole was described[1] following the *"Manual para a descrição e codificação do solo para o banco de dados (SDB)"* in use at DARN/IIAM (INIA/UEM, 1995) and samples were taken at two soil depths (0-20 and 40-60cm). Samples were bulked from five points surrounding the *"auger hole"* at a distance of 5-7m, and then sub-sampled. In addition two soil profiles (one on abandoned mashambas and another one in bush land) were fully described and sampled according to the identified soil horizons; the soil profile were classified following the WRB (2006) framework for international soil classification and correlation. Apart from soils, four samples of manure (bat guano, rock hyrax, elephant, and buffalo) and one ash sample of black wood (*Dalbergia melanoxilon*), were taken for laboratory analysis.

(ii) *Wet season* *(March 2017)*
The patternship between Mbamba community and Mariri Environmental Centre was healthy and peaceful; fact that contributed to carry out the following activities:

d) soil sampling in active mashamba in Nkuti community, and abandoned fields (mashambas) in Mbamba, and one soil profile description and sampling in Mbamba area;
e) visit to some active mashambas where were implemented FFS activities and honey bee initiatives;
f) soil sampling under and outside the canopy of *Faidherbia albida* mature tree species in the Mbamba river alluvial plain; and a full soil profile description and sampling; and
g) a soil profile description and sampling at Mariri Environmental Centre near the garden.

1.2.1 Site location and brief description

Initially, the sampling areas were defined to be in the active and abandoned mashambas of Mbamba village and due the social turbulence during the dry season, Nkuti area was selected replacing the Mbamba. In the wet season the sampling was done covering Mamba and Nkuti villages. The biophysical conditions (soils and climate) in both areas are similar including the cropping systems dominated by mixed cropping of maize, sorghum, millet, cowpeas and groundnuts. The soil samplings (dry and wet season) were carried out at the following locations:

a) active mashambas - Nkuti (site code: *Nkuti02* - dry season)
The auger hole on the soil was done at site located at 12^{o} 13' 00.7" South Latitude, and 37^{o} 54' 58.5" East Longitude. The soil samples were taken one day after the first rains had fallen and in some mashambas farmers were already sowing maize, sorghum, millet, cowpeas, groundnuts and bambara beans. From the auger hole it was seen that the rainfall had infiltrated down to the first 30*cm* soil depth from the surface. At the site the soil is deep (>1.20m) and well drained; dark-reddish-brown to dark-red, and an estimated soil texture varies from loamy-sand

[1] Complete soil auger hole and soil profile descriptions are presented in Annex 1.

to sandy-loam on the topsoil; and gradually it changes to red colour, and sandy-clay-loam or sandy-clay in the subsoil. _Samples_: (0-20*cm*) and (40-60*cm*).

b) abandoned mashamba - Nkuti (site code: *Nkuti01 and Nkuti01P* - dry season)
The abandoned mashambas are located near the Nkuti village and the soil sampled site was at 12^o 12' 57.06" South Latitude and 37^o 55' 6.16" East Longitude. The samples were taken on the same day and a full soil profile was described and sampled one day later. The soil is well drained and moderately deep (underlying a 40cm layer thick of medium to coarse rock fragment of quartz origin). The estimate of soil texture at the topsoil varies from loamy-sand to sandy-loam; dark-reddish-brown; and gradually changes to sandy-clay-loam, and dark-reddish colour in the subsoil. _Samples_: (0-20cm and 40-60cm); and the _soil profile samples_: (0-20; 20-50; 50-100 and 100-140*cm*).

Figure 1: Site location codes on the *Google image* covering Nkuti, Mbamba and Mariri areas.

c) _*bush land*_ - *Mbamba* (site code: *Mbamba01P* - dry season)
This site is located in the bush land between Nkuti and Mbamba villages at 12^o 13' 22.2" South Latitude, and 37^o 58' 22.0" East Longitude. The soil is deep and well drained, loamy-sand to sandy loam; dark-reddish-brown on the topsoil. The soil texture in the subsoil is estimated to vary from sandy-clay-loam to sandy-clay, and dark-reddish-brown to reddish-brown. _*Samples taken at*_ (0-20 and 40-60cm). The soil profile was described and sampled at 0-15; 15-35; and 35-110*cm* soil depth.

d) abandoned mashamba - *Mbamba* (site code: *Mbamba02P* - wet season)
In the abandoned mashambas (field) within electric fence in Mbamba one soil profile was described and sampled a site located at 12^o 11' 29.2" South Latitude, and 38^o 00' 46.0" East Longitude. The soil profile is similar to the one described in Nkuti. Deep to very deep, well drained, the soil texture is loamy-sand or sandy-loam in the topsoil and gradually changes to sandy-loam, sandy-clay-loam, and sandy-clay with the depth in the subsoil. The soil colour is dusky-red when moist in the topsoil (0-15*cm*) and gradually changes up to red when moist in the subsoil (140-155*cm*). Many fine and medium roots throughout the profile. At this site two composed samples were taken at 0-20*cm* and 40-60*cm* soil depths. In addition, the soil profile was also sampled at 0-15; 15-45; 45-78; 78-110; and 110-140*cm* soil depth.

e) active and abandoned mashambas - (site code: *FFS01* - wet season)

A closer looking into the farming practices in the active mashambas (fields) in Nkuti and Mbamba areas, two major conclusions can be arrived, being:

- poor crop combination (mixed) that do not provide enough soil cover to guarantee moisture retention and stimulate biological activities to incorporate much of organic matter into the soil (maintain or build an arable soil layer); and

Photos 1: Current cropping systems that provide poor soil covering, low moisture retention, soil erosion by wind and rain. *Right side photo*: some maize plants already *dying*!!! with only 30*cm* height, due to witchweed *(S. asiatica)* surrounding the plants, and non or little effect of witchweed on other crops (cowpea, groundnut and bambara beans).

Note: the two mashambas will unfortunately be abandoned in the coming cropping season (2017/18) due to the outbreak and severe infestation of *Striga asiatica*.

- most crops grown are just nutrient extracting rather than fixing one. And the crucial and most critical "*threat*" that drives farmers to abandon their mashambas, a part from the soil fertility decline is the incidence of "*Striga*" or 'witchweeds' after 2-3 of consecutive cereal cropping years. Within the mixed intercropping, witchweed attack the most important and valuable staple food crops for the local farmers namely maize, sorghum and millet. Other crops like cassava, groundnuts, okra, sesame, cowpeas are less or not affected by this weed (*striga*). The local name of this witchweed (*Striga* sp.) is "*Xikungulu*", in xitsuwa[2] it is called "*Nyasavari*" meaning - weed that kills cereals.

[2] Local language spoken in South of Mozambique

 

Photos 2: Striga asiatica - active mashamba (left side photo); and *Striga hermonthica* - abandoned mashamba (right side photo).

Note: Maize highly infested and affected by *Striga asiatica* (left side photo); and abandoned mashamba two years ago with approximately 90% covered by *Striga hermonthica* (right side photo).

> Namaluma Martinho Ajali (régulo of Nkuti community) said "*if your mashamba is dominated by striga, then you are not going to get the expected yields*". Solution to this problem, "*you must look for another new mashamba concluded Euzébio*". In the active and abandoned mashambas, two type of striga were observed: one with red flowers (*Striga asiatica*) and another with purple flowers (*Striga hermonthica*). Stemborers were also mentioned by the régulo of Nkuti and Eusébio, being of low weight on the decision to abandon an active mashambas (fields).

Khan, Z.R. *et al.,* (2007), described *Striga*[3] or '*witchweeds*' as being parasitic weeds that affect cereal crops in many parts of Africa, reducing production from 30 to 100%, or complete loss of the crop. If maize plants are attacked by both stemborers and *striga* weed, the yield loss is

[3] Full description of "*Striga* sp" see Annex 5.

often 100%. In East Africa, there are two common species of *witchweed* mostly affecting the following crops: maize, sorghum, millet, rice, and sugarcane.

Striga is amongst the world's worst weeds (Holm *et al.* 1997), reducing the value of grain crops, particularly in Africa. *Striga* is an obligate parasite, drawing moisture, nutrients and photosynthate from its graminoid host plants. Host plants are typically subsistence crops, including maize, sorghum, upland rice, sugarcane and millet. It is typically found in dry, infertile soils in semi-arid tropical grasslands and savannahs (Cochrane and Press 1997). Thus, its effects are disproportionately felt by poor farmers on the infested lands.

Taking into account the peculiar nature of *Striga* seeds, farmers are advise to control it before the weed emerges above the soil. The reason for this is that by the time it emerges, much of the damage to the crop will have been already caused.

Within the Nkuti and Mbamba village centres, other crops like cassava, pigeon pea, groundnut, sesame, and bambara bean are being grown as homesteads crops and they are healthy and vigorous plants promising high yields. In these village centres, the soil types are the same as those occurring in the abandoned fields - soil profiles (code Nkuti01P) described in Nkuti and Mbamba (code Mbamba02P) sites - see the site locations Fig.:1. Small plots of maize and sorghum were observed as homesteads crops in both village centres, instead, cassava, pigeon pea, sesame had shown a fantastic vegetative growth near the houses within the villages.

In general, farmers in the region usually cultivate a range of food crops, cereals (maize, sorghum and millet) roots (cassava, sweet potato), groundnut, bambara beans cowpea, pigeon peas, and fruit, etc. for domestic consumption and sale. But their definition of food security is usually framed around grain, the staple food. A farm family will say they are food secure if they can grow enough maize, sorghum or millet to feed themselves from one cropping season to the next.

This can lead us to conclude that the driving force on decision taking/making to remain and/or abandon a mashamba and open new one is the incidence of "*striga*" and its degree of infestation in maize, sorghum and millet. Although the stemborer was not consistently mentioned, both "*striga*" and stemborer are the most devastating and destructive to maize, sorghum and millet as the main staple food crop in the region.

Photos 3: Cassava, pigeon peas and sesame at homesteads in Mbamba village. The soil type is similar to the ones on abandoned mashambas.

f) <u>soil sampling *"under"* and *"outside"* the canopy of *Faidherbia albida* mature tree</u>

The *Faidherbia albida* tree species is one of the referenced nutrient-fixing-tree (NFT) species, in the region this tree is commonly found on Lugenda, Mbamba and Nkuti riverine systems. Four soil samples were taken at two soil depths (0-20, and 40-60*cm*), one set under the tree canopy and another one at 7 to 10 metres away from the *F. albida* tree canopy. Under the tree canopy, a soil profile was also described and sampled (five samples). The soil profile is typical of alluvium environment showing a clear stratification of soil layers on the lower terraces of the Mbamba river system.

g) soil profile description and sampling at Mariri Environmental Centre (MEC) garden

At MEC, a garden is being implanted with various vegetables species. The use of animal manures (bat guano, buffalo, hyrax rock, and elephant dungs) and tree species ash (black wood) to fertilise the soil is a promising a demonstrating activity to improve the soil fertility status for crop production. Good news from the Mariri garden are reported on the Vegetables component (Chipiri, T. 2016).

A soil profile was also and interactively, with part of MEC local staff members, described and sampled at five soil layer depths (0-15; 15-30; 30-50; 50-70; and 70-90*cm*). The site is located on the levee bunk of Lugenda river (soil profile full description, see Annex 1) on the left side according to the river water flow direction.

Summary 1:

Based on the site visits (*e, f,* and *g*) observations and descriptions at the wet season, the major aspects on the cropping systems can be summarised as follows:

- poor crop combination (mixed) that do not provide enough soil cover to guarantee moisture retention and stimulate biological activities to incorporate much of organic matter into the soil for continuous building of a healthy arable soil layer;
- most crops grown are just nutrient extracting rather than nutrient fixing ones;
- the incidence (and infestation) of "*Striga asiatica,* and *Striga hermonthica*" common know as 'witchweeds' after 2-3 years of consecutive production of cereals attacking the main staple food crops (maize, sorghum and millet), fact that drive farmers to abandon their mashambas, a part from the soil fertility decline, and immediately start the new mashambas (fields);
- farmers in the region usually cultivate a range of food crops, cereals (maize, sorghum and millet) roots (cassava, sweet potato), groundnut, bambara beans cowpea, pigeon peas, and fruit, etc., for domestic consumption and sale. But their definition of food security is usually framed around grain, the staple food. A farm family will say they are food secure if they can grow enough maize, sorghum or millet to feed themselves from one cropping season to the next;
- presence of *Faidherbia albida*[4], a nutrient-fixing-tree species along the Lugenda, Mbamba, and Nkuti riverine ecosystem, a promising source of seeds to implement a pioneer program for reforestation and fertility restoration in the vast active and abandoned mashambas in L4-East and L5-South concession areas, (why not?, in other communities within the entire Niassa National Reserve).
- at Mariri Environmental Centre, some initiatives on growing vegetables are an alive demonstration that fertility issues can be environmental and locally handled, although Mbamba and Nkuti residual soils are different from those of Mariri (fluvial soils) the manures tested locally, had shown promising results to overcome the soil fertility problems.

[4] There is a need to test if the local F. albida present on alluvial environment can perform successfully on the top of the interfluves topography where most active and abandoned mashambas (fields) are currently located. Tests with *F. albida* seeds from other regions are highly recommended.

1.2.2 Soil physical and chemical methodology analysis

The soil samples were air-dried, crushed and sieved through 2*mm* and 0.5*mm* meshes for the particle size distribution, pH (H_2O & KCl), total nitrogen (N) by the modified Kjeldahl method; organic matter (OM), according to Walkley and Black method; available Phosphorous (P) by Olsen Caroline method; the exchangeable cations (Ca, Na, Mg and K) and exchangeable acidity by titration and flame photometry. The particle size analysis was carried out by the pipette method. Soil pH was determined in 1:2.5 soil and water ratio.

2. BIOPHYSICAL CHARACTERIZATION OF THE REGION

2.1 Geology and Geomorphology

The area is laying on a vast gneiss-granite complex of the Mozambique belt with direction of foliation (Ferro and Bouman, 1987), coincident with the flat-to-gently undulating landscapes of the African and post-African plateau. The underlying geology of the plateau is largely Precambrian composed mainly Archean metavolcanics and metasediments of the Basement Complex and intrusive granites and granitic gneisses of varying ages. Extensive regional metamorphism has occurred on the flanks of the older cratons leading to the formation of banded gneisses, quartzites, and schists.

In places on the plateau the basement complex rocks have been covered by variety of mid to late Precambrian sedimentary formations. The lithology of the metamorphosed rocks of Precambrian age is accordingly varied; metamorphic limestone (marbles), metamorphosed sandstones (quartzites), metamorphosed basalt flows or dykes (amphibolites), and a considerable proportion of rocks of more or less granitic composition. The variation in chemical and mineralogical composition of these rocks can explain the wide range of variation in landforms and soils. The presence of huge granitic rock *inselbergs* are the most impressive on the panoramic overview of the landscapes that went to several erosion processes in the region.

2.2 Soils

As it is described in geology and geomorphology the main process of soil formation, in the region, are weathering, humification and pedoturbation (biological or animal activity). The combination of the crystalline nature of many different rocks, low relief, moisture climate, and warm temperature has produced highly weathered soils. Deep and intensive weathering has resulted in a residual concentration of resistant primary minerals, and the formation of kaolinitic clays and iron and aluminium oxides and hydroxides (mainly concentrated in the subsoil). This mineralogy and the low pH account for the stable micro-structure dominated by the sandy particles and yellowish (goethite) or reddish (hematite) sandy-clays.

In these environment, loamy-sand to sandy-loam dominate the topsoil and sand-clay-loam to sandy-clays dominate the subsoil. The amount of clay often increases substantially with the soil depth, sometimes resulting in a marked texture contrast between the topsoil and subsoil. Nevertheless most of the soils have good to rapid permeability due to micro-aggregation of the clays or their low activity (1:1 type). On the top of the interfluves the soils are generally freely drained or well drained although drainage is restricted or imperfect locally on the footslopes/toeslopes of the interfluves.

Shallow and/or stony soils are common along the transition flanges between the top of flat-to-gently undulating interfluves (deep soils) to the narrow or wide alluvial valleys along the natural drainage pathways. These natural water pathways may commonly start in the isolated huge stand up of the more resistant rocks that give an impressive view in the landscape common known as *"inselbergs"*.

According to the "Carta Nacional de Solos", INIA (1995), the soil moisture and temperature regimes are ustic, meaning that soil moisture is present at a time when conditions are suitable for plant growth but is limited for at least 90 consecutive days at some time during the year. Soil temperature regimes are isohyperthermic (mean annual soil temperatures are greater than 22°C, with less than 5°C difference between mean summer and winter soil temperatures).

The sampled soils, according to the "World reference base for soil resources, FAO (2006)" and the "Major soils of the world, Driessen & Dudal (1989)", are in the group classified as *Rhodic Ferralsols*. These soils have a red to dusky red *B-horizon* (rubbed soil has hues redder than 5YR with a moist value equal or less than 4 and a dry value not more than one unit higher than the moist value).

2.3 Hydrology

The rainy season contributes to almost 70% of the annual run-off (Ferro & Bouman, 1987). Most of the rivers have a torrential regime. Severe floods are very common in the downstream of the natural drainage network system. On the hydrological map, Lugenda river is classified as perennial river (Ferro & Bouman, 1987), this classification is partly based on the preliminary river and lake index. Although the perennial streams have water throughout the year, it may happen in exceptionally dry years that some rivers, classified as perennial, have no flow at the end of dry season.

The seasonal rivers in the region (Mbamba, Nkuti, Mecula, Nkalawe, etc.) have water throughout the wet season but are otherwise dry. Frequently the river bed still functions as an underground drain. The ephemeral streams have only water during and immediately after heavy rains.

2.4 Climate[5]

The sampled area has no climatic recording station. The nearest station is located at Mecula-sede Village which is approximately 70 kilometres west of the sampled area. The station has a comprehensive data for at least 10 years (1971-1981). Rainfall data and other climatic data for the region can be found in the "assessment of land resources for rainfed crop production in Mozambique" (Kassam, *et al.*, 1981) report. At the Mariri Environmental Centre a rain gauge was recently installed and as a result the data recorded was not used in the long term climatic analysis.

The area has two distinct climatic seasons a wet season from the end of November to April (heavy rains starts in December) and a dry season from May to October and has an annual average temperature of 24.5^{o}C. The annual rainfall within the region is 1,418.4*mm*, potential evapotranspiration of about 1,345.3*mm*, and the mean relative humidity of 69.6%.

[5] For the alternative crops and tree species selection for the region, see the full climatic characterisation (reference climatic data - Mecula-sede Village) in the Annex 2.

2.5 Vegetation and Land Use

Miombo is an ecologically very rich ecosystem, Mbamba and Nkuti villages are located within Miombo woodland in the Niassa National Reserve, both villages are within concession areas and the wildlife is the main dealership and humans have to adapt themselves to cooperate and live peacefully with the wildlife. The adaptation in this context must mean improvement of the cropping systems oriented to a permanent agriculture type near the villages, where the mashambas can be protected.

The current cropping production systems are dominated by a 3 to 5 consecutive years of maize, sorghum, millet, cowpea, cassava and groundnuts production. These crops, except groundnuts, are nutrient extracting from the soils rather than nutrient-fixing ones.

Not much time left to describe the *fauna* and *flora* of miombo woodland (it is not the objective of this short report). But the most important issue is to appoint and refer the valuable number of tree species identified by the several studies carried out in the Niassa National Reserve. For this specific study is a must to refer to the four identified "Honeybee tree species": *Julbarnadia globiflora; Brachystegia bochnii; Brachystegia speciformis; and Pseudolchnostflis mapproneifolia*. The honeybee collection activity can be seen as one of the key actions to complement the farmers income in the area. The alternative crops to be identified should also be potentially high contributors to the honeybee initiative by providing bees with a year-round supply of nectar.

Mariri Environmental Centre is already implementing an improved beehive project for the community at Nkuti and Mbamba villages with the purpose to complement the food crop production on the farmer's life working on active fields (mashambas) protected by the electric fence.

Most of the honeybee tree species and the food crops do flower at the same time and the bees are the one of the very active pollinators, while getting their essential for the honey manufacture. The continuous honeybee collection can highly and sustainably be contributed by the nutrient-fixing-plants and tree species in the farmlands with more emphases to those of "*inverted phenology*" (deciduous in the wet season, foliated and flowered in the dry season).

From the visit during the wet season to Nkuti and Mbamba on active and abandoned mashambas the cropping systems composition can be grouped as:

- main crops grown for family consumption in the region are: maize, sorghum, and millet;
- other crops that complement the diet chain are: pigeon pea, cowpeas, groundnut, bambara beans, cassava, pumpkins, okra, and rice (where there is water seepage from the top and middle of interfluves into the natural drainage pathways);

Fruit trees, cashew nut, mangoes, and papayas are grown near homestead within villages centres.

In general, farmers in the region usually cultivate a range of food crops: maize, sorghum, millet, groundnuts, cowpeas, bambara beans, etc. for domestic consumption and sale. But their definition of food security is usually framed around grains (maize, sorghum and millet), the staple food. A farm family will say they are food secure if they can grow enough maize, sorghum or millet to feed themselves from one cropping season to the next.

3. Results and Discussions

3.1 Soil Physical and Chemical Analysis

The general low fertility status of theses soils is evidenced by their poor chemical properties. The laboratory soil analysis shown in Table 1, indicate that although they are not to moderately acid soils, have low cation exchange capacities (CEC), they are low in nitrogen and available phosphorous. The current land-use practices and crop pattern are the main responsible for negative impact on soil properties. The traces of organic matter are absolutely low in the abandoned fields (mashambas) compared to active fields (mashambas), except on bush lands under densely wooded vegetation.

3.1.1 Soil Texture

From the analytical data of the three sampled sites at 0-20 and 40-60*cm* soil depths (covering active fields (mashambas), abandoned fields (mashambas) and bushlands in Nkuti area the soil texture varies from sandy to loamy-sand in 0-20*cm* soil depth to sandy-loam in 40-60*cm* soil depth. The soil profile analytical data show a gradually increase in clay content, changing from sandy or loamy-sand texture on the topsoil to sandy-loam at 40-60*cm* and sandy-clay-loam even sandy-clay below 60*cm* soil depth (see analytical data - Annex 1).

The clay content increase with soil depth may indicate the high rate of water infiltration which highly contributes to nutrient leaching and enriching clay content in the subsoil layers. The most important issue to retain so fare is the good physical soil properties evidenced by the soil structure, internal drainage, and porosity observed in these soil profiles. Few active biological activities on the topsoil but some voids and termite channels throughout the profile.

3.1.2 Organic matter

Healthy soil is the foundation of the food system. It produces healthy crops that in turn nourish people. Maintaining a healthy soil demands care and effort from farmers because farming is not benign. By definition, farming disturbs the natural soil process including that of nutrient cycling, the release and uptake of nutrients.

Plants obtain nutrients from two natural sources: organic matter and minerals. Organic matter includes any plant or animal material that returns to the soil and goes through the decomposition process. In addition to providing nutrients and habitat to organisms living in the soil, organic matter also binds soil particles into aggregates and improves the water holding capacity of soil. Most healthy soil contain 2-10 percent organic matter. However, even in small amounts, organic matter is very important.

Soil is a living, dynamic ecosystem. Healthy soil is teeming with microscopic and larger organisms that perform many vital functions including converting dead and decaying matter as well as minerals to plant nutrients. Different soil organisms feed on different organic substrates. Their biological activity depends on the organic matter supply. The role of organic matter in the soil is detailed explained in Annex 4.

Soil organic matter content is a key issue and it contribute substantially to the cation exchange capacity in the soil. From the soil analysis of the sampled sites it is clearly shown that the abandoned fields have only a trace of less than 0.01% of organic matter content on 0-20*cm* soil depth (topsoil) compared to the active fields with 0.26% rated as *very low* and the bush land with 0.69% rated *low*. The abandoned fields and bush land had shown, at sampling time, flesh signs of burning of vegetation and the active fields had very little crop residues left from the previous crop on the soil surface (see the photo - Annex 1).

Table 1: Physic-chemical characteristics of composed soil samples from three sites.

	Sites Sampled - Dry season - December 2016			
Soil parameter	*Nkuti01*[6]	*Nkuti02*[7]	*Mbamba01*[8]	*Observations*
Soil depth: 0-20cm				*Needed:*
Sand (%)	85.9	88.9	87.7	• *mulching and vegetative crop cover to stimulate water & nutrient retention, and biological activities.*
Silt (%)	7.8	6.3	7.6	
Clay (%)	6.3	4.8	4.7	
Texture (class)	Loamy-sand	Sandy	Sandy	
Organic matter (%)	0.26	<0.01	0.69	*Needed*:
Organic carbon (%)	0.15	<0.01	<0.01	• *crop residues, green manure to improve organic matter and active biological activities;*
Total Nitrogen (%)	0.08	0.10	0.10	• *addition of organic manure with exceptionally high content of nitrogen, phosphate, and potassium, nutrients essential for plant growth (guano, or others).*
C/N ratio	1.88	<0.01	<0.01	
Available Phosphorous (ppm)	2.60	1.43	2.08	
Exch. Calcium (meq $100g^{-1}$)	2.80	0.92	1.06	
Exch. Magnesium (meq $100g^{-1}$)	0.86	0.44	0.46	
Exch. Potassium (meq $100g^{-1}$)	0.09	0.14	<0.01	
Exch. Sodium (meq $100g^{-1}$)	0.09	0.03	0.00	
Cat. Exch. Capacity (meq $100g^{-1}$)	3.84	1.53	1.52	
pH-H_2O	7.3	6.8	6.5	*Note:*
pH-KCl	5.4	5.2	5.2	• *No evidence of acidity and salinity problems.*
EC ($mScm^{-1}$)	0.10	0.09	0.06	
Soil depthl: 40-60cm				*Needed: on (0-40 cm soil depth)*
Sand (%)	74.3	81.5	75.1	• *a concept of improvement on an "arable or productive soil layer" is crucial.*
Silt (%)	6.3	5.7	6.8	
Clay (%)	19.4	12.8	18.1	
Texture (class)	Sandy-loam	Sandy-loam	Sandy-loam	
Organic matter (%)	<0.01	<0.01	<0.01	*Needed:*
Organic carbon (%)	<0.01	0.01	<0.01	• *if above (0-20cm soil depth) is applied, then it will automatically be corrected.*
Total Nitrogen (%)	0.08	0.06	0.04	
C/N ratio	-	-	-	
Available Phosphorous (ppm)	0.52	0.65	2.34	
Exch. Calcium (meq $100g^{-1}$)	0.70	0.50	0.14	
Exch. Magnesium (meq $100g^{-1}$)	0.84	0.08	0.50	
Exch. Potassium (meq $100g^{-1}$)	0.29	0.09	0.22	
Exch. Sodium (meq $100g^{-1}$)	0.13	0.00	0.00	
Cat. Exch. Capacity (meq $100g^{-1}$)	1.96	0.67	0.86	
pH-H_2O	6.9	6.7	6.5	*Note*:
pH-KCl	5.1	4.8	4.9	• *Not relevant.*
EC ($mScm^{-1}$)	0.08	0.05	0.04	

[6] Active fields (mashamba) opened in 2014 - Nkuti area;
[7] Abandoned fields (mashamba) in 2010 - in Nkuti area; and
[8] Bush land halfway between Mbamba and Nkuti Villages.

It is also known that repeated burning of crop residues or forests depletes the soil organic matter and biological activity falls as the food supply to soil biota is reduced. The ways which fires modify the soil nutrients are complex. The interrelations and their durations are not easily monitored in terms of cause and effects. The main processes that may occur are: (1) transformation of nutrients from organic to inorganic forms, (2) nutrient transfers to atmosphere in smoke (volatilisation), (3) stimulate the erosion of ash and nutrient-rich surface soil, (4) change in nitrogen-fixing systems, (5) modification of decomposition rates of litter and soil organic matter.

Just to mention some direct effects of fire on soil biota: litter dwelling organisms die; true soil dwellers are little affected in uncultivated soils; some large invertebrates can survive fires by sheltering under rocks; soil microbes increase after fire due to "liming effects" of wood ash.

The laboratory analytical data got from the sampled sites and soil profile samples, the values of organic matter at 0-20*cm* soil depth were 0.26; <0.01 and 0.69% in active field, abandoned field, and bush land, respectively; and at 40-60*cm* soil depth just a trace of organic matter <0.01% was registered in the samples of the above mentioned sites, theses values are rated according to Geurts (1996) as *very low* to *low*.

3.1.3 Total Nitrogen (N)

The amount of this element in available forms in the soil is small, while the quantity withdrawn annually by crops is comparatively large. Nitrogen can be added to the soil by some microbes that fix it from the atmosphere, and can then be released back to the atmosphere by still other organisms. Nitrogen acidify the soil as it is oxidized. Most soil nitrogen is unavailable to higher plants. All in all, nitrogen is an important nutrient element that must be conserved and carefully farm managed.

The nitrogen content in the topsoil (0-20*cm*) varies from 0.08 to 0.10%. There is not much difference in N-content between active fields (0.08%), abandoned fields and busland (0.10%). These values are rated as *low*, nevertheless for sandy textured soils the ranges of 0.02 to 0.05% are acceptable. At 40-60*cm* soil depth, the nitrogen content is even less ranging from 0.04 to 0.08%. In active field is 0.08%; and 0.06% in abandoned field, and 0.04% in the bush land. These values are below the normal rates for sandy-clay-loam or sandy-clay soil textured.

3.1.4 Available Phosphorous (P)

Next to nitrogen, phosphorus and potassium are critical essential elements in influencing plant growth and production everywhere. Unlike nitrogen, these elements are not supplied through biochemical fixation but must come from other sources to meet plant requirements. The sources include animal manures; plant residues, including green manures; human, industrial, and domestic wastes; and native compounds of potassium and phosphorus, both organic and inorganic, already present in the soil.

Among the more significant functions and qualities of plants on which phosphorus has an importance effect are: photosynthesis; nitrogen fixation; crop maturation (flowering and fruiting, including seed formation); root development, particularly of the lateral and fibrous rootlets; strength of straw in cereals crops, thus helping to prevent lodging; and improvement of crop quality, especially of forages and of vegetables.

The sampled sites are very poor in phosphorus. At 0-20*cm* soil depth, available phosphorus vary from 1.43ppm in the abandoned field; 2.08ppm in bush land and 2.60ppm in active field. In active and abandoned fields the level of phosphorus decreases at soil depth of 40-60*cm* to values of 0.52ppm (active field) and 0.65ppm (abandoned field). In the bush land, the phosphorus content is *slightly high* (2.34ppm) compared to the active and abandoned fields, but still is rated as *very low*.

3.1.5 Exchangeable Potassium (K)

Potassium plays many essential roles in plants. It is an activator of dozens of enzymes responsible for such plant processes as energy metabolism, starch synthesis, nitrate reduction, and sugar degradation. Potassium is extremely mobile within the plant and helps regulate the opening and closing of stomates in the leaves and the uptake of water and other macro- and micro-nutrients by root cells.

Generally, in contrast to phosphorus, potassium is found in comparatively high levels in most mineral soils, except those of sandy nature. In fact, the total quantity of this element is generally greater than that of any other major nutrient element.

The soil analysis from the sampled sites at 0-20*cm* soil depth show values of exchangeable potassium of 0.09; 0.14 and <0.01meq $100g^{-1}$ in active, abandoned fields, and bush land, respectively. These values for the sandy textured soils are rated as *very low* to *low*. In the 40-60*cm* soil depth the exchangeable potassium registered values of 0.29; 0.09 and 0.22meq $100g^{-1}$, these values for sandy-loam textured soil are rated as well as *very low* (0.09meq $100g^{-1}$), and *slightly moderate* (0.22 and 0.29meq $100g^{-1}$).

3.1.6 Exchangeable Calcium (Ca)

The exchangeable Calcium (Ca) is rated depending on the Effective Cation Exchange Capacity (ECEC). The ECEC in the 0-20*cm* soil depth is less than 5.0meq $100g^{-1}$ and exchangeable Ca values are 2.08; 0.92 and 1.06meq $100g^{-1}$ for active and abandoned fields, and the bush land, respectively. These values are *slightly high* (2.80meq $100g^{-1}$ in the active field), and *moderate* (0.92 and 1.06meq $100g^{-1}$ in the abandoned field and bush land, respectively). At a soil depth of 40-60*cm*, the exchangeable calcium is *low* (0.70; 0.50; and 0.14meq $100g^{-1}$ in active, and abandoned fields, and bush land, respectively).

3.1.7 Exchangeable Magnesium (Mg)

The exchangeable Magnesium (Mg) was also analysed and the rating are ECEC dependent. The ECEC in both sampled soil depths is less than 5.0meq $100g^{-1}$. At the topsoil (0-20*cm* soil depth) the exchangeable Mg is 0.86; 0.44 and 0.46meq $100g^{-1}$. It is rated as *very high* (0.86meq $100g^{-1}$) in the active field; and *high* (0.44 and 0.46meq $100g^{-1}$) in abandoned field and bush land. At soil depth of 40-60*cm*, the values of exchangeable magnesium are 0.84; 0.08 and 0.50meq $100g^{-1}$, the active fields have a *very high* value (0.84meq $100g^{-1}$); *very low* (0.08meq $100g^{-1}$) at abandoned fields and *high* (0.50meq $100g^{-1}$) in the bushland.

3.1.8 Exchangeable Sodium (Na)

The values of exchangeable sodium in the sampled sites at two soil depths vary from *very low* to *low* (<0.01-0.13meq $100g^{-1}$). The active field had shown values of 0.09meq $100g^{-1}$ at a soil depth of 0-20cm and 0.13meq $100g^{-1}$ at 40-60*cm*; and in the abandoned field, a value of 0.03meq $100g^{-1}$. No evidence of exchangeable sodium presence at 40-60*cm* soil depth in the abandoned field, and throughout the soil profile in the bush land.

3.1.9 Effective Cation Exchange Capacity (ECEC)

The effective cation exchange capacity at the three sampled sites is *very low* and decreases with the soil depth. Values of 3.84; 1.53; and 1.52meq $100g^{-1}$ are registered in active and abandoned fields and bush land, respectively at the soil depth of 0-20*cm*. At 40-60*cm* soil depth the ECEC values are 1.96; 0.67 and 0.86meq $100g^{-1}$ (active, abandoned fields, and bushland, respectively) and they are rated as *very low* even when are compared to the ones on the topsoil.

3.1.10 Acidity/Alkalinity (pH) & Electrical conductivity (EC)

In general the soil are not acid throughout the soil profile, the pH-H_2O values vary from 6.5 to 7.3. In the actives field the values are relatively high 7.3 *(very slightly alkaline)* at soil depth 0-20*cm* and 6.9 *(very slightly acid)* at soil depth 40-60*cm*; in the abandoned field (mashamba) the pH-H_2O values are very similar 6.8 and 6.7 *(very slightly acid)* at 0-20cm and 40-60*cm*, respectively; in the bushland 6.5 *(slightly acid)* is the value of pH-H_2O registered in both soil sampled depths.

No evidence or trace of soil salinity problem were found in samples collected at two soil depths in sampled sites of interest. The analytical data revels values ranging from 0.04 to 0.10mS cm^{-1} and these being rated as no saline soils.

<u>Summary</u>: 2

- The general low fertility status of theses soils is evidenced by their poor chemical properties. The soil profile descriptions had shown good physical conditions observed throughought the soil structure, internal drainage, permeability, and porosity but very little evidence of biological activities in the abandoned field and relative high in the bush land; the soil texture varies from sandy to loamy-sand at 0-20*cm* soil depth and sand-loam to sandy-clay below 60*cm* soil depth;
- The organic matter content is *low* to *very low*; the total nitrogen, available phosphorus and exchangeable potassium are most critical nutrients being *low* throughout the soil profile;
- Exchangeable calcium and magnesium are *moderately high* to *very high* in the topsoil in the active fields and bushland but *low* in abandoned fields;
- In general the soils are not acid and have no salinity evidences; and
- The values of exchangeable sodium in the sampled sites at two soil depths vary from *very low* to *low* (0.00-0.13 meq $100g^{-1}$).

3.2 Missing nutrients in the soils

From the above soil data and discussions, the most essential missing nutrients for plant growth were identified. These missing nutrients are from three crucial elements: nitrogen (N), available phosphorus (P) and exchangeable potassium (K), all being "*very low*" at sampled 0-20*cm*, 40-60*cm* soil depths and throughout the soil profiles described in abandoned and in bushland; others elements like exchangeable calcium and magnesium are relatively present in the soil due to the repeated burning of vegetation including crop residues that produce ash which is rich in these (Ca & Mg) elements. The soil organic matter content that is a key issue and it contribute substantially to the cation exchange capacity and soil aggregation formation, particularly in the topsoil is also missing fact that reduce significantly the microbial activity. Different soil organisms feed on different organic substrates. Their biological activity depends on the organic matter supply.

3.3 Manure Chemical Analysis

Apart from the soil physical and chemical analysis, four manures (guano, dungs of elephant, buffalo and rock hyrax) and one ash from the "black wood tree species" (*Dalbergia melanoxilon*) samples were collected and analyzed. Acidity/alkalinity (pH), total nitrogen, available phosphorus and exchangeable Ca, Mg, K and Na were assessed and the Table 2, below shows the results.

3.3.1 Guano (*bat*)

In general, the *bat guano* shows exceptionally *high* content of nitrogen (16.55%), phosphate (34.20ppm) and potassium (27.14mg kg^{-1}), these nutrients are the essential for plant growth. The ash from black wood *(Dalbergia melanoxilon)* despite *low* (0.11%) in nitrogen, it shows *high* values (19.06ppm) in phosphorus as well as in potassium (11.71mg kg^{-1}). The exchangeable calcium (39.54mg kg^{-1}) and magnesium (47.86mg kg^{-1}) are *extremely high* concentrated in the ash, and the ash pH is *very strongly alkaline* (pH value: >8.0).

3.3.2 Ash of "black wood tree species" (*Dalbergia melanoxilon*)

Currently burning in the mashambas is made purposely to produce ash which can fertilise the soils. For specific tree species (*Dalbergia melanoxilon*) the ash collected in the kitchen at Mariri centre is very rich in exchangeable calcium with 39.54mg kg^{-1} rated as *very high* and magnesium with 47.86mg kg^{-1} rated *very high* as well. The available phosphorus (19.06ppm), and exchangeable potassium (11.71mg kg^{-1}) are *high*. The total nitrogen is low (0.11%).

Table 2: The concentration of nutrients in the manure[9] and ash, collected in 2016.

Manure source	pH	N-total	P	K	Ca	Mg	Na
		%	ppm	(mg kg^{-1})			
Guano (bat)	5.9	<u>16.55</u>	<u>34.20</u>	<u>27.14</u>	<0.01	<0.01	4.44
Rock hyrax	7.0	2.49	17.37	6.43	4.94	10.82	0.46
Elephant	6.9	1.08	19.12	8.18	3.76	3.86	0.78
Buffalo	7.8	1.54	18.52	7.44	8.22	8.82	0.97
Ash (black wood)	10.0	0.11	19.06	11.71	<u>39.54</u>	<u>47.86</u>	2.00

3.3.3 Total Nitrogen (N)

The content of nitrogen in elephant (1.08%), rock hyrax (2.49%) and buffalo (1.54) manures is *very low* compared to the guano (16.55%) but these manure are relatively rich in exchangeable calcium and magnesium than in guano. So, these can be considered as an alternative organic source of calcium and magnesium to complement the nutrient supply for plant growth (for small areas - gardens).

3.3.4 Available Phosphorus (P) and Exchangeable Potassium (K)

The available phosphorus content is rated as *high* in elephant (19.12ppm), rock hyrax (17.37ppm), and buffalo (18.52ppm) manures. These values are low compared to the guano. The average exchangeable potassium content in these manures is 7.35mg kg^{-1} being rated as *high* (8.18; and 7.44mg kg^{-1}) in the elephant and buffalo manure, respectively, and rated *medium* (6.43mg kg^{-1}) in rock hyrax manure.

3.3.5 Exchangeable Calcium (Ca) and Magnesium (Mg)

The exchangeable calcium content (average of 5.64mg kg^{-1}) and magnesium (average of 7.83mg kg^{-1}) content were best found on the elephant's, buffalo's and rock hyrax's manure rather than in bat guano. The exchange calcium ranged from 3.76mg kg^{-1} (elephant's) to 8.22mg kg^{-1} (buffalo's) and 4.94mg kg^{-1} (rock hyrax's) manures. The exchangeable magnesium content is, in general, rated as *very high* (10.82; and 8.82mg kg^{-1}, respectively) in the rock hyrax's and buffalo's manure; and *high* (3.86) in the elephant's manure.

3.3.6 Exchangeable Sodium (Na)

The exchangeable sodium content in the analysed manures were *extremely high* in guano (4.44mg kg^{-1}) and *very high* (2.00mg kg^{-1}) in ash. In other manures, they are rated as *medium* (0.46mg kg^{-1}) in rock hyrax, and *high* (0.78; and 0.97mg kg^{-1}) in elephant's and buffalo's, respectively.

Note: the nutrient content from these manures may vary according to the season since the sources (native vegetation) and availability of it for referred animals is different throughout the year. The manure gathering process to be used as organic fertilizer is another issue that make a big difference when dealing with bat guano and rock hyrax (these can locally be collected in specific places) compared to elephant and buffalo manures - scattered in their habitat.

[9] The elephant's and buffalo's manures were taken when fresh.

3.4 Nutrient present in manures

The *summary 3*, gives the organic nutrient content in manure of the most important elements for plant growth. The local bat guano has an *exceptionally high* nutrient content of nitrogen (N), phosphorus (P) and potassium (K). A relative *high* available phosphorus (P) content is also be found in the elephant's, rock hyrax's, and buffalo's manures despite being *low* when compared to the bat guano. The exchangeable calcium and magnesium content are best found on the elephant's, buffalo's and rock hyrax's manures rather than in bat guano. The ash of a black wood (*Dalbergia melanoxilon*) is *extremely rich* in exchangeable calcium and magnesium. This organic nutrient source can potentially complement the bat guano.

<u>*Summary*</u>*: 3*

- In general, the bat guano shows *exceptionally high* content of nitrogen (16.55%), phosphate (34.20ppm) and potassium (27.14mg kg^{-1}), nutrients most essential for plant growth;
- The ash from the black wood tree species is *very rich* in exchangeable calcium with 39.54mg kg^{-1} (*very high*) and magnesium with 47.86mg kg^{-1} (*very high*). Still in ash, the available phosphorus (19.06ppm), and exchangeable potassium (11.71mg kg-1) are rated as *high*.; and the total nitrogen is *low* (0.11%);
- The content of nitrogen in elephant's (1.08%), rock hyrax's (2.49%) and buffalo's (1.54) manures are *very low* compared to the bat guano's (16.55%);
- The available phosphorus content is *high* in the elephant's (19.12ppm), rock hyrax's (17.37ppm), and buffalo's (18.52ppm) manures despite being *low* when compared to bat guano's manure;
- The exchangeable calcium content (average of 5.64mg kg^{-1}) and magnesium (average of 7.83mg kg^{-1}) content are best found on the elephant's, buffalo's and rock hyrax's manures rather than in bat guano's; and
- The exchangeable sodium content are *extremely high* in bat guano's (4.44mg kg^{-1}) and *very high* (2.00mg kg^{-1}) in ash. In the other manures, the sodium is rated as *medium* (0.46mg kg^{-1}) in rock hyrax, and *high* (0.78; and 0.97 mg kg^{-1}) in elephant and buffalo manures, respectively.

3.5 Current food crops production *vs* Nutrients present in manures

The current food production systems are dominated by the most nutrient extracting crops namely maize, sorghum, millet, cowpea and cassava. These crops in the region are being grown on soils of very low fertility status due to their poor chemical properties as shown in *summary 2*, and the most preferred crops as the food securing are the ones most attacked by the *striga*. The information provided in *summary 3*, gives an indication of how the present soil fertility issues can be addressed - guano is a potential source of missing nutrients to supplement for a healthy plant growth. The *summery 4* presents the way forward.

<u>Summary</u>: 4

- The active fields are the ideal starting point to implement the soil fertility status recovering activities through "push-pull modified technology" where the main staple food crops (maize, sorghum and millet) can be intercropped with nutrient-fixing alternative selected food crops, making sure that these fields will continuously produce cereals and other crops, promoting a permanent agriculture that ensure food security and wildlife conservation;
- On the abandoned fields, starting with "push-pull technology" including the use of bat guano in the first years and reforestation initiative planting nutrient-fixing-tree species, for example: (*Faidherbia albida*) planted at regular spacing (e.g. 10x10*m*).

Land Utilization Type (LUT) (crops production)	Required organic nutrientes					
	N	P	K	Ca	Mg	Na
Maize Sorghum Millet Cassava Other food crops Fruit trees[10] Vegetables[11]	<u>Guano supplying</u>: N: 16.5 % P: 34.2 ppm K: 27.1 mg kg^{-1}			<u>Rock hyrax supplying</u>: Ca: 39.5 mg kg^{-1} Mg: 47.8 mg kg^{-1}		Guano and Rock hyrax

<u>Note</u>: Guano and rock hyrax manures are finite! (limited resources) to be used in all abandoned fields within L4-East and L5-South concession units. But planting accordingly the *Faidherbia albida* in the active and abandoned fields may contribute to recover the soil fertility for agricultural use and promote apiculture (already being implemented). This can be seen as "A community management for conservation strategy" - A pioneer issue for Saving Ecosystems within Niassa National Reserve.

[10] Fruit trees include: *citrus* spp, mangoes, avocado pear, papaya, banana, cashew, guava and pineapple.

[11] Wherever there is enough fresh water during the cool-dry season, vegetables can organically (using of combined guano and rock hyrax manures) be grown for local consumption and sell to neighbouring villages and touristic units within the Reserve. These vegetables include: onions, garlic, peppers, tomatoes, okra, cucurbitaceous, potatoes, etc. Think on indigenous flowers species unique present in the reserve!!!.

4. Soil Fertility Recover (plant/animal) - Fertilisers Origin

The soils in the visited and sampled sites have good physical properties but they are chemically very poor. Their low natural fertility due (probably) to absence of active weatherable minerals, and very low organic matter content are serious limitations for current rainfed agriculture, exacerbated by poor cropping systems practiced in the region. The soil fertility decline is worsened by the breakout of "*Striga asiatica,* and *Striga hermonthica*" common know as 'witchweeds' after 2-3 of consecutive production of cereals attacking mostly the main staple food crops (maize, sorghum and millet), fact that drives farmers to abandon their fields, and immediately start the new ones.

All the sampled sites (bush land, active, and abandoned fields) had shown a dark-reddish-brown (an habitat for active biological activity) coloured topsoil, poor in organic matter content, that gradually changes into red colour in the subsoil (very low active biological activity), the last, meaning less organic matter content but moderate to high water retention capacity (sandy-loam, sandy-clay-loam, or sandy-clay). Under current cropping system, very low to low biological activities are present in these soils which contribute to the rapid topsoil structure deterioration and natural fertility decline.

Introduction of nutrient-fixing crops can markedly reverse these trends through improvements in soil aggregations. Farming practices that should establish the development of a concept of improvement on an *"arable or productive soil layer"* is crucial. The *"arable or productive soil layer"* is a topsoil layer (0-15; 0-25 or 0-30*cm* depth), with improved soil physical, chemical and biological properties. This is essential for developing a topsoil layer that is capable to support sustainable rainfed agriculture.

The *"arable layer"* concept proposed, is based on introduction of new food and cash crops in the current farming system in Mbamba and/or Nkuti villages, namely soybean, pigeon pea, sunflower, lablab bean, sesame. These crops with the purpose of improving soil fertility through nitrogen-fixing process. And for the long term, reforestation with known nitrogen-fixing-trees (NFTs) species in the active and abandoned fields is highly recommended. The most and worldwide known NFT species is *Faidherbia*[12] *albida* this specie has an additional advantage of its *"inverse phenology"* (*u*nlike most other trees, it sheds its leaves in the rainy season).

4.1 Nitrogen fixing plants (NFPs)

Nitrogen Fixing Plants (NFPs) have the ability to take nitrogen from the air and pass it on to other plants through the cycling of organic matter. Nitrogen is an essential nutrient for plant growth, and the NFPs are a major source of nitrogen fertility in tropical ecosystems. When integrated with a farm, orchard, garden, or forest, NFPs can be a major source of nitrogen fertilizer and mulch for crops. According to Elevitch and Wilkinson (2000), aside from their nutrient and organic matter contribution, NFPs have many other uses on the farm, including bee forage (for honey production), animal fodder, living fences, wind shelter, and animal food.

[12] Brief tree species characterisation and recent successes on land management histories with NFP is given in the Annex 3.

These plants can be tree, shrubs, and food crops that have the ability, through a symbiotic association with certain soil bacteria, to take nitrogen out of the air and use it for plants and food crops growth. Nitrogen as one of most essential nutrient for plant growth its lack is viewed as a major problem in agriculture, but nature had an immense reserve of it everywhere in the air under where the plants grow. Air consists of approximately 80% nitrogen gas (N_2), representing about 9,000 kg above every hectare (Elevitch and Wilkinson, 2000). However, N_2 is an a stable gas, normally unavailable to plants, nitrogen fixation in the soil is a process by which certain soil bacteria on the roots of nitrogen fixing plants *fix* or *gather* nitrogen from the air, and allow their NFPs hosts to incorporate it into their leaves and plant tissues.

In nature, when NFPs drop their leaves or die back, the organic matter and fertility they accumulated in their tissues is passed on to other plants. This process is the major source of nitrogen fertility in tropical a sub-tropical ecosystems. When nitrogen fixing plants (perennial species) are incorporated in a certain farming system, they can be cut back (pruning) repeatedly, and the cuttings applied to the crops as mulch. With proper management, NFPs can be a major source of fertility for crops and also provide the benefits of mulch and organic matter.

Incorporating nitrogen fixing plants is a way for a farmer to restore natural fertility processes to the farm system, growing a source of nitrogen fertilizer on-site, rather than having to buy it. Synthetic nitrogen fertilizers are produced using an energy intensive process, and the end product is nitrogen in a form which can be detrimental to soil microorganisms and which can pollute ground water due to rapid loss through leaching.

Notes taken on *"Nitrogen Fixing Tree Start-Up Guide"* indicate that in farm systems using NFPs, it is estimated that 110-1,100 kg of nitrogen per hectare are accumulated every year by the NFPs, depending on species, soil and climate, *Rhyzobium* effeciency, and management.

Fertility provided by nitrogen fixing plants can promote healthy plants and soil life naturally. Elevitch and Wilkinson (2000) on the *"Nitrogen Fixing Tree, Start-Up Guide"* highlighted a study carried out in Hawaii, that revelled results that by using 15% of certain tract of land for NFPs, approximately 10 tons of mulch could be produced per acre per year containing 210kg of N/ha, 12kg of P/ha; and 80kg of K/ha.

In addition to the fertility, the mulch and organic matter provided by NFPs is important for healthy plants and soils. Mulching improves nutrient and water retention in the soil, encourages favourable soil microbial activity and worms, and suppresses weed growth. When properly done, mulching can significantly improve the well-being of plants and reduce maintenance as compared to bare soil culture. Mulched plants have better vigour and, consequently may have improved resistance to pests and diseases.

Table 3: Typical levels of Nitrogen-fixation from different crops or plants.

Crop or plant	Associated organism	Typical levels of nitrogen fixation (kg N ha^{-1} yr^{-1})
Symbiotic		
Legumes (nodulated)	Bacteria (*Rhizobium*)	
Alfalfa (*Medicago sativa*)		150-250
Clover (*Trifolium pratense* L.)		100-150
Soybean (*Glycine max* L.)		50-150
Cowpea (*Vigna unquiculata*)		50-100
Lupine (*Lupinus*)		50-100
Vetch (*Vicia vilbosa*)		50-125
Bean (*Phaseolus vulgaris*)		30-50
Nonlegumes (nodulated)		
Alders *(Alnus*)	Actinomycetes (Frankia)	50-150
Species of *Gunnera*	Blue-green algae (Nostoc)	10-20
Nonlegumes (nonnodulated)		
Pangola grass (*Degetaria decumbens*)	Bacteria (*Azospirillum*)	5-30
Bahia grass (*Paspalum notatum*)	Bacteria (*Azotobacter*)	5-30
Azolla	Blue-green algae (*Anabaenta*)	150-300
Nonsymbiotic	Bacteria (*Azotobacter, Clostridium*)	5-20
	Blue-green algae (various)	10-50

Source: Brady, N.C. 1990.The nature and properties of soils.

4.2 Land suitability assessment for alternative crops selection

Land suitability assessment is one of the main factors for sustainable production of food and cash crops. Soils and climate play a critical role in the assessment of land suitability for rainfed agriculture, and it is essential to understand the spatial distribution of uniform land units with specific soil types, or soil associations, in order to quantify the suitability of land for selected crops.

Based on the point profile soil data (see Annex 1: landscape and soil equipments) and climatic data characterization (Annex 2: climatic requirements) brief land suitability assessment was carried out for selecting crops (land utilization types - LUTs) under rainfed conditions. Seven landscape and soil requirements and five climatic requirements were considered. Each land quality was rated for point soil data of sampled sites in the region. A land suitability evaluation criteria was set for each crop separately taking into account its requirements.

The land qualities of the soil point data were compared (*matched*) with the limits set for each crop to arrive at suitability classes. From the six land suitability classes distinguished namely: a) very suitable; b) suitable; c) moderately suitable; d) marginally suitable; e) conditionally suitable; and f) not suitable, only the first three classes were taken for the final decision for alternative crop selection to be included in the current cropping system practiced in region.

The major limiting factors in order of severity were: availability of nutrients, effective rooting depth, drainage, availability of oxygen for root growth, capacity for water retention, salinity, sodicity, annual precipitation, length of growing period, precipitation of growing period, mean temperature of the growing period, and relative humidity of growing period. Except the first one (availability of nutrients) the following five factors are considered to be the most important. And these factors leaded to the crop selection with the main purpose to guarantee the food security and income generation with the background of soil fertility recover.

The crop selection came out with a long list of alternative crops, most of them with nutrient-fixing properties, these crops are: soya bean, lablab bean, pigeon pea, cowpea, sesame, sunflower and groundnut. The selection included a tree species namely *Faidherbia albida*. The brief characterization of each crop is given below.

4.2.1 Soya bean (*Glycine max*)

Cultivation is successful in climates with hot summers, with optimum growing conditions in mean temperatures of 20 to 30 °C; temperatures of below 20 °C and over 40 °C stunt growth significantly. They can grow in a wide range of soils, with optimum growth in moist alluvial soils with a good organic content. Soybeans, like most legumes, perform nitrogen fixation by establishing a symbiotic relationship with the bacterium *Bradyrhizobium japonicum* (syn. *Rhizobium japonicum*). For best results, though, an inoculum of the correct strain of bacteria should be mixed with the soybean (or any legume) seed before planting. Modern crop cultivars generally reach a height of around 1 m, and take 80–120 days from sowing to harvesting.

Like many legumes (alfalfa, clover, lupins, peas, beans, lentils, groundnuts, and others), soybean contain symbiotic bacteria called *Rhizobia* within nodules of their root systems. These bacteria have the special ability of fixing nitrogen from atmospheric, molecular nitrogen (N_2) into ammonia (NH_3). The ammonia is then converted to another form, ammonium (NH_4^+), usable by (some) plants.

4.2.2 Lablab bean *(Lablab purpureus)*

Lablab is a dual-purpose legume. It is traditionally grown as a pulse crop for human consumption. Flowers and immature pods also used as a vegetable. It is also used as a fodder legume sown for grazing and conservation in broad-acre agricultural systems in tropical environments with a summer rainfall. Also used as green manure, cover crop and in cut-and-carry systems and as a concentrate feed. It can be incorporated into cereal cropping systems as a legume ley to address soil fertility decline and is used as an intercrop species with maize to provide better legume/stover feed quality.

It grows in a wide range of soils from deep sands to heavy clays, provided drainage is good, and from pH 4.5-7.5. Low salinity tolerance with symptoms being chlorotic leaves, reduced growth and plant death. Lablab does not always nodulate well with native strains of *rhizobia* but some virgin soils appear to have suitable native *rhizobia* populations, which have resulted in good growth without inoculation of seed. Nevertheless it is recommended to be sown with the appropriate lablab *rhizobia* strain.

Adapted to annual rainfall regimes of 650-3,000*mm*. Drought tolerant when established, and will grow where rainfall is <500*mm*, but loses leaves during prolonged dry periods. Capable of extracting soil water from at least 2 metres depth even in heavy textured soils. It tolerates short periods of flooding but intolerant of poor drainage and prolonged inundation. It grows best at average daily temperatures of 18-30°C and is tolerant of high temperatures. Able to grow at low temperatures (down to 3°C) for short periods. Frost susceptible, but tolerates very light frosts. More tolerant of cold than either *Mucuna pruriens* or cowpea (*Vigna unguiculata*). It grows at altitudes from sea level to elevations of up to 2,000*m* asl in tropical environments.

When used for forage in large areas, lablab is often sown with annual crops such as annual sorghums and millets. In smallholder systems, lablab can be intercropped with maize. The lablab should be sown about 28 days after the maize to avoid severe cereal crop yield depression from competition. Seasonally yields dry matter of 2 ton ha^{-1} leaf or 4 ton ha^{-1} stem and leaf are common in sub-humid sub-tropics. Dry matter yield is usually higher than for cowpea, particularly under drought conditions. For human nutrition, 2-7 ton ha^{-1} green pods. In monoculture, 1-2.5 ton ha^{-1} dry matter, depending on cultivar.

Intermittent flowering and pod production. Grain maturation on the forage cultivars is not uniform but crop landrace types often have more synchronous maturity. High grain yields of 1-2.5 ton ha^{-1}, depending on cultivar, but when grown on trellises in smallholder systems the grain yields can be far greater. In mixtures with other crops, grain yields 0.5 ton ha^{-1}. Late seeding varieties may be affected by early frosts. There is some evidence that lablab accessions with light coloured seeds have poor storage potential, which in turn affects seedling vigour and establishment.

4.2.3 Pigeon pea *(Cajanus cajan)*

The pigeon pea is a perennial legume from the family Fabaceae. Since its domestication in India at least 3,500 years ago, its seeds have become a common food grain in Asia, Africa, and Latin America. It is consumed on a large scale mainly in south Asia and is a major source of protein for the population of that subcontinent.

Today, pigeon pea is widely cultivated in all tropical and semitropical regions of the worlds. Pigeon peas can be of a perennial variety, in which the crop can last three to five years (although the seed yield drops considerably after the first two years), or an annual variety more suitable for seed production.

Pigeon pea is an important legume crop of rainfed agriculture in the semiarid tropics. The Indian subcontinent, eastern Africa and Central America, in that order, are the world's three main pigeon pea-producing regions. Pigeon peas are cultivated either as a sole crop or intermixed with cereals, such as sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), or maize (*Zea mays*), or with other legumes, such as peanuts (*Arachis hypogaea*). Being a legume capable of symbiosis with *Rhizobia*, the pigeon pea enriches soil through symbiotic nitrogen fixation. It grows in symbiosis with *rhizobia* - bacteria with the ability to fix atmospheric nitrogen, then the nitrogen also benefits other plants growing nearby.

The crop is cultivated on marginal land by resource-poor farmers, who commonly grow traditional medium and long duration (5–11 months) landraces. Short-duration pigeon peas (3–4 months) suitable for multiple cropping have recently been developed.

4.2.4 Cowpea *(Vigna unguiculata)*

It is one of the most widely adapted and nutritious grain legumes grown in warm and hot regions of the world. Cowpea belongs to the *Fabaceae family*. Cowpea has several common names. In English cowpeas are commonly known as Bachapin beans, Black-eyed pea, Southern

Crowder pea, China pea and Cowgram. Summerfield et al. (1974), describe cowpea as an annual herb reaching heights of up to 80*cm*, with a strong taproot and many spreading lateral roots in the surface soil. Its growth forms vary and many are erect, trailing, climbing, or bushy, usually indeterminate growers under favourable conditions.

Cowpea plants are tolerant to drought and acid soil, and their ability to fix atmospheric nitrogen contribute to their fast growth habit in tropical climates characterized by low rainfall, high temperatures and soil with low fertility (Ehlers & Hall,1997). Being a drought tolerant crop, it is well adapted in areas where other food legumes do not perform well, and grows well even in poor soils with more than 85% sand, less than 0.2% organic matter and low levels of phosphorus.

Grain legumes are grown on very small portions of the land on smallholder farms, and though N_2 fixation rates can be high, overall farm N inputs from biological N_2 fixation are in some cases as low as 5kg farm^{-1} year^{-1} as the area planted to legume is often small (Giller, 2001). In Africa cowpea is cultivated under diverse soil and climatic conditions and it is mostly intercropped or rotationally grown with cereals such as millet, sorghum and maize.

4.2.5 Sesame (*Sesamum indicum*)

Sesame is an annual plant growing 50 to 100*cm* tall, with opposite leaves 4 to 14*cm* long with an entire margin; they are broad lanceolate, to 5*cm* broad, at the base of the plant, narrowing to just 1*cm* broad on the flowering stem. The flowers are yellow, tubular, 3 to 5*cm* long, with a four-lobed mouth. The flowers may vary in colour, with some being white, blue, or purple.

Sesame seeds occur in many colours depending on the cultivar. The most traded variety of sesame is off-white coloured. Other common colours are buff, tan, gold, brown, reddish, gray, and black. The colour is the same for the hull and the fruit.

Sesame fruit is a capsule, normally pubescent, rectangular in section, and typically grooved with a short, triangular beak. The length of the fruit capsule varies from 2 to 8*cm*, its width varies between 0.5 and 2*cm*. The fruit naturally splits open to release the seeds by splitting along the septa from top to bottom or by means of two apical pores, depending on the varietal cultivar.

Sesame seeds are small. Their size, form, and colours vary with the thousands of varieties now known. Typically, the seeds are about 3 to 4*mm* long by 2*mm* wide and 1*mm* thick. The seeds are ovate, slightly flattened, and somewhat thinner at the eye of the seed than at the opposite end. The weight of the seeds is between 20 and 40*mg*. The seed coat may be smooth or ribbed.

4.2.6 Sunflower (*Helianthus annuus*)

The domesticated sunflower, *H. annuus*, is the most familiar species. Perennial sunflower species are not as popular for gardens due to their tendency to spread rapidly and become invasive. Sunflowers are usually tall annual or perennial plants that grow to a height of 3.0*m* or more. They bear one or more wide, terminal capitula (flower heads), with bright yellow ray florets at the outside and yellow or maroon (also known as a brown/red) disc florets inside.

Several ornamental cultivars of *Helianthus annuus* have red-colored ray florets; all of them stem from a single original mutant. During growth, sunflowers tilt during the day to face the sun, but stop once they begin blooming. This tracking of the sun in young sunflower heads is called heliotropism. By the time they are mature, sunflowers generally face east. The rough and hairy stem is branched in the upper part in wild plants but is usually unbranched in domesticated cultivars. The petiolate leaves are dentate and often sticky. The lower leaves are opposite, ovate or often heart-shaped.

They are distinguished technically by the fact that the ray florets (when present) are sterile, and by the presence on the disk flowers of a pappus that is of two awn-like scales that are caducous (that is, easily detached and falling at maturity). Some species also have additional shorter scales in the pappus, and there is one species that lacks a pappus entirely.

There is quite a bit of variability among the perennial species that make up the bulk of the species in the genus. Some have most or all of the large leaves in a rosette at the base of the plant and produce a flowering stem that has leaves that are reduced in size. Most of the perennials have disk flowers that are entirely yellow, but a few have disk flowers with reddish lobes.

4.2.7 Groundnuts (*Arachis hypogea*)

Groundnut or peanut is an annual herbaceous plant growing 30 to 50*cm* tall. As a legume, it belongs to the botanical family Fabaceae (also known as Leguminosae, and commonly known as the bean or pea family). Like most other legumes, peanuts harbor symbiotic nitrogen-fixing bacteria in their root nodules. The leaves are opposite and pinnate with four leaflets; each leaflet is 1 to 7*cm* long and 1 to 3*cm* across. Like many other legumes, the leaves are nyctinastic, that is, they have "*sleep*" movements, closing at night.

Peanut pods develop underground, an unusual feature known as geocarpy. The flowers are 1.0 to 1.5*cm* across, and yellowish orange with reddish veining. They are appear in axillaries clusters on the stems above ground and last for just one day. The ovary is located at the base of what appears to be the flower stem but is actually a highly elongated floral cup.

After sometimes, a short stalk at the base of the ovary (termed a pedicel) elongates to form a thread-like structure known as a "peg". This peg grows down into the soil, and the tip, which contains the ovary, develops into a mature peanut pod. Pods are 3 to 7*cm* long, normally containing one to four seeds.

Peanuts grow best in light, sandy loam soil with a pH of 5.9–7.0. Their capacity to fix nitrogen means that, providing they nodulate properly, peanuts benefit little or not at all from nitrogen-containing fertilizer, and they improve soil fertility. Therefore, they are valuable in crop rotations. Also, the yield of the peanut crop itself is increased in rotations, through reduced diseases, pests and weeds.

To develop well, peanuts need warm weather throughout the growing season. They can be grown with as little as 350 mm of water, but for best yields need at least 500*mm*. Depending on growing conditions and the cultivar of peanut, harvest is usually 90 to 130 days after planting for subspecies *A. h. fastigiata* types, and 120 to 150 days after planting for subspecies *A. h. hypogaea* types. Subspecies *A. h. hypogaea* types yield more, and are usually preferred where the growing seasons are long enough.

After the peanuts have dried sufficiently, they are threshed, removing the peanut pods from the rest of the plant. It is particularly important that peanuts are dried properly and stored in dry conditions. If they are too high in moisture, or if storage conditions are poor, they may become infected by the mold fungus *Aspergillus flavus*. Many strains of this fungus release toxic and highly carcinogenic substances called aflatoxins.

4.2.8 Acacia albida (*Faidherbia albida*)[13]

Faidherbia albida is a leguminous nitrogen-fixing acacia-like tree species that is indigenous almost all over Africa. *Faidherbia* has a unique compatibility with cropping systems due its *"reverse leave phenology"* - it is dormant during the wet season and drops its leaves to fertilize associated crops. Its leaves only grow during the dry season. Its properties and utility have been researched for more than 60 years by several agroforestry scientists.

First flowering occurs in the seventh year and subsequent flowerings occur 1-2 months after the start of the dry season for up to 5 months. Ripe fruits towards the end of the dry sesaon. The seeds are dispersed by animals, which eat the pods.

Faidherbia albida grows on variety of including sandy alluvial or flat land where Vertisols predominate. It thrives in climates characterized by long summers, or a dry season with long days. It tolerates seasonal waterlogging and salinity but cannot withstand heavy clays.

Aside from nitrogen fixing properties, *Faidherbia albida* people eat the seeds. The leaves and pods are palatable to domestic animals and an important source of protein for livestock in the dry season.

In apiculture, this species is for bee-keepers, it has the advantage of producing flowers at the end of the rains while most of species flower just before or during the rains. It becomes the main source of pollen and nectar at this time.

In medicine, the use of bark and roots either externally or internally against infections, digestive disorders, malaria and other fevers is widespread. The bark is used to clean teeth, as it is believed to contain fluorine; an extract is used for toothache in humans and eye infections in livestock.

As services, shade or shelter; *Faidherbia albida* is maintained and protected on farms to shade coffee and to provide shade for livestock in the dry season. in reclamation: the plant's spreading root system offers excellent protection to the banks of watercourses.

Soil improver: *Faidherbia albida* sheds its leaves in the rain season; therefore, boosting the nutrient status of the soil for the new seasons's crops. The fact that the tree is leafless during rainy season minimizes competition for sunlight with crops and protects them from birds until harvest time. Highly recommended for integration with maize as an alternative to *Leucaena leucocephala*.

it is a useful ornamental tree for gardens and avenues. Used as a boundary/barrier/support: branches lopped for fencing compounds and livestock enclosures.

[13] Further reading is highly recommended in Annex 3: "A million tree-A-year community markets for conservation (COMACO) formula for saving an ecosystem"

5. Ways to Control Striga and Stemborers

The International Centre of Insect Physiology and Ecology (ICIPE) and partners have developed an effective, low-cost and environmentally friend technology[14] known as *'push-pull'* for the control of stemborers and suppression of *striga* weeds in cereals (maize, sorghum, millet and rice).

The '*push-pull*' habitat management approach exploits chemical ecology and biodiversity in a novel manner to limit crop losses due stemborers and striga weeds. At same time, it conserves soil and water while preserving biodiversity. This technology involves trapping stemborers on highly attractant trap plants (the *pull*) and driving them away from the maize crop using repellant intercrops (the *push*). Plants which repel stemborers as well as inhibit *striga* are known - napier grass and desmodium, respectively.

The technology consists on planting "Desmodium" in between the rows of maize, sorghum or millet. Desmodium produces a smell or odour that stemborer moths do not like. The smell *'pushes'* away the stemborer moths from maize or sorghum crops. The single greatest benefit of Desmodium intercropping is that by eliminating the threat of *striga*, it increases cereal production and thereby improves food security.

Desmodium improves crop yields not only by controlling *striga*, but also by improving soil fertility. As well as fixing nitrogen, the long trailing vines of this low-growing plant also conserve soil moisture, prevent erosion by wind and rain, and contribute organic matter to the soil. And it has the advantage of being a perennial crop that, once established, can continue being productive for many years. Nevertheless farmers who may want to begin desmodium intercropping require seeds or vines (if available) in their first cropping season.

The technology (*'push-pull'*) is a 'platform technology' around which other agricultural innovations can be incorporated to bring an overall improvement in the farming systems and livelihoods. It simultaneously reduces crop losses; improves productivity, household nutrition and income.

A modified model on integrated management of *Striga* weed and stemborer on maize, sorghum and millet methodology, known as *"Planting and Management 'Push-Pull[15]' fields for Striga weeds and stemborer control"* is the most appropriate and strategic tool to adopt since the active and abandoned fields are within the conservation wildlife habitats, and the use of chemical fertilisers, herbicides, and insecticides is not permitted.

A modified model because we may include on it leguminous crops (not affected by *striga*) that can provide food for humans and fix nutrients in the soil. A complete picture could also include nutrient-fixing-tree species planting at regular spacing, especially, for species with inverted phenology that in medium or long terms can provide nutrients to the soils and nectar to foraging bees when few plants have flowers.

[14] The detailed description of "*Push-Pull*" technology, see Annex 6.
[15] Brief description of "Managing Push-Pull fields for Striga weeds and stemborer control in maize, see the Annex 6.

6. CONCLUSIONS[16] AND RECOMMENDATIONS

Based on the data gathered in both seasons (dry and wet), the current cropping systems practiced in the region are dominated by poor crop combination (mixed) that do not provide enough soil cover to guarantee moisture and nutrient retention and stimulate biological activities to incorporate much of organic matter into the soil.

Most crops grown are nutrient extracting rather than nutrient-fixing ones and worsened by the critical "*threat*" for cereals - the incidence (and infestation) of *Striga* (*asiatica* and *hermonthica*) common knwn as '*witchweeds*' which becomes very severe after 2-3 years of consecutive production of crops attacking the main staple food crops - maize, sorghum and millet.

Farmers in the region usually cultivate a range of food crops, cereals (maize, sorghum and millet) roots (cassava, sweet potato), groundnut, bambara beans cowpea, pigeon peas, and fruits, etc., for domestic consumption and sale. But their definition of food security is usually framed around grain, the staple food. A farm family will say they are food secure if they can grow enough maize, sorghum or millet to feed themselves from one cropping season to the next.

If a mashamba (field) is infested and dominated by *Striga*, non or very low maize, sorghum and millet yields will be achieved, fact that highly contribute to the food insecurity for the farm families, and the immediately solution is to abandon the infested mashamba, even if it can still be productive for other crops (cassava, pigeon pea, groundnut, bambara beans, etc.).

The active and abandoned fields are geographically distributed on soils naturally of low fertility status, fact evidenced by their poor chemical properties. But, according to the soil and profile data analysis, they have good physical properties (texture, structure, internal drainage, porosity, root distribution, and biological activities - the last only observed in bush land profile). These soils can be continuously productive as the first year of a new mashamba if conservation agricultural management issues are well addressed.

In the region, some organic manures (guano, hyrax rocks, elephant, buffalo) are available. And the most confident and well located for its collection is "*bat guano*"; the chemical composition of it show high content of the most essential elements missing in these soil types for a promising plant growth, these elements are N-P-K. This guano can be effectively used in the demonstration plots (in active as well as in the abandoned mashambas).

The matching of other food and cash crop requirements and the biophysical conditions (soils & climate requirements) brought a number of alternative crops (nutrient-fixing-plants) that can significantly contribute to food security and natural soil fertility restoration; there is a need to interact with local farmers to fine tune the list and define the most appropriate crops to start with.

The *Faidherbia albida* is nutrient-fixing-tree species naturally present in the region although in a specific environment - riverine ecosystem of Lugenda, Mbamba and Nkuti alluvial valleys. And the climate is similar in the region where the active and abandoned mashambas are located.

[16] The Conclusions are based on the Summary tables presented (Summary: 1 up to 4) along this report.

For the long term of soil fertility restoration a regular plant spacing (10x10*m*) can effectively contribute to overcome the soil fertility decline problems.

A modified model on integrated management of *Striga* weed and stemborer on maize, sorghum and millet methodology, known as *"Planting and Management 'Push-Pull' fields for Striga weeds and stemborer control"* is the most appropriate and strategic tool to adopt since the active and abandoned mashambas (fields) are within the conservation wildlife habitats, and the use of chemical fertilisers, herbicides, and insecticides is not permitted.

7. WAY FORWARD

The two problems identified are: (i) soil fertility decline due to the poor chemical property composition of the soils in the areas where the fields are located, and (ii) incidence of *striga* attacking mainly the most staple food crops - cereals (maize, sorghum and millet) fact that highly contribute to food insecurity, thus, an implementation of integrated management based on low-cost and environmentally friend technology to control *striga* and improve soil fertility is a strategic way forward.

If this, is of a common consensus then a "modified Step-by-Step guide" has to be prepared to implement the pioneer field demonstration plots (on active and abandoned fields). The guide must list the needs in terms of:

1. Equipment and materials;
2. Manure (bat guano);
3. Land preparation;
4. Seeds and nursery preparation (*Faidherbia albida*);
5. Crop seeds and planting materials;
6. Planting the '*Push-Pull*' crops;
7. Weeding (*1st* and *2nd* stages);
8. Management of Napier grass (*pull*);
9. Management of *Desmodium* (*push*);
10. Harvesting the cereal crops / sowing lab-lab;
11. Harvesting and processing *desmodium* seed;
12. Field activities for the subsequent cropping season;
13. Use of harvested napier and desmodium for feeding animals; and
14. Others.

Let us have a 2017/2018 cropping season as a starting point to implement the demonstration plots in active and abandoned fields in Nkuti and Mbamba villages. The most important aspect of the demo plots is to get the essential data and information for a consolidated permanent agriculture with a background of preserving the native forest from being converted to agriculture through "s*lash-and-burn*".

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ANNEX 1: SOIL AUGER AND PROFILE DESCRIPTIONS

SOIL AUGER HOLE DESCRIPTION

SDBm Plus. FAO-CSIC Multilingual Soil Profile Database

Auger hole code: *NKuti01*	**Date**: 08-12-2016
Survey Area: L4-East - Concession;	**Coordinates**: 12° 13' 04.2 "S / 37° 54' 35.1" E
Location: Nkuti community	**Elevation:** (..)*m*
Authors: Jacinto Mafalacusser & Hugo Prereira.	
WRB 2006: *Rhodic Ferralsols*	**Topography**: Almost flat
Land use: Traditional rainfed	**Land form**: Plateau
Human influence: Land cleared	**Land element**: Interfluves
Crops: Maize, sorghum, millet, cowpea	**Position**: Top of interfluves
Vegetation: -	**Slope**: Direct
Species: -	**Micro topography**: nil
Grass cover: -	**Drainage**: moderate
Parent material: Sedimentary rocks	**Water table**: not observed
Effective soil depth: >1.20m	**Flood**: Non evidence
Rock outcrops: not observed	**Moisture conditions**: moist (0-60cm)
Surface stoniness: not observed	**Sealing/crusts**: not observed

Remarks: *First rains on two days before the sampling and moist down to 60cm soil depth. Two composed soil samples from the five subsamples collected around the soil auger hole were taken at 0-20cm; and 40-60cm soil depths. (Photo: Soil auger hole and description tools).*

Horizon	Depth (cm)	Description
Ap1	0-10	Dark-reddish-brown (5YR 3/3) moist; non mottles, loamy-sand; non sticky and non plastic in wet;
Ap2	10-40	Dark-red (2.5YR 3/6) moist; non mottles, sandy-loam; non sticky and non plastic in wet;
A/B	40-50	Red (10R 4/8) moist; non mottles, sandy-loam to sandy-clay-loam; slightly sticky and slightly plastic in wet;
Bt_1	50-70	Red (10R 4/8) moist; non mottles, sandy-clay-loam; slightly sticky and slightly plastic in wet;
Bt_2	70-120	Red (10R 4/8) moist; non mottles, sandy-clay-loam; sticky and plastic in wet;

Site view - Dry season *(December - 2016).*

Photo (upper side) - 8/12/2016: *The 2016/2017 cropping season had already started with direct seeding of maize, sorghum and cowpeas.* ***Photo (lower right corner)***: *locals witnessing the soil sampling at Nkuti01 site - active field (mashamba) opened in 2014 within the "Improved Beehive initiative" coordinated by Hugo Pereira (Mariri Envir. Centre).*	

<u>Site view - Wet season</u> (March, 2017)

Active mashamba in Nkuti village: mixed cropping system consisting of maize, sorghum, millet, cowpea, pumpkins, okra, and mono-cropping of cowpea, and cassava (some crops only near the homestead), bambara beans, groundnut and rice as mono crops. Below, a closer overlook into the crops and Striga infestation in the region.

- Poor soil cover, low moisture and nutrient retention, soil erosion by wind and rain (splash);
- Non or little arable soil layer building; and
- *Striga* (*asiatica* and *hermonthica*).

SOIL PROFILE DESCRIPTION

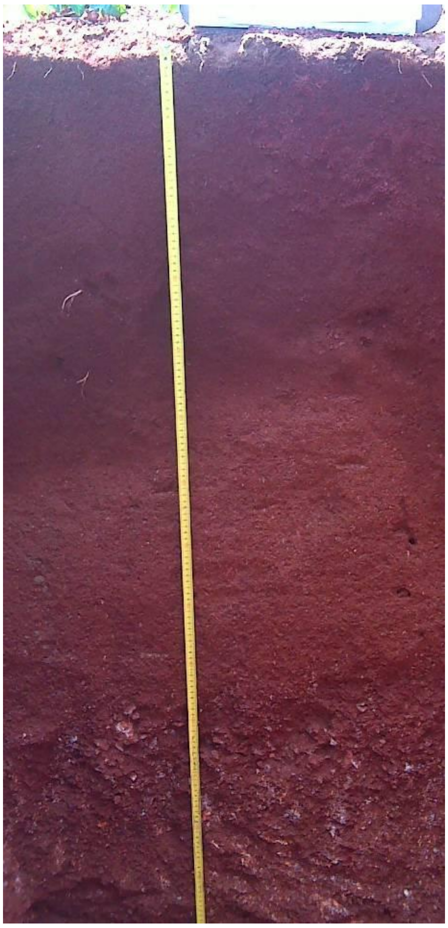
SDBm Plus. FAO-CSIC Multilingual Soil Profile Database

Soil Profile code: *NKuti01P*
Survey Area: L4-East - Concession;
Location: Nkuti community
Authors: Jacinto Mafalacusser & Hugo Pereira.
WRB 2006: *Rhodic Ferralsols*
Land use: Fallow
Human influence: Land cleared
Crops: Abandoned mashamba
Vegetation: -
Species: -
Grass cover: -
Parent material: Sedimentary rocks
Effective soil depth: >1.40m
Rock outcrops: Not observed
Surface stoniness: Not observed

Date: 09-12-2016
Coordinates: 12° 12' 57.0"S / 37° 55' 06.1" E
Elevation: (..)*m*
Topography: Almost flat
Land form: Plateau
Land element: Interfluves
Position: Top of interfluves
Slope: Direct
Micro topography: Irregular
Drainage: Moderate
Water table: Not observed
Flood: Non evidence
Moisture conditions: Moist (0-60cm)
Sealing/crusts: Not observed

Remarks: *Two composed soil samples from the five subsamples collected around the soil auger hole were taken at 0-20cm; and 40-60cm soil depths; and soil profile samples: (0-20; 20-50; 50-100; and 100-140cm); (Photo: Soil profile).*

Horizon	Depth (cm)	Description
Ap	0-20	Dark-reddish-brown (5YR 3/4) moist; non mottles, loamy-sand; weak fine to moderate blocky subangular structure; very friable in moist; non sticky, and non plastic; non coatings; non cementation or compaction; abundant fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine and medium roots; diffuse and plain boundary;
AB	20-50	Dark-reddish-brown (2.5YR 3/4) moist; non mottles, sandy-loam; weak fine to moderate blocky subangular structure; very friable in moist; non sticky, and non plastic when moist; non coatings; non cementation or compaction; abundant fine and medium voids; non rock fragments; non calcareous; common termite or



		ant channels; abundant very fine and many fine and medium roots; diffuse and plain boundary;
Bt_1	50-100	Red (10R 4/6) when dry, and when moist; slightly stick and slightly plastic when moist; non mottles; sandy-clay-loam; weak fine to moderate blocky subangular structure; very friable in moist; slightly sticky, and slightly plastic when moist; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine and medium roots; diffuse and plain boundary;
BC	50-70	Red (10R 4/6) when dry, and when moist; slightly stick and slightly plastic when moist; non mottles; sandy-clay-loam; weak fine to moderate blocky subangular structure; very friable in moist; slightly sticky, and slightly plastic when moist; non coatings; non cementation or compaction; common fine and medium voids; common to abundant, fine and medium, irregular and hard rock fragments of quartzite origin; non calcareous; non termite or ant channels; rare very fine, fine and medium roots.

Site view: ***Nkuti01P*** *- Abandoned mashamba (more than five years under fallow).*

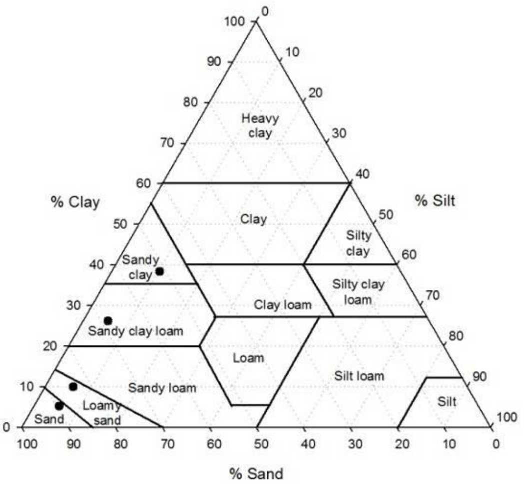
Very little and poor re-growth of emerging tree species

Termite mound - Biological activity a contribution to the soil fertility recovering.

Table 4: Analytical soil data for Soil Profile: Nkuti01P

Soil parameters	Soil depht (cm)			
	0-20	20-50	50-100	100-140
Sand (%)	89.4	84.0	68.5	51.4
Silt (%)	5.4	6.0	5.3	10.2
Clay (%)	5.2	10.0	26.2	38.4
Texture (class)	S	LS	SCL	SC
Organic matter (%)	<0.01	<0.01	<0.01	<0.01
Organic carbon (%)	-	-	-	-
Nitrogen (%)	0.06	0.05	0.03	0.08
C/N ratio	-	-	-	-
Phosphorous (ppm)	2.99	2.34	1.04	2.47
Calcium (meq $100g^{-1}$)	0.64	0.36	1.10	1.49
Magnesium (meq $100g^{-1}$)	0.00	0.28	1.10	1.57
Potassium (meq $100g^{-1}$)	0.10	0.09	0.21	0.55
Cat. Exch. Capacity (meq $100g^{-1}$)	1.31	0.86	2.47	3.76
pH-H_2O	6.5	6.2	6.0	5.7
pH-KCl	5.2	4.6	4.5	4.6
EC ($mScm^{-1}$)	0.05	0.05	0.03	0.07

Soil Textural classes



- ✓ the soil profile was sampled at four soil depths and from the textural soil diagram is noted a gradual increase of clayey particles with the soil depth, soil texture changing from the topsoil (sand, loamy-sand) to the subsoil (sandy-clay-loam and sandy-loam) - some leaching of nutrients may occur in the topsoil but there is a physical condition of nutrient and water retention in the subsoil;
- ✓ the organic matter content is low or just a trace of it throughout the soil profile;
- ✓ the N and P content in the soil profile is low to very low;
- ✓ very poor in exchangeable cations; and

slightly acid and; non saline and non sodic.

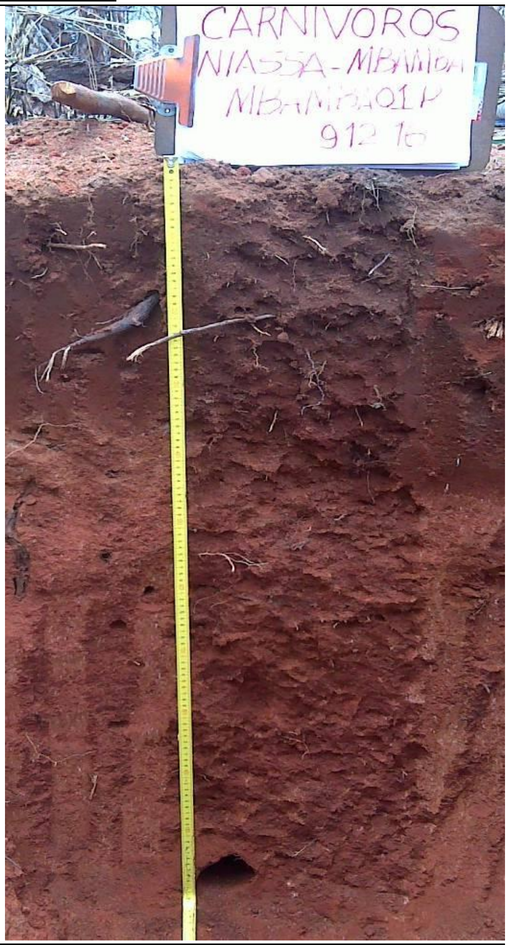
SOIL PROFILE DESCRIPTION

SDBm Plus. FAO-CSIC Multilingual Soil Profile Database

Soil Profile code: Mbamba01P
Date: 09-12-2016
Survey Area: L5-South - Concession;
Coordinates: 12^{o} 13' 22.2"S / 37^{o} 58' 22.0" E
Location: Mbamba community
Elevation: (..)*m*
Authors: Jacinto Mafalacusser & Hugo Pereira.
WRB 2006: *Rhodic Ferralsols*
Land use: Bush land
Human influence: Fire & Honey collection
Crops: Bushland
Vegetation: Open woodland
Species: -
Grass cover: Burned
Parent material: Sedimentary rocks
Effective soil depth: >1.40m
Rock outcrops: Not observed
Surface stoniness: Not observed
Topography: Almost flat
Land form: Plateau
Land element: Interfluves
Position: Top of interfluves
Slope: Direct
Micro topography: Irregular
Drainage: Moderate
Water table: Not observed
Flood: Non evidence
Moisture conditions: Moist (0-35cm)
Sealing/crusts: Not observed

Remarks: *Two composed soil samples from the five subsamples collected around the soil auger hole were taken at 0-20cm; and 40-60cm soil depths; and soil profile sampled at: (0-15; 15-35; and 35-110^{+}cm); (Photo: Soil profile).*

Horizon	Depth (cm)	Description
A	0-15	Dark-reddish-brown (5YR 3/3) moist; non mottles, loamy-sand to sandy-loam; weak fine to moderate blocky subangular structure; very friable in moist; non sticky, and non plastic; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine, many fine and medium roots; diffuse and plain boundary;
A/B	15-35	Dark-reddish-brown (5YR 3/4) moist; non mottles, sandy-clay-loam; weak fine to moderate blocky subangular structure; very friable in moist; non slightly sticky, and slightly plastic



		when moist; non coatings; non cementation or compaction; abundant fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine and medium roots; diffuse and plain boundary;
Bt_1	$35\text{-}110^+$	Reddish-brown (2.5YR 4/4) when dry, and dark-reddish-brown (2.5YR 3/4) when moist; slightly stick and slightly plastic when moist; non mottles; sandy-clay-loam; medium and moderate blocky subangular structure; very friable in moist; sticky, and slightly plastic when moist; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine and medium roots.

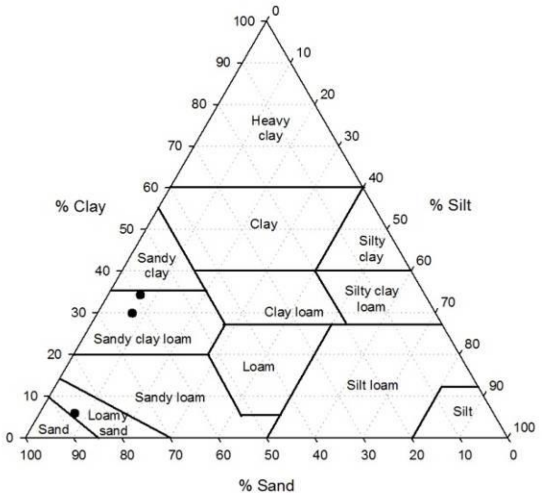
*<u>Site view</u>: <u>**Mbamba01P**</u> - Bush land. Open woodland*

<u>Upper left and right</u>, *the pictures were taken at the Mbamba01P soil profile*.

<u>Lower right</u>, *the picture was taken nearby (≤300m) the Mbamba01P soil profile. Beehive (Honey had already be collected) <u>Tree species</u>: Afzelia quazensis, evidence of burning.*

Table 5: Analytical soil data for soil profile: Mbamba01P

Soil parameters	Soil depht (cm)		
	0-15	15-50	50-110
Sand (%)	86.8	62.9	59.0
Silt (%)	7.3	7.2	6.7
Clay (%)	5.9	29.9	34.3
Texture (class)	LS	SCL	SCL
Organic matter (%)	0.85	<0.01	<0.01
Organic carbon (%)	0.49	-	-
Nitrogen (%)	0.03	0.07	0.08
C/N ratio	16.3	-	-
Phosphorous (ppm)	2.47	1.17	1.77
Calcium (meq $100g^{-1}$)	1.92	1.88	2.60
Magnesium (meq $100g^{-1}$)	0.18	0.00	0.54
Potassium (meq $100g^{-1}$)	0.11	0.57	0.47
Cat. Exch. Capacity (meq $100g^{-1}$)	5.50	2.54	3.72
pH-H_2O	6.3	6.3	6.4
pH-KCl	5.5	4.7	4.7
EC ($mScm^{-1}$)	0.06	0.04	0.03



- ✓ the soil profile was sampled at three soil depths and from the textural soil diagram is noted a gradual increase of clayey particles with the soil depth, soil texture changing from the topsoil (loamy-sand) to the subsoil (sandy-clay-loam) - some leaching of nutrients may occur in the topsoil but there is an opportunity of nutrient and water retention in the subsoil;
- ✓ the organic matter content is low on the topsoil and just a trace of it in the subsoil;
- ✓ the N and P content throughout the soil profile is low to very low;
- ✓ very poor in exchangeable cations; and
- ✓ slightly acid and; non saline and non sodic.

SOIL PROFILE DESCRIPTION

SDBm Plus. FAO-CSIC Multilingual Soil Profile Database

Soil Profile code: *Mbamba02P*
Survey Area: L5-South - Concession;
Location: Mbamba Community
Authors: Jacinto Mafalacusser & Hugo Pereira.
WRB 2006: *Rhodic Ferralsols*
Land use: Bush land
Human influence: Fire & Honey collection
Crops: Abandoned mashamba
Vegetation: Regeneration of tree species
Species: Local names[17];
Grass cover: 20% including "*Striga*"
Parent material: Sedimentary rocks
Effective soil depth: >1.40m
Rock outcrops: Not observed
Surface stoniness: Not observed

Date: 23-03-2017
Coordinates: 12° 11' 48.8"S / 38° 00' 00.7" E
Elevation: (..)*m*
Topography: Almost flat
Land form: Plateau
Land element: Interfluves
Position: Top of interfluves
Slope: Direct
Micro topography: Irregular
Drainage: Moderate
Water table: Not observed
Flood: Non evidence
Moisture conditions: Moist (0-35*cm*)
Sealing/crusts: Not observed

Remarks: *Two composed soil samples from the five subsamples collected at surrounding of the soil profile were taken at 0-20cm; and 40-60cm soil depths; and the soil profile was sampled at: (0-15; 15-45; 45-78; 78-110; and 110-140cm); (Photo: Soil profile).*

Horizon	Depth (cm)	Description
Ap1	0-15	Dark-reddish-brown (2.5YR 3/2) when moist; non mottles, loamy-sand to sandy-loam; weak fine to moderate blocky subangular structure; very friable in moist; non sticky, and non plastic; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine, many fine and medium roots; diffuse and plain boundary;
Ap2	15-45	Dark-reddish-brown (2.5YR 3/3) when moist; non mottles, sandy-loam; weak fine to moderate blocky subangular structure; very friable in moist; non slightly sticky, and slightly plastic when moist; non coatings; non cementation or compaction; abundant fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine and medium roots; diffuse and plain boundary;
B/A	45-78	Dusky red (10R 3/4) when moist; very friable; slightly stick and slightly plastic when moist; non mottles; sandy-loam; medium and moderate blocky subangular structure; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine and medium roots.
Bt_1	78-110	Weak red (10R 4/4) when moist; very friable; stick and slightly plastic when moist; non mottles; sandy-clay-loam; medium and moderate blocky subangular structure; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous;

[17] ***Local names***: *N'chenga; M'pissavago; M'piruo; Ngongo; Ntalala, Nsondoka*. grass: *N'tchissundi* and *Xikungulu* ("*Striga*").

		common termite or ant channels; abundant very fine and many fine and medium roots.
Bt_2	110-140	Dark red (10R 3/6) when moist; very friable; stick and slightly plastic when moist; non mottles; sandy-clay-loam; medium and moderate blocky subangular structure; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine and medium roots.
B/C	$140\text{-}155^{+}$	Red (10R 4/6) when moist; very friable; slightly stick and slightly plastic when moist; non mottles; sandy-loam; medium and moderate blocky subangular structure; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine and medium roots.

*<u>Site view</u>: **<u>Mbamba02P</u>** - Abandoned mashamba (2007), near the Mbamba village.*

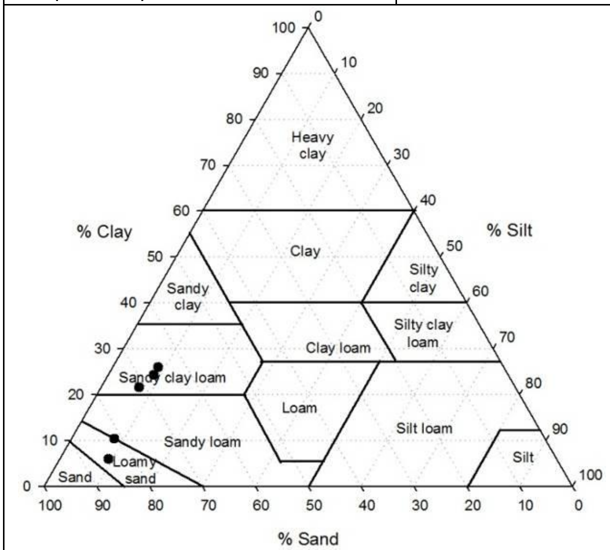
***a)** Soil Profile site.*

***b)** "<u>Striga</u>" in abandoned mashamba after 10 years (2007)!*

***c)** Re-growth/regeneration of some shrub and tree species in the abandoned mashamba - year 2007.*

Table 6: Analytical soil data for soil profile Mbamba02P - abandoned mashamba (in 2007).

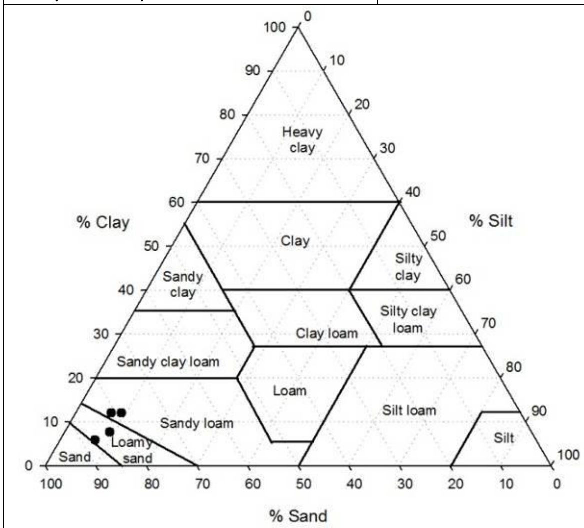
	Sampled soil depths				
Soil parameters	0-15	15-45	45-78	78-110	110-140
Sand (%)	84.8	81.5	71.2	64.5	67.8
Silt (%)	9.2	8.1	7.2	8.6	8.6
Clay (%)	6.0	10.4	21.6	26.0	24.3
Texture (class)	LS	LS	SCL	SCL	SCL
Organic matter (%)	0.62	0.11	0.19	0.15	0.13
Organic carbon (%)	0.36	0.06	0.11	0.09	0.08
Nitrogen (%)	0.14	0.04	0.06	0.09	0.08
C/N ratio	2.57	1.5	1.8	1.0	1.0
Phosphorous (ppm)	0.67	0.22	0.56	0.45	0.56
Calcium (meq $100g^{-1}$)	1.70	1.88	1.62	0.96	1.50
Magnesium (meq $100g^{-1}$)	0.38	0.56	0.34	0.64	0.36
Potassium (meq $100g^{-1}$)	0.16	0.14	0.10	0.18	0.24
Sodium (meq $100g^{-1}$)	0.16	0.18	0.14	0.18	0.18
∑ Exch. bases (meq $100g^{-1}$)	2.40	2.76	2.20	1.96	2.28
pH-H_2O	6.3	6.6	6.5	6.7	6.5
pH-KCl	5.5	5.1	5.1	5.2	5.2
EC ($mScm^{-1}$)	0.04	0.02	0.03	0.02	0.03



- ✓ the soil profile is similar to the previous and it was sampled a four soil depths the textural soil diagram, also shows a gradual increase of clayey particles with the soil depth, soil texture changing from the topsoil (loamy-sand) to the subsoil (sandy-clay-loam) - some leaching of nutrients may occur in the topsoil but there is an opportunity of nutrient and water retention in the subsoil;
- ✓ the organic matter content is low on the topsoil and just a trace of it in the subsoil;
- ✓ the N and P content throughout the soil profile is low to very low;
- ✓ very poor in exchangeable cations; and
- ✓ slightly acid and; non saline and non sodic.

Table 7: Analytical soil data for composed soil samples from active and abandoned mashambas

Soil parameters	Nkuti (active mashamba)		Mbamba (abandoned mashamba)	
	0-20cm	40-60cm	0-20cm	40-60cm
Sand (%)	87.2	80.9	83.4	78.9
Silt (%)	6.9	7.0	8.9	9.0
Clay (%)	5.9	12.1	7.7	12.1
Texture (class)	LS	SL	LS	SL
Organic matter (%)	0.57	0.05	0.34	0.22
Organic carbon (%)	0.33	0.03	0.20	0.13
Nitrogen (%)	0.63	0.08	0.12	0.05
C/N ratio	0.52	0.34	1.67	2.60
Phosphorous (ppm)	2.92	1.33	0.93	0.80
Calcium (meq $100g^{-1}$)	2.9	2.3	1.38	1.54
Magnesium (meq $100g^{-1}$)	0.52	0.84	0.26	0.36
Potassium (meq $100g^{-1}$)	0.14	0.26	0.12	0.14
Sodium (meq $100g^{-1}$)	0.08	0.14	0.08	0.14
∑ Exch. bases (meq $100g^{-1}$)	3.64	3.54	1.84	2.18
pH-H_2O	6.4	6.6	6.5	6.4
pH-KCl	6.3	6.5	5.9	5.6
EC ($mScm^{-1}$)	0.03	0.02	0.01	0.01



- ✓ the four composed soil samples taken in Nkuti (active mashamba) and Mbamba (abandoned mashamba) are loamy-sand textured at 0-20*cm* soil depth and gradually change to sandy-loam at 40-60*cm* soil depth. These soils have a good physical properties and can hold moisture and nutrient in the subsoil due to the gradual increase of clay content;
- ✓ poor to very poor in chemical nutrient content;
- ✓ moderate to slightly acid;
- ✓ Non saline and non sodic.

SOIL PROFILE DESCRIPTION

SDBm Plus. FAO-CSIC Multilingual Soil Profile Database

Soil Profile code: *Mbamba03P*
Survey Area: L5-South - Concession;
Location: Mariri Env. Centre
Authors: Jacinto Mafalacusser; H. Pereira; and Euzébio.

Date: 23-03-2017
Coordinates: 12° 11' 45.1"S / 38° 00' 00.9" E
Elevation: (..)*m*

WRB 2006: *Eutric Fluvisols*
Land use: Bush land
Human influence: Fire & Honey collection
Crops: NA
Vegetation: Wooded grassland
Species: Dominated by *Faidherbia albida*
Grass cover: 80% including
Parent material: Sedimentary rocks
Effective soil depth: >1.40m
Rock outcrops: Not observed
Surface stoniness: Not observed

Topography: Almost flat
Land form: Mbamba river valley
Land element: Terrace
Position: Middle of the terrace
Slope: Direct
Micro topography: Irregular
Drainage: Moderate to imperfect
Water table: Not observed
Flood: Annual
Moisture conditions: Moist (0-132$^+$cm)
Sealing/crusts: Not observed

Remarks: *Two composed soil samples from the five subsamples collected at surrounding of the soil profile were taken at 0-20cm; and 40-60cm soil depths; and the soil profile was sampled at: (0-14; 21-47; 47-62; 62-71; and 86-110cm); (Photo: Soil profile - under F albida tree canopy).*

Horizon	Depth (cm)	Description
I	0-14	Very-dark-gray (10YR 3/1) when moist; non mottles, silt-clay; weak fine to moderate blocky subangular structure; very friable in moist; sticky, and plastic; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine, many fine, medium, and coarse roots; clear and plain boundary;
II	14-21	Dark-brown (10YR 3/3) when moist; non mottles, coarse sand; massive structure; very friable in moist; non slightly sticky, and non plastic when moist; non coatings; non mottles; non cementation or compaction; abundant fine and medium voids; non rock fragments; non calcareous; few termite or ant channels; abundant very fine and many fine, medium and coarse roots; clear and plain boundary;
III	21-47	Black (10YR 2/1) when moist; very friable; very stick and very plastic when moist; common fine and medium, diffuse grayish mottles; silt-clay; medium and moderate blocky subangular structure; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine, medium and coarse roots; clear and plain boundary;

IV	47-62	Yellowish-brown (10R 5/4) when moist; very friable; non sticky and non plastic when moist; non mottles; sandy; massive; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine, medium and coarse roots; clear and abrupt boundary;	
V	62-71	Black (10YR 2/1) when moist; very friable; very stick and very plastic when moist; common fine and medium, diffuse on pedfaces grayish mottles; clay; medium and moderate blocky subangular structure; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine, medium and coarse roots; clear and plain boundary;	
VI	71-86	Yellowish-brown (10R 4/3) when moist; very friable; non sticky, and non plastic when moist; non mottles; sandy; massive; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine, medium and coarse roots; clear and abrupt boundary;	
VII	86-110	Very-dark-gray (10YR 3/1) when moist; very friable; very stick and very plastic when moist; common fine and medium, mottles; sandy-clay-loam; medium and moderate blocky subangular structure; non coatings; non cementation or compaction; common fine and	

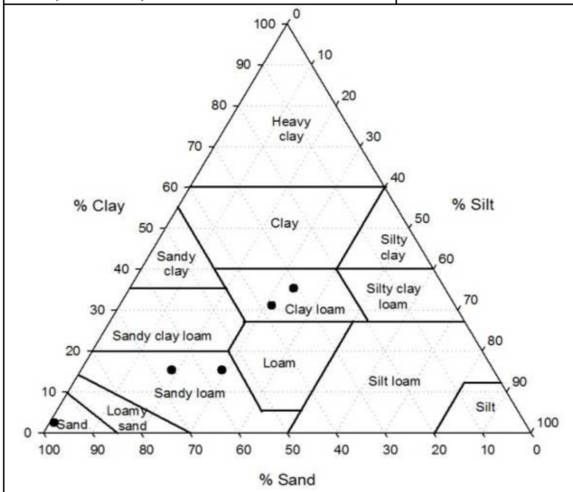
		medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine, medium and coarse roots; clear and plain boundary;
VIII	110-120	Brown (10R 5/3) when moist; very friable; non sticky, and non plastic when moist; non mottles; sandy; massive; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine, medium and coarse roots; clear and abrupt boundary;
IX	120-132^{+}	Very-dark-gray (10YR 3/1) when moist; very friable; very stick and very plastic when moist; common fine and medium, diffuse grayish mottles; sandy-clay-loam; medium and moderate blocky subangular structure; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine, medium and coarse roots.

<u>Site view</u>: **<u>Mbamba03P</u>** - *(Faidherbia albida)* - Soil Profile site, under canopy of the tree.

Photos: *Mbamba alluvial river valley - Riverine ecosystem, open woodland dominated by the "Faidherbia albida" - (shaded) and few others tree species mainly of Fabaceae family. The grass cover is estimated to > 80% of Panicum maximum.*

Table 8: Soil profile Mbamba03P - under *Faidherbia albida* - Mbamba riverine ecossystem.

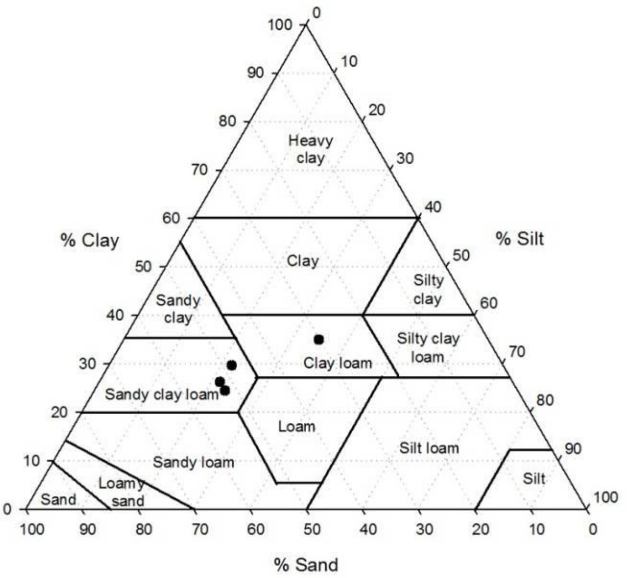
Soil parameters	Sampled soil depths				
	0-14	21-47	47-62	62-71	86-110
Sand (%)	55.7	31.0	96.6	37.6	66.0
Silt (%)	28.9	33.6	0.9	31.2	18.6
Clay (%)	15.4	35.4	2.5	31.2	15.4
Texture (class)	SL	CL	S	CL	SL
Organic matter (%)	5.56	2.06	0.19	2.36	0.34
Organic carbon (%)	3.22	1.19	1.37	0.11	0.20
Nitrogen (%)	0.46	0.14	0.03	0.19	0.15
C/N ratio	7.00	8.50	45.6	0.57	1.33
Phosphorous (ppm)	0.34	5.39	4.72	10.10	19.42
Calcium (meq $100g^{-1}$)	26.50	22.70	1.10	21.60	8.38
Magnesium (meq $100g^{-1}$)	0.40	0.50	1.56	0.80	0.42
Potassium (meq $100g^{-1}$)	2.08	0.50	0.06	0.48	0.28
Sodium (meq $100g^{-1}$)	1.32	0.44	0.08	0.38	0.20
∑ Exch. bases (meq $100g^{-1}$)	30.30	24.14	2.80	23.26	9.28
pH-H_2O	6.4	6.4	6.5	6.2	6.4
pH-KCl	5.4	5.0	5.1	4.8	4.8
EC ($mScm^{-1}$)	0.16	0.04	0.02	0.04	0.02



- ✓ the soil profile is located under tree canopy of *Faidherbia albida*, it is a typical soil profile of alluvial environment with clear stratification of recent sediment net deposits; the soil texture varies (alternatively) from pure sand to sandy-loam and clay-loam;
- ✓ in the alluvial environment the heavy textured layers within the soil profile are, in general, very rich in nutrients compared to lighter textured soil layers, the organic matter content varies from 0.19 to 5.56% throughout the soil profile, which highly contribute to the biological activity; and
- ✓ the nutrient status balance in this site is *very high* when compared to the mineral soils occurring in Nkuti and Mbamba areas.

Table 9: Soil samples taken under & outside canopy of *Faidherbia albida* tree species.

Soil parameters	Under canopy of *F. albida*		10*m* away from canopy of *F. albida*	
	0-20*cm*	40-60*cm*	0-20*cm*	40-60*cm*
Sand (%)	30.2	48.4	52.4	52.2
Silt (%)	34.8	21.9	23.3	21.5
Clay (%)	35.0	29.7	24.5	26.3
Texture (class)	CL	SCL	SCL	SCL
Organic matter (%)	4.13	1.97	3.03	1.80
Organic carbon (%)	2.40	1.14	1.78	1.04
Nitrogen (%)	0.38	0.16	0.17	0.19
C/N ratio	6.31	7.13	10.47	5.47
Phosphorous (ppm)	25.78	16.34	32.69	12.89
Calcium (meq $100g^{-1}$)	18.86	17.94	13.96	18.84
Magnesium (meq $100g^{-1}$)	3.04	0.56	0.54	0.76
Potassium (meq $100g^{-1}$)	1.24	0.56	0.68	0.40
Sodium (meq $100g^{-1}$)	0.90	0.42	0.46	0.32
∑ Exch. bases (meq $100g^{-1}$)	24.04	19.48	15.63	20.32
pH-H_2O	6.0	6.4	6.0	6.4
pH-KCl	5.2	5.1	5.4	5.3
EC ($mScm^{-1}$)	0.11	0.04	0.10	0.06



- ✓ the soil texture variation between topsoil (0-20*cm*) samples - clay-loam (under tree canopy) and sand-clay-loam (10*m* away from the tree) was because site location - the last was much closer to the river channel; and the soil texture of both soil samples at 40-60*cm* is sandy-clay-loam;
- ✓ in general the nutrient balance is slightly high under *F. albida* canopy compared to 10*m* away from it, two aspects can help to explain this:
    - short distance between sampling site locations where wind would influence the spreading of tree leaves; and
    - both sampled sites are located on the alluvial valley seasonally subject to flooding.
- ✓ the soils nutrient status in this environment are extremely high when compared to those soils in active and abandoned mashambas and bush lands in Nkuti and Mbamba areas.

SOIL PROFILE DESCRIPTION

SDBm Plus. FAO-CSIC Multilingual Soil Profile Database

Soil Profile code: *Mariri01P**
Date: 23-03-2017

Survey Area: L5-South - Concession;
Coordinates: 12° 10' 40.5"S / 38° 05' 34.3" E

Location: Garden (Mariri Env. Centre)
Elevation: (..)*m*

Authors: Jacinto Mafalacusser; H. Pereira; and MEC staff team.

WRB 2006: *Eutric Fluvisols*
Topography: Gently undulating

Land use: Bush land/Garden
Land form: Lugenda river valley

Human influence: Garden and Camping
Land element: Levee

Crops: Vegetables / Riverine ecosystem
Position: Levee (top) - 5-7*m* away of riverbed,

Vegetation: Wooded grassland
Slope: Direct

Species: Mainly Fabaceaes
Micro topography: Irregular

Grass cover: 20% including trees & shrubs
Drainage: Moderate to imperfect

Parent material: Sedimentary rocks
Water table: Not observed

Effective soil depth: >1.40m
Flood: Annual (March and April).

Rock outcrops: Not observed
Moisture conditions: Moist (0-132^{+}cm)

Surface stoniness: Not observed
Sealing/crusts: Not observed

Remarks: *The soil profile was sampled at: (0-15; 15-30; 30-50; 50-70; and 70-90cm); (Photo: Soil profile, MEC staff team and the garden - fresh vegetables; - Mariri, local initiatives).*

Horizon	Depth (cm)	Description
I	0-15	Dark-brown (10YR 3/3) when moist; few, faint, diffuse brownish mottles; silt-clay-loam; weak fine to moderate blocky subangular structure; very friable in moist; sticky, and plastic; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine, many fine, medium, and coarse roots; clear and plain boundary;
II	15-30	Dark-yellowish-brown (10YR 4/4) when moist; few, faint, diffuse grayish mottles, silt-clay-loam; fine to medium, moderate subangular structure; friable in moist; stick and plastic when moist; non coatings; slight cementation or compaction; abundant fine and medium voids; non rock fragments; non calcareous; few termite or ant channels; abundant very fine and many fine, medium and coarse roots; clear and plain boundary;
III	30-50	Brown (10YR 5/3) when dry, grayish-brown (10YR 5/2) when moist; very friable; few to common, faint, fine and medium grayish mottles; clay; slightly hard and firm (when dry), friable; stick and plastic (when moist) medium and moderate blocky subangular structure; non coatings; non cementation or compaction; common fine

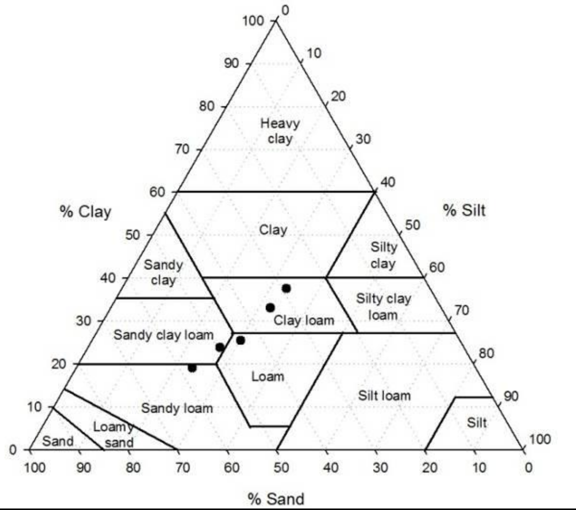
		and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine, medium and coarse roots; diffuse and plain boundary;
IV	50-70	Grayish-brown (2.5Y 5/2) when dry, dark-olive-brown (2.5Y 3/3) when moist; hard, firm (when dry), sticky and plastic when moist; common, faint, fine and medium grayish mottles; clay; non coatings; non slightly cementation or compaction; few fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine, medium and coarse roots; diffuse and irregular boundary;
V	70-90	Very-dark-grayish-brown (2.5Y 3/2) when dry, very-dark-gray (2.5Y 3/1) when moist; slightly hard, firm (when dry) friable, stick and plastic when moist; clay; common fine and medium diffuse grayish mottles; medium and moderate blocky subangular structure; non coatings; slightly cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine and many fine, medium and coarse roots; diffuse and irregular boundary;
VI	90-100	Dark-gray (2.5Y 4/1) when dry, very-dark-gray (2.5Y 3/1) when moist; slightly hard, firm, very friable; slightly sticky, and slightly plastic when moist; common fine and medium diffuse grayish mottles; clay; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine, medium and coarse roots; clear and abrupt boundary;
VII	90-120$^+$	Grayish-brown (2.5Y 5/2) when dry, gray (2.5Y 5/1) when moist; very friable, slightly stick and slightly plastic when moist; silty-clay-loam; very stick and very plastic when moist; common fine and medium diffuse grayish mottles; clay; non coatings; non cementation or compaction; common fine and medium voids; non rock fragments; non calcareous; common termite or ant channels; abundant very fine, medium and coarse roots.

Site view: ***Mbamba03P*** - Soil profile site near the Mariri centre garden.

Photos: *Upper row*: soil profile site location and the MEC team busy on soils data collection near the Mariri garden (organic vegetable production) & *Lower row*: some of the vegetables organically grown and consumed locally.

Table 10: Profile Mbamba03P - under tree canopy of *Faidherbia albida*.

Soil parameters	Sampled soil depths 0-15	15-30	30-50	50-70	70-90
Sand (%)	57.4	49.4	44.4	34.6	29.1
Silt (%)	23.5	26.7	30.1	32.3	33.3
Clay (%)	19.1	23.9	25.5	33.1	37.6
Texture (class)	SL	SCL	L	CL	CL
Organic matter (%)	0.31	0.95	0.22	1.02	0.49
Organic carbon (%)	0.18	0.55	0.13	0.59	0.28
Nitrogen (%)	0.13	0.10	0.11	0.13	0.13
C/N ratio	1.38	5.50	1.18	4.54	2.15
Phosphorous (ppm)	9.43	6.06	22.57	13.02	6.26
Calcium (meq $100g^{-1}$)	11.86	14.20	16.35	18.20	14.80
Magnesium (meq $100g^{-1}$)	0.84	0.60	1.85	0.40	2.00
Potassium (meq $100g^{-1}$)	0.16	0.14	0.16	0.26	0.34
Sodium (meq $100g^{-1}$)	0.66	1.20	1.54	1.96	2.24
∑ Exch. bases (meq $100g^{-1}$)	13.52	16.14	19.90	20.82	19.38
pH-H_2O	6.9	7.4	7.5	8.2	7.7
pH-KCl	5.1	5.3	5.8	6.0	5.6
EC ($mScm^{-1}$)	0.09	0.16	0.36	0.28	0.27



- ✓ the process of sediment net deposition within alluvial ecosystem is dynamic and mostly vary within a short distance, the profile near Mariri centre garden shows a gradual and regular enrichment of clay with the soil depth throughout the soil profile, there is not stratification of soil layer although located a few meters to Lugenda river flow

- ✓ the fertility status balance measured throughout the sum of the exchangeable bases and phosphorous content is *high* compared to the mineral soils on active and abandoned mashambas and bushlands in Nkuti and Mbamba areas, but relatively *low* to those of under tree canopy and nearby *Faidherbia albida*.

ANNEX 2: CLIMATE

The sampled area has no climatic recording station. The nearest station is located at Mecula-sede Village which is approximately 90 kilometres? west of the sampled area. The station has a comprehensive data for at least 10 years (1971-1981). Rainfall data and other climatic data for the region can be found in the "assessment of land resources for rainfed crop production in Mozambique" (Kassam, *et al.*, 1981) report. At the Mariri centre a rain gauge was installed recently and as a result the data recorded was not used in the long term climatic analysis.

The area has two distinct climatic seasons a wet season from the end of November to April (heavy rains starts in December) and a dry season from May to October and has an annual average temperature of 24.5°C. The annual mean rainfall within the region is 1,418.4mm, potential evapotranspiration of about 1,345.3mm, and the mean relative humidity of 69.6%.

Precipitation

The rainfall in the sampled area, like in most parts of the northern Mozambique occurring East of Rift Valley, is controlled by the North-South movement of the inter tropical convergence zone and is under the influence of the equatorial low pressure zone with NE monsoon in the warm season.

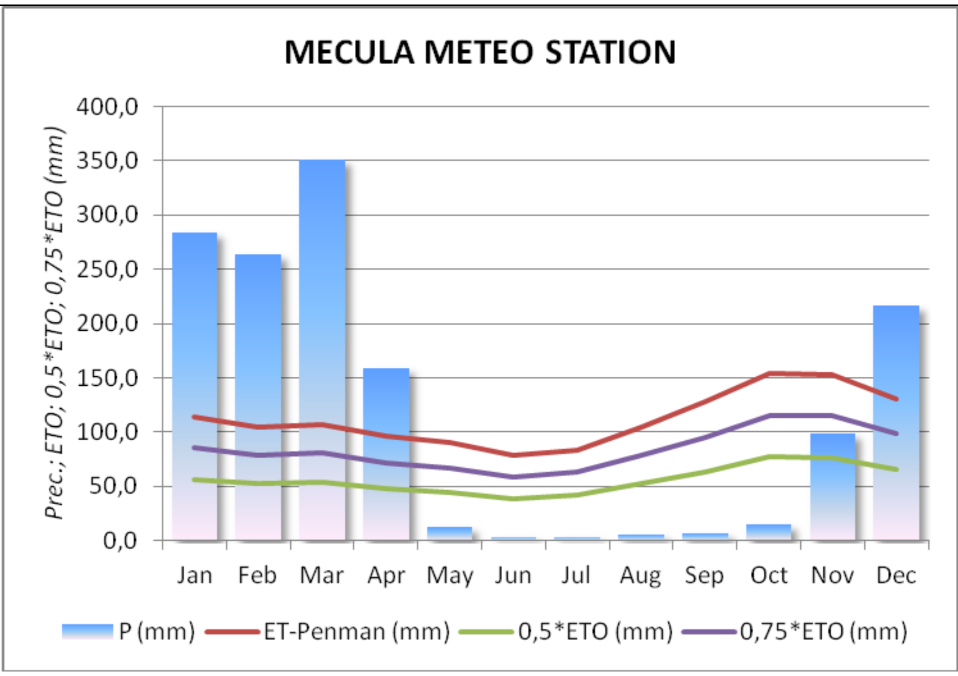


Figure 2: Water balance and the length of growing period, Mecula meteo station.

Note: A clear distinction between two seasons (wet and dry) and a well defined length of growing period of more than 150 days makes the region climatically suitable for many annual food crops and well defined the dry period for *Faidherbia albida* plantation.

The rainfall is mainly restricted to the warm season November/December and April. According to the climatic classification of Köppen, the northern and coastal regions of Mozambique have a tropical rain savanna climate with well defined two seasons: warm and rainy (November to April) and cool and dry (May to October).

The annual rainfall at the reference climatic station (Mecula) is 1,418.4 mm. The warm and rainy season accounts for 1,371.9mm representing 96,7% of total precipitation. But the heavy rains are concentrated from later December to early April where more than 1,273.5mm (90%) of rain falls. The dry season in the region is between May and October with an accumulated 46,5mm which corresponds to less than 4% of the annual precipitation.

The accumulated evapotranspiration in the region is about 1,345.3mm. In monthly basis is higher from May to November compared to the rainfall and it becomes lower from December to April fact that makes water available in the soil meaning that soil moisture is present at a time when conditions are suitable for plant growth.

The rainfall and evapotranspiration distribution pattern along the year in the region show a perfect combination that climatically suits better conditions for intensive annually food crop growing and the establishment of perennial *"inverted"* phenology species with nutrient-fixing-plant (NFP) properties, (e.g. *Faidherbia albida* intercropped with soybean, pigeon pea, lablab, sunflower, sesame, etc., with common crops grown in the region maize, sorghum, millet and cow peas).

Temperature

The general trend is interrupted and influenced by the altitude. The reference data recorded at Mecula (620 m.a.s. l.), indicates that the average annual temperature is 24.5^{o}C; the maximum is 29.6^{o}C and the minimum is 19.4^{o}C. The hottest months are October and November with 32,0 and 32,8^{o}C; respectively. The coolest months are June and July with absolutely low temperatures of 16.1 and 15.9^{o}C, respectively.

ANNEX 3: NUTRIENT-FIXING CROPS AND PLANTS

Soya bean (*Glycine max*)

Family: Leguminosae (Papilionoideae);
Other names: soy, soya bean; feijão soja (Portuguese); soja (Spanish).

General
The soya bean is of major importance as a source of oil and relatively high quality protein for human and livestock feeding; it contains all the essential amino acids required by man. The seeds contain 16-24 per cent oil and 30 per cent crude protein.
Botany and propagation
It is erect legume 60-100 cm tall. The leaves have three leaflets which they shed at maturity stage. Small white or purple flowers grow in bunches from the leaf axils. Pods are short, hairy and brown. Seeds are of different colours and sizes. It is grown from seed.
Climate and soil
Soya bean is indigenous to the warm temperate or sub-tropical regions but is now grown extensively from the Tropics to about 52^{o}C attitude north or south. Heat resistant and less photo-sensitive varieties are grown in humid Tropics. In equatorial regions maturation occurs in about 90 days and all times of the year daylength seems to be below the critical level for flowering of photo-sensitive types. Soya bean grows best on rich sandy loam soils.
Cultivation and management
In the humid and sub-humid tropics, seeds are sown at a spacing of 45 by 15 cm at rates of 40-60 kg per hectare at a depth of about 2 cm. Lime should be applied on acid soils; 15-30 kg per hectare of phosphorous and 25-40 kg of potassium per hectare are also given. Yields of up 2 tonnes of dry seeds per hectare and 20 tonnes of green forage per hectare can be expected. After harvest, soya bean is threshed and dried; it is stored at about 12 percent moisture.
Protection
The most serious pest is bean fly (*Ophiomyia phaseoli*). Spraying with an insecticide such as diptrex will effect control. Other pests are pod borers, blister beetles and leaf-eating caterpillars. Diseases caused by bacteria are bacterial blight, leaf pustule and stem blight. Fungal diseases are wild fire, downy mildew and frog-eye spots; spray with fungicides to control. Virus disease are soybeans mosaic and yellow bean mosaic. Organic piri-piri tea spray to be tested on soya bean (*Tomás, take a note and action!!!*).

Pigeon peas (*Cajanus cajan*)

General
Pigeon peas are short lived perennial legumes. They have deep woody tap roots. Their stems, which also became woody, may grow as high as 3.5 m. The leaves are trifoliate with narrow leaflets. The flowers are usually yellow but are sometimes red, orange or a mixture of these colours. The pods contain up to eight seeds but 4-6 are more common; there are marked depressions in the pods between each seed.
Ecology
Pigeon peas are drought resistant. They grow between sea level and 1,500 m but are sometimes found as high as 2,100 m. Any free draining soil is suitable.
Cultivation and management
They can be usually intersown with finger millet or maize; they remain in the field after the millet and maize have been harvested and sesame or cowpeas are often sown amongst them in the following year. The soacing recommended for pure stands is 1.5x1.2 m or 1.8x1.8 m. Harvesting can begin about five months after sowing and may continue for a further six months or for several years. The harvesting is done either by picking individual pods or by cutting off the bearing branches. Sometimes the branches are dried in the field; sometimes they are taken to the homestead for drying. Yields are usually 450-670 kg ha-1 annum-1 but with good husbandry they should be at least 1,100 kg ha-1 annum-1.
Pests & diseases
A root mealy bug may occurs and build up in to the soil to such extent that fields have to be rested from pigeon peas for several years. The yields of pigeon peas are seldom seriously reduced by diseases. An exception is the incidence of *Fusarium* wilt.

Cowpea *(Vigna unguiculata, or Vigna sinensis)*

Family: Leguminosae (Papilionoideae)
Other names: black-eye pea or bean, marble pea, China pea, southern pea, tonkin bean, paayap, kibil.

General

Cowpeas are a dual leguminous crop. In most areas they are grown more for their leaves than for seeds; this is especially true where rainfall is high and seed production, because of insect damage , is low.

Botany and propagation

Cowpeas are an annual crop. Varieties may be spreading , semi-upright or erect in growth habitat. Their flowers may be purple, pink, white, blue, or yellow. The pods of most varieties hang downwards but in some varieties they point sideways or upwards. The seeds may be white, cream-coloured purple, brown, mottled brown or black. In most cases the percentage of cross-pollination is only about 2%. The duration of the cropdepends largely on the growth habitat, the rainfall and local practices but it is seldom more than five or six months.

Climate and soil

The cowpea originated in tropical Africa and is found now all over the Tropics and sub-tropics. It requires warm conditions and only give good yields of seed below about 1,500*m*. They are drought resistant and can give better yields in drought conditions than beans (*Phaseolus vulgaris*). They can grow on most soils provided they are well drained.

Cultivation and management

Most cowpeas are intersown with other food crops. Pure stands are sometimes established near the homesteads for their leaves. Experiments have shown that within reasonable limits spacing has no significant effect on seed yields; spacing of 0.6m x 0.3m strikes a reasonable balance between economising with seed and obtaining a sufficiently rapid cover to suppress weeds, and guarantee moisture retention in sandy spoils. Generally, pods are produced three to five months after planting. Yields of up to 2,500 kg of dry seed per hectare can be obtained in the humid Tropics.

Protection

Fungus diseases attacking cowpea are cowpea wilt (*Fusarium oxysporum*) and charcoal rot (*Sclerotium bataticola*). Other disease are cowpea mosaic due to a virus spread by bean leaf-beetle, and root-knot nematodes. The most serious pest is cowpea curculio (*Chalcodermus aenus*). Bean flies damage sedlings; they may be controlled with insecticides, (*Thomas if it happen, then try the piri-piri!!!!*).

Utilisation

Leaves are usually crushed, fried and then boiled although they may simply be boiled. They are sometimes dried and ground into powder which can be stored for later consumption. The seeds may be boiled with maize or boiled in their pods. Alternatively their seed coats may be removed, after which they are boiled or fried to make a pasture or sauce which can be eaten with "*xima*; *sadza* or *ugali*".

Sesame (Sesamum indicum)

Family: Pedaliaceae

General

Sesame is a flowering plant in the genus *Sesamum*, also called benne. It is widely naturalized in tropical regions around the world and is cultivated for its edible seeds, which grow in pods or "buns". Sesame seed is considered to be the oldest oilseed crop known to humanity. Its seeds have an oil content of 45-55%. With a rich, nutty flavor, it is a common ingredient in cuisines across the world.

Botany and propagation

Sesame is an annual plant growing 50 to 100cm tall, with opposite leaves 4 to 14cm long with an entire margin; they are broad lanceolate, to 5cm broad, at the base of the plant, narrowing to just 1cm broad on the flowering stem. The flowers are yellow, tubular, 3 to 5cm long, with a four-lobed mouth. The flowers may vary in color, with some being white, blue, or purple.

Sesame seed occur in many colours depending on the cultivar. The most traded variety of sesame is off-white coloured. Other common colours are buff, tan, gold, brown, reddish, gray, and black.

Sesame fruit is a capsule, normally pubescent, rectangular in section, and typically grooved with a short, triangular beak. The length of the fruit capsule varies from 2 to 8*cm*, its width varies between 0.5 and 2*cm*, and the number of loculi varies from f4 to 12*cm*. The fruit naturally splits open to release the seeds by splitting along the septa from top to bottom or by means of two apical pores, depending on the varietal cultivar.

Sesame seeds are small. Their size, form, and colours vary with the thousands of varieties now known. The seeds are ovate, slightly flattened, and somewhat thinner at the eye of the seed than at the opposite end. The weight of the seeds is between 20 to 40*g*.

Climate and soil

Sesame is moderately drought resistant; this is especially true of branching varieties because these have a more prolific root system. At least 400-500*mm* of rain are needed during the growing season. It can still be capable of growing in areas which receive an average rainfall of only 625*mm* per annun. Moist conditions are needed during the early stages of growth but heavy rain immediately after sowing may do considerable damage by washing away many of the seeds or by capping the soil surface, thus preventing emergence of many of small seedlings. It only grows well in warm climate and from sea level up to 1,500*m* of altitude. Most varieties are photoperiod sensitive, and do best in all soils but very intolerant of water logging.

Cultivation and management

A rough seedbed is usually preferred for sesame despite the small size of the seeds. The reason for this is that a fine seedbed is more likely to form a cap if heavy rain falls, thus hindering emergence of the seedlings.

Sesame must be sown as early in the rains as possible; it can sometimes be sown in the first rains, usually as a pure stand, or may be sown amongst pigeon peas after the finger millet has been harvested from a mixture of pigeon peas and millet. Alternatively it may be inter-sown with maize or sorghum.

Sesame is usually broadcast at a rate of 5.5-9.0 kg ha^{-1}, it is often mixed with soil before in order to achieve an even spread. Thinning is often neglected, if it is done the remaining pants should be 23-25*cm* apart. Sowing in rows is rare but very much recommended; if it is done, the optimum population is 170,000-200,000 plants ha^{-1}.

Sesame grows slowly at the beginning stage and it is very intolerant of competion from weeds when it is young.

At harvesting sesame time there are two highly recommended actions to observed:

- The capsules split and shed their seeds when they are mature and they ripen unevenly from the bottom upwards. If harvesting is delayed until the top capsule is ripe, the lower ones split and the wind blows the plants about so much that most of the seed is shed. It is therefore essential to harvest the plants as soon as the lowest capsules ripen;
- The plants are then stoked or tired to a fence. The fences are as high as 3m, and are usually built parallel to the prevailing wind to prevent them being blown over. After three or four weeks all the capsules should have matured. the seeds are removed by beating the plants on a mat.

Yields are usually 220-330 kg ha^{-1}.

Protection

Sisame webworm (*Antigastria catalaunalis*), the larvae of this pest spin a silken web around the terminal leaves and eat the foliage and pods; Gall midge (*Asphondylia sesami*), these minute insects lay their eggs in the ovaries of the flowers. When the larvae hatch they devour the inside of ovaries and in place of capsules round barren galls are produced; and, Flea beetle (*Aphthona bimaculata*), this is the most important pest for the crop, it eats the foliage during the early stages of growth.

Sunflower *(Helianthus annuus)*

Family: Asteraceae

General

Sunflowers are annuals which grow from 0.6 to 4.5m high, depending on the variety. They have strong tap roots with dense surface mats of feeding roots. The stems are seldom branched and bear large ovate leaves. The flowers are often more than 0.3m in diameter and have yellow petals. Plants flower three to four months after planting and take a total 3 and half to 6 months to mature, depending on the variety.

Climate and soil

Sunflowers are very drought resistant, possibly because of their deep tap roots, and grow well in areas which receive an annual rainfall of 750mm or more. For best yields they need a reasonable rainfall during the three or four weeks that coincide with flowering. It is important that there should be dry weather during ripening otherwise the heads rot. Sunflowers can be grown from sea level up to 2,600m. Any soil that will produce a good crop of maize is suitable for sunflower.

Cultivation and management

The optimal plant population is from 32,000 to 42,000 plants per hectare, these populations can be achieved by spacing of 0.75x0.4*m* and 0.75x0.3*m*. It is necessary to weed sunflowers only until the crop is about 0.9m high; after this stage weeds are suppressed by shading.

Protection

Pests: Birds are the main pests. The American bollworm (*Heliothis armigera*), sometimes damages the developing seeds.

Diseases: Rust - this disease is caused by the fungus *Puccinia helianthi*. It is the most serious disease of sunflowers. Small lesions on the leaves produce red pustules on the lower surfaces. Leaf spots and white blister - these are caused, respectively, by the fungi *Septonia helianthi* and *Cystopus tragopogonis*. The cause, respectively, brown leaf spots and white leaf blisters. Root and stem rot - these are caused by Sclerotinia spp. The main symptom is wilting; the stems and heads contain a black fungus. Healthy seed, crop rotations and destruction of crop residues should prevent outbreaaks.

Lablab *(Lablab purpurea)*

Family: *Fabaceae*

<u>*General*</u>

Lablab is a dual-purpose legume. It is traditionally grown as a pulse crop for human consumption. Flowers and immature pods also used as a vegetable. It is also used as a fodder legume sown for grazing and conservation in broad-acre agricultural systems in tropical environments with a summer rainfall. Also used as green manure, cover crop and in cut-and-carry systems and as a concentrate feed. It can be incorporated into cereal cropping systems as a legume ley to address soil fertility decline and is used as an intercrop species with maize to provide better legume/stover feed quality. As a dual purpose (human food and animal feed) legume, it is sown as a monoculture or in intercrop systems.

<u>*Climate and soil*</u>

Grows in a wide range of soils from deep sands to heavy clays, provided drainage is good, and from pH 4.5-7.5. Low salinity tolerance with symptoms being chlorotic leaves, reduced growth and plant death. Lablab does not always nodulate well with native strains of rhizobia. Nevertheless it is recommended to be sown with the appropriate lablab rhizobia strain.

Adapted to annual rainfall regimes of 650-3,000*mm*. Drought tolerant when established, and will grow where rainfall is <500*mm*, but loses leaves during prolonged dry periods. Capable of extracting soil water from at least 2 metres depth even in heavy textured soils. Will tolerate short periods of flooding but intolerant of poor drainage and prolonged inundation.

Grows best at average daily temperatures of 18-30°C and is tolerant of high temperatures. Able to grow at low temperatures (down to 3°C) for short periods. More tolerant of cold than either *Mucuna pruriens* or cowpea (*Vigna unguiculata*). Will grow at altitudes from sea level to elevations of up to 2,000 m asl in tropical environments.

<u>*Cultivation and management*</u>

Percentage of hard seed is very low and no scarification is required. Complete cultivation is used for lablab monocultures with seeding rates of between 12 and 20 kg ha^{-1}. Rows should be 80-120*cm* apart, with 30-50*cm* between plants. Seed can be planted to a depth of 3-10*cm*. Will establish readily when sown into subsurface moisture to a depth of at least 7-10*cm*. When planted with grasses, seed rates should be 5-8 kg ha^{-1}. Will not establish readily into existing pastures without some form of soil disturbance. Provided seed is of good quality, germination should be rapid and uniform as commercial cultivars have soft seed and require no scarification .

<u>*Protection*</u>

The pod boring insect *Adisura atkinsoni* can reduce seed yields but has been controlled experimentally by strain HB-III of *Bacterium cereus* var. *thuringensis*. Other insect pests include *Heliothis armigera*, *Exelastis atomosa* and *Maruca testulalis*. Bruchid beetles (*Callosobruchus* spp.) damage seed during growth and storage. Lablab roots are attacked by several nematodes: *Helicotylenchus dihystera*, *Meloidogyne hapla* and *M. incognita*. Anthracnose (caused by *Colletotrichum lindemuthianum*), leaf-spot (caused by *Cercospora dolichi*) and powdery mildew (caused by *Leveillula taurica* var. *macrospora*) have been reported. A stem rot caused by *Sclerotinia sclerotiorum* may attack the plant under wet conditions. In Australia, cultivar Rongai is fairly disease-free and generally lablab is more tolerant to root diseases than cowpeas.

A Million Trees-A-Year: Community Markets for Conservation (COMACO) Formula for Saving an Ecosystem - *"Successes histories of community land management for conservation"*

Full History:

Charcoal-making continues to threaten the Luangwa Valley watershed, one of the major environmental challenges COMACO is confronting. Deforestation by people who make charcoal is a growing land management problem. Zambia now has one of the top 5 worst deforestation problems in the world.

Annual deforestation rate has increased from 0.9% from 1990-2000 to a current 1% per year due to slash-and-burn agriculture and illegal charcoal production. Total CO_2 emissions are increasing from 1,883,000 metric tons in 2000 to 2,446,000 metric tons in 2005 (the last available data year). Firewood production trends peaked in 1995 and have stayed consistently high at over 7 million meter3 per year. High electricity tariffs have pushed many urban people to use charcoal instead of electricity, while many rural people simply don't have access to electricity.

COMACO's efforts to preserve the Luangwa Valley ecosystem and protect its life-giving functions for this premiere wildlife area continue to grow. With its expanding market presence in rural communities on both the west and eastern regions of the Valley, COMACO is able to offer more and more farmers better income and food security by supporting conservation. The underlying strategy is to help farmers remain more stationary and avoid the need to clear forests to replace depleted farmland every few years.

COMACO will scale up these efforts in the coming year by embarking on a planting campaign of one million *Faidherbia albida* trees on farm plots across the Valley landscape and adding such valuable assets like bee hives to their farming ecology.

Faidherbia albida is a thorny tree growing up to 6-30 m tall and 2 m in the trunk diameter. Its deep-penetrating tap root makes it highly resistant to drought; its wood can be used for canoes, pestles, and for firewood. The wood has a density of about 560 kg/m^3 at a water content of 12%. The energy value of the wood as fuel is 19.741kJ/kg.

It is also used for nitrogen fixation, erosion control for crops, for food, drink and medicine. unlike most other trees, it shed its leaves in the rainy season; for this reason, it is highly valued in agro forestry as it can grow among field crops without shading them. The tree is known having medicinal value in the treatment of respiratory infections, malaria and fevers. The bark is employed in dental hygiene and its extract is employed in the treatment of toothache. The extract has also been used to treat ocular infections in farm animals.

In the warm soils this tree grows fast. In about 5-6 years, the tree becomes a source of free nitrogen fertilizer for farmers who plant them in well-laid out rows where crops are grown on both sides, boosting yields by over 50%. Not only is *Faidherbia albida* a great nitrogen fixer, as the tree matures, it is also an excellent source of nectar for honey bees, since its flowers provide bee forage at the close of the rainy season, when other tree or crops flowers are past their prime. In the years ahead, farmers will be able to earn a double income from these trees; premium price for soil management credits and for honey converted to its Wild!

Over next several years, COMACO registered farmers will plant 100 *Faidherbia albida* seedlings per hectare of existing farmland, until the entire Luangwa Valley is transformed into a higher food-yielding and sustainable farm system, one that allows more space for both trees and wildlife. Just as exciting is COMACO's strategy to give more value to trees for people who produce honey, especially with the use of a new bee hive design that boosts production of both honey and queen bees and has the potential of dramatically increasing honey production for rural farmers all across the Valley. Pushing these two efforts to give more impact and help in conserving the Valley's ecosystem is COMACO's market prices that reward farmers for successful survivorship of *Faidherbia albida* seedlings and maintaining large firebreaks around the bee apiaries.

Hundreds of transformed poachers live in areas where *Faidherbia albida* grows naturally. These ex-poachers will collect and sell seeds to COMACO for the tree nurseries that each farmer will establish, COMACO extension staff will train participating farmers on tree nursery management and tree planting methods. After the growing season, extension staff visits farmers to validate seedling survivorship. A validation earns the farmer a 15% top-up on his commodity market price when selling farm surplus to COMACO.

Recent successes land management include:

- Farmers in Mfuwe were rewarded by trade bonuses for planting over 30,000 *Faidherbia albida* trees;
- 100s of honey producers received trade bonuses for maintaining firebreaks around their forested apiaries;
- 8,000 bee hives have provided alternative income to charcoal making to thousands of households, adding economic value to living forests;
- Over 8 million woody plants planted as part of agroforestry interventions to promote food security.

Keeping trees safe and soils fertile, COMACO's markets are giving Nature a chance to work and sustain better lives for rural farmers in Luangwa Valley.

ANNEX 4: SOIL ORGANIC MATTER AND ITS ROLE ON PLANT GROWTH

ORGANIC MATTER

Healthy soil is the foundation of the food system. It produces healthy crops that in turn nourish people. Maintaining a healthy soil demands care and effort from farmers because farming is not benign. By definition, farming disturbs the natural soil process including that of nutrient cycling - the release and uptake of nutrients.

Plants obtain nutrients from two natural sources: organic matter and minerals. Organic matter includes any plant or animal material that returns to the soil and goes through the decomposition process. In addition to providing nutrients and habitat to organisms living in the soil, organic matter also binds soil particles into aggregates and improves the water holding capacity of soil. Most soil contain 2-10 percent organic matter. However, even in small amounts, organic matter is very important.

Soil is a living, dynamic ecosystem. Healthy soil is teeming with microscopic and larger organisms that perform many vital functions including converting dead and decaying matter as well as minerals to plant nutrients. Different soil organisms feed on different organic substrates. Their biological activity depends on the organic matter supply.

Nutrient exchanges between organic matter, water and soil are essential to soil fertility and need to be maintained for sustainable production purposes. Where the soil is exploited for crop production without restoring the organic matter and nutrient contents and maintaining a good structure, the nutrient cycles are broken, soil fertility declines and the balance in the agro-ecosystem is destroyed.

Soil organic matter - the product of on-site biological decomposition - affects the chemical and physical properties of the soil and its overall health. Its composition and breakdown rate rate affect: the soil structure and porosity; the water infiltration rate and moisture holding capacity of soils; the diversity and biological activity of soil organisms; and plant nutrient availability. Many common agricultural practices, especially ploughing, disc-tillage and vegetation burning, accelerate the decomposition of soil organic matter and leave the soil susceptible to wind and water erosion. However, there are alternative management practices that enhance soil health and allow sustained agricultural productivity.

Conservation agriculture encompasses a range of such good practices through combining no tillage or minimum tillage with a protective crop cover and crop rotations. It maintains surfaces residues, roots and soil organic matter, helps control weeds, and enhances soil aggregation ant intact large pores, in turn allowing water infiltration and reducing runoff and erosion. In addition to making plant nutrients available, the diverse soil organisms that thrive in such conditions contribute to pest control and other vital ecological processes.

Soil organic matter content is a function of organic matter inputs (residues and roots) and litter decomposition. It is related to moisture, temperature and aeration, physical and chemical proprties of the soils as well as bioturbation (mixing by soil macrofauna), leaching by water and humus stabilization (organomineral complexes and aggregates). Land use management practices also affects soil organic matter.

Farming systems have tended to mine the soil for nutrients and to reduce soil organic matter levels through repetitive harvesting of crops and inadequate efforts to replenish nutrients and restore soil quality. This decline continues until management practices are improved or until a fallow period allows a slow and gradual recovery through natural ecological processes. Only carefully selected diversified cropping systems or well-managed mixed cropping systems are able to maintain a balance in nutrient and organic matter supply and removal.

Farmers can take many actions to maintain, improve and rebuild their soils, especially soils that have been under cultivation for a long time. A key to soil restoration is to maximize the retention and recycling of organic matter and plant nutrients, and to minimize the losses of these soil components caused by leaching, runoff and erosion. However, rebuilding soil quality and health through appropriate farming practices may take several years, especially in seasonally dryland areas where limited moisture reduces biomass production and soil biological activity. Thus, the challenge is to identify soil management practices that promote soil organic matter formation and moisture retention and ensure productivity and profitability for farmers in the short term.

Soil organic matter content is a key issue and it contribute substantially to the cation exchange capacity in the soil. From the soil analysis of the three sites it is clearly shown that the abandoned mashambas have a trace of <0.01% of organic matter content on 0-20cm soil depth compared to the active mashambas with 0.26% and the bush land with 0.69%. The abandoned mashambas and bush land had shown, at sampling time, flesh signs of burning of vegetation and the active mashamba had very little crop residues of previous crop on the soil surface (see the photos in ANNEX 1).

It is also known that repeated burning of crop residues or forests depletes the soil of organic matter and biological activity falls as the food supply to soil biota is reduced. The ways which fires modify the soil nutrients are complex. The interrelations and their durations are not easily monitored in terms of cause and effects. The main processes are: 1) transformation of nutrients from organic to inorganic forms, (2) nutrient transfers to atmosphere in smoke (volatilisation), (3) erosion of ash and nutrient-rich surface soil, (4) change in nitrogen-fixing systems, (5) modification of decomposition rates of litter and soil organic matter.

ANNEX 5: STRIGA WEED - "WITCHWEEDS" BRIEF DESCRIPTION

Family: Orobanchaceae

Common Names: Witchweeds, red witchweed, Asiatic witchweed, buri, common mealiewitchweed, isona weed, Matabele flower, mealie poison, mealie witchweed, scarletlobelia, yaa mae mot;

Synonyms: *Buchnera asiatica* L., *Striga hirsuta* Benth., *Striga coccinea* Benth., *Striga lutea* Lour., *Striga parvula* Miq., *Striga pusilla* Hochst., *Striga spanogheana* Miq., *Striga zangebarica* Klotzsch.

Primary Crop Hosts: Maize (*Zea mays*), rice (*Oryza sativa* L.), sorghum (*Sorghum* spp.), millets (*Pennisetum* spp., *Panicum* spp., *Eleusin* spp., *Digitaria* spp., etc), sugarcane (*Saccharum* spp.)

Striga sp., is amongst the world's worst weeds (Holm *et al*. 1997), reducing the value of grain crops, particularly in Africa. *Striga asiatica* is an obligate parasite, drawing moisture, nutrients and photosynthate from its graminoid host plants. Host plants are typically subsistence crops, including maize, sorghum, rice, and sugarcane. It is typically found in dry, infertile soils in semi-arid tropical grasslands and savannahs (Cochrane and Press 1997). Thus, its effects are disproportionately felt by poor farmers on marginal lands. *Striga* spp. are prolific seed producers. The fine dust-like seed (20,000-50,000 per plant) can last more than 15 years, and consequently, eradication and control attempts are extremely difficult and prolonged. A striga germinates, its roots grow towards the host crop. They penetrate that crop's roots and start to draw nutrients from the host. This causes severe stunting of the host crop and yield loss.

As with other *Striga* spp., *Striga asiatica* reduces crop yields by extracting water, nutrients (particularly nitrogen), and photosynthate from the root system of its host plant, resulting in stunting and yield reduction (Musselman, 1980). If maize plants are attacked by both stemborers and striga weeds, the yield loss is often 100%. In East Africa, there are two common species of the witchweed, *Striga asiatica* and *striga hermonthica*. The mots affected crops are maize, sorghum, rice, sugarcane and millet. When a farm is infested with *striga*, the affected plants seldom grow more than 30cm tall. The weed does not put roots into the soil so as to grow on its own, but grows by attaching itself onto the host (e.g. maize, sorghum or millet.

Taking into account the peculiar nature of *Striga* seeds, farmers are advised to control it before the weed emerges above the soil (almost impossible!!!). The reason for this is that by time it emerges, much of the damage to the host crop will have been already caused.

Although various control methods have been proposed, they are usually not successful. For example, manual removal of the *striga* reduces re-infestation, it is considered uneconomical since most damage is done even before the weed emerges. Therefore, any control strategy has to begin within soil.

Striga asiatica is an annual obligate hemiparasite of monocotyledonous plants. It reproduces by seed, producing tens of thousands of minute seeds per plant (Musselman and Parker, 1981). The seeds are quite cold-tolerant, able to withstand prolonged storage at -7^{o}C (Patterson 1990). However, the minimum temperature for germination is relatively high 20^{o}C and the optimum temperature for growth appears to be approximately 32^{o}C (Patterson *et al,* 1982). Raynal-Roques (1987) notes that *S. asiatica* can withstand temporary water-logging.

ANNEX 6: CONTROL OF STRIGA WEEDS AND STEMBORER USING A 'PUSH-PULL' STRATEGY

The International Centre of Insect Physiology and Ecology (ICIPE) and partners have developed an effective, low-cost and environmentally friend technology known as *'push-pul'* for the control of stemborers and suppression of striga weeds in maize and sorghum. It is a simple cropping system strategy, whereby farmers use Napier grass and desmodium legume (silverleaf and greenleaf desmodium) as intercrops.

Desmodium is planted in between the rows of maize or sorghum. It produces a smell or odour that stemborer moths do not like. The smell *'pushes'* away the stemborer moths from maize or sorghum crops.

Napier grass (*Pennisetum purpureum*) is planted around the maize or sorghum crops as a trap plant. Napier grass is more attractive to stemborer moths than maize and it *'pulls'* the moths to lay their eggs on it. But napier grass does not allow stemborer larvae to develop on it. When the eggs hatch and the small larvae bore into Napier grass stems, the plant produces a stick subsistence like glue which traps them, and they die. So, very few stemborer larvae survive and the maize is saved because of the 'push-pull' strategy.

In addition, a ground cover of desmodium (*Desmodium uncinatum*, or silverleaf), interplanted among the maize, reduces striga weed. Research has shown that chemicals produced by the roots of desmodium are responsible for suppressing the striga weed. Therefore, striga does not grow where desmodium is growing. Being a legume, desmodium also fixes nitrogen in the soil and thus acts to enrich the soil.

According to the Khan, F.N. (2007), some of benefits on adopting a *"push-pull"* strategy are:

- increasing maize or sorghum yield by 25-30% in the areas where stemborers are the only problem. Where both stemborers and striga are problems, maize and sorghum can double the yields;
- increasing the supply of feed from harvesting Napier grass and desmodium;
- fixing nitrogen into farmer's soil by desmodium legume rather than using mineral fertilisers;
- protecting soil from wind and splash erosion, as desmodium acts as a cover crop;
- retaining soil moisture, as desmodium acts as mulch;
- earning money from the sale of desmodium seed at an attractive price in the region since the problem is widely affecting the entire reserve and neighbouring areas;
- saving on farm labour, as there will be not or less need for manually remove of striga weed from the farms.

ANNEX 7: DESMODIUM & NAPIER GRASS

DESMODIUM UNCINATUM, DESMODIUM INTOTUM

Desmodium is a genus in the flowering plant family Fabaceae, sometimes called tick-trefoil, tick clover, hitch hikers or beggar lice. Several *Desmodium* species contain potent secondary metabolites. They are used aggressively in agriculture in push-pull technology. Tick-trefoils produce high amounts of antixenotic allomones, chemicals which repel many insect pests, and allelopathic compounds which kill weeds. For example, *Desmodium intortum* and *Desmodium uncinatum* are employed as groundcover in maize and sorghum fields to repel *Chilo partellus*, a stem-boring grass moth. They also suppress witchweeds such as Asiatic witchweed (*Striga asiatica*) and purple witchweed (*Striga hermonthica*).

Tick-trefoils are generally useful as living mulch and as green manure, as they are able to improve soil fertility via nitrogen fixation. Most also make good fodder for animals including bobwhite, turkey, grouse and deer.

Soil requirements**:** it is adapted to a wide range of soils, from sands to clay loams; is productive on red basaltic loams and on gleyed podzolics (Mears *et al.,* 1964) . It is not as successful on sands as D. intortum. Does well on soils with an open texture and not so well on compact heavy clays. Will grow at pH 5.0 (Andrew and Bryan, 1958), do well at pH 5.5 to 6.5 and grow up to pH 7.0. Anderson and Naveh (1968) stated that it was fairly tolerant of soil acidity in Tanzania. Does not tolerate salinity (Andrew and Robins, 1969).

Sowing methods: sow using a drill, ground broadcasting, aerial seeding or sod-seeding. Some seed cover after sowing is desirable. Very little success has been achieved by oversowing into existing pastures. Sow in early summer at the rate of 2.2 kg ha^{-1}, no deeper than 1*cm* (Suttie and Ogada, 1967). Number of seeds per kg: 198,000 to 220,000.

Temperature requirements: summer-growing perennial, starting growth early in the spring. Whiteman (1968) found the optimum temperature for growth to be 30/25°C. It wilts during the high temperatures of summer (Douglas and Luck, 1964). It is fairly cold-tolerant (Huang, 1967). Whiteman and Lulham (1970) put the growth minimum at about 15°C. Ludlow and Wilson (1970) found that *Desmodium uncinatum* at 20°C yielded 23 percent of the dry matter it yielded at 30°C, 42 percent of the relative growth rate and had 14 percent of the leaf area. It is susceptible to frosts but more tolerant than siratro. Heavy frosts affect the tops, but in warm weather the plant recovers quickly (Huang, 1967).

Pests: it can be severely damaged by the Amnemus weevil (*Amnemus quadrituberculatus*), the adults of which feed on the foliage in summer and the larvae on the root tissue in winter.

NAPIER GRASS *(PENNISETUM PURPUREUM)*

Napier grass (*Pennisetum purpureum*) is the most high-yielding of all the perennial tropical grasses. It is fibrous compared to other perennial forage grasses such as Guinea grass (*Panicum maximum*) and Guatemala grass (*Tripsacum laxum*) when allowed to grow for more than about 50 days. At this age it has a digestible nutrient content of about 60% and a fibre content of 30-35%. Napier is used for producing dried grass pellets for compounding animal feeds and for fresh forage production

Botany: it is a perennial grass producing large shoots and is only moderately tillering. Consequently it tends to form tussocks, or when planted in rows to maintain itself in the rows without colonising the spaces between the rows. Napier grass is best planted from stem cuttings that sprout rapidly from the nodes. Initially tillering occurs and after a time, with repeated cutting, a massive stool of shoot stalks will form from which new tillers develop following each cut. After a cut, or on establishing cuttings, predominantly leafy growth occurs for about the first 30 days. Although growth will continue for more than 100 days under good conditions, growth rate declines sharply after about 70 days and the best and highest yield of forage is obtained with cutting frequencies in the range 50-70 days.

Climate and soil: Very high yields may be obtained in the tropics from climatically-adapted strains with high sunshine levels. Napier requires good drainage and yields poorly in heavy soils. Root growth in friable soils is vigorous and roots will follow the water-table over a dry period.

Cultivation and management: Napier should be grown in rows 1m apart which will permit cultivation between the rows. O free-draining soils planting should be on the flat. Cuttings up to three nodes should be sown in furrows about 6cm deep to end. Longer cuttings should not be used because they will bend upwards at the nodes and become exposed. Under good conditions Napier will take about 4 months to establish with cuts at about 50 days. Management involves weeding and cultivation in inter-row areas.

Harvesting and processing: For feeding to livestock such as cattle and goats, napier should be cut between 50 and 70 days. Yields in excess of 60 ton ha-1 of dry material or 300 ton ha-1 of fresh forage may be obtained under good physical conditions. When napier is used for producing grass pellets for non-ruminants (poultry and pigs) cuts should be made at 4weeks intervals and yields will be only half the above rates. For four-week cuts a closer row spacing of 60cm is recommended.

Protection: napier is extraordinarily free of serious pests and diseases. Occasional leaf-spot fungi infect the crop to a minor extent and certain varieties are susceptible to a die-back virus.

ANNEX 8: Soil Analysis and Recommendations - ToRs

Duration: 10 days field work + 2 days report writing
Name of Consultant: Jacinto M. Mafalacusser
Reporting to: Collen Begg
Location: Mariri Environmental Centre, L5-South

Overall Task
The overall task will be to provide specific recommendations based on wet and dry season soil analysis of abandoned fields in Mbamba Village of ways to recover fertility of these areas and suitable crops that can be grown in these areas for alternative livelihoods.

Overview
Mbamba village is a large community (ca 2000 people in south eastern Niassa National Reserve. Their main activities are subsistence slash and burn agriculture, hunting and fishing. Food security is low and people have few alternative livelihoods. The soils are naturally infertile (Miombo woodland) and crops are limited by very long dry season from March to December. Increasing habitat conversion through slash and burn agriculture is a major risk to the protected area as the human population inside Niassa Reserve grows. Conservation of wildlife habitats relies on us finding alternative livelihoods for people inside Niassa Reserve (about 40,000 people) and increasing food security. Fields tend to become infertile after 5-7 years. They are then abandoned and new fields are opened. The area covered by mashambas in Mbamba Village has grown substantially in the past 15 years with new areas opened every year. However, other areas inside the electric fence have been abandoned and never reused. These areas are the focus of this consultancy.

We have been working with the Village through a farmer field school to encourage mixed cropping, low tillage, mulching to increase the time active fields remains fertile and increase production and food security. This program is ongoing. However, a problem remains of how to reclaim abandoned fields and find a productive use for those areas.

We wish to:

a) Identify nutrients missing in abandoned, fallow fields;
b) recover the soil through natural fertilisers or other means;
c) Plant these areas with alternative crops that can produce food or income for the community on a sustainable basis.

Consultancy - Outputs

1. Soil samples taken in the dry season (November 2016 and wet season - March 2017) in abandoned fields, currently occupied fields and natural bush both in the dry season and wet season inside Mbamba Village.

2 Analysis and clear interpretation of soil analysis to let us know what is missing in these soils and provide practical recommendation on how these soils can be improved. These recommendations should not involve of chemical fertilizers as

this is against conservation objectives but should investigate use of natural fertilizers and crops that can recover soils.

3. Expert recommendations on what crops can be grown in these fields (once they have been treated) and given soil structure and type., climate and local conditions. These recommendation should be focused on crops that can generate food and/or alternate livelihoods for the village. These could be fruits, medicinal, food, crops for oil (sesame) etc.

4. A full digital report provided by 30 April 2017 without jargon that provides us with practical advice on way forward as well as detailed analysis of the soil with summary of results. The focus must be on the abandoned fields not the current crop techniques as we have already received a lot of guidance on the cropping methods.