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EVALUATION OF THE SOIL AND WATER CONDITIONS OF SMALLHOLDER COMMUNITIES IN PAPUA NEW GUINEA

Masterarbeit

zur Erlangung des akademischen Grades

Diplomingenieur

eingereicht von:

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CONTENT

Abstract

In Papua New Guinea extreme climatic events such as the El Niño Southern Oscillation phenomenon (ENSO) pose a significant threat to food security. It is believed that the impacts of climate change in Papua New Guinea are mainly related to the ENSO phenomenon, whereas an increase of this event would bring more or longer droughts or periods of heavy rainfall. Consequently this exacerbates the problem of food insecurity especially in rural areas where a high percentage of the population practices subsistence farming. To overcome this problem, agricultural management strategies need to be adapted or new technological options for rural farmers developed. On that account an investigation of the soil and water conditions of two pilot areas has been conducted in the course of the present master thesis. The pilot communities were both located in the highlands of Papua New Guinea, whereas one was in an area of high rainfall and therefore suffered from excess soil moisture and the other lied in a seasonally dry area that suffered from deficit soil moisture. The soils of the selected areas were surveyed during March and April 2012 and analysed in terms of their physical and chemical properties.

It was found that the soils of the dry site were clay soils of non volcanic origin with very low hydraulic conductivities and moderate compaction. Furthermore they were less acidic, had higher contents of exchangeable bases and lower contents of organic matter compared to the soils from the wet site. A common characteristic of the soils from both sites was a deficit in potassium. At the dry site, the situation of local farmers could be improved through soil moisture conservation practices as well as nutrient recycling and supplementary irrigation during periods of drought. At the wet site soil conservation practices, the improvement of drainage systems and mounds could be enhanced.

Kurzfassung

In Papua Neuguinea stellen extreme Klimaereignisse so wie das Phänomen der El Niño Southern Oscillation (ENSO) eine erhebliche Gefährdung der Ernährungssicherheit dar. Man nimmt an, dass die Auswirkungen des Klimawandels in Papua Neuguinea hauptsächlich im ENSO Phänomen zu spüren sind, wobei eine Zunahme mehrere oder längere Trockenperioden beziehungsweise Perioden von Starkniederschlägen bedeutet. Das Problem der Ernährungsunsicherheit wird dadurch speziell in ländlichen Gegenden, in welchen zum größten Teil Subsistenzlandwirtschaft betrieben wird, verschärft. Um die Ernährungsunsicherheit auch dort zu sichern, müssen neue landwirtschaftliche Managementstrategien oder technische Lösungen erarbeitet werden. Im Hinblick auf dieses Ziel wurde im Zuge der vorliegenden Masterarbeit eine Untersuchung von Boden und Wasserhaushaltes zweier Pilotregionen durchgeführt. Beide Untersuchungsgebiete liegen im Hochland von Papua Neuguinea, wobei eines durch hohe Niederschlagsmengen und daher überschüssige Feuchtigkeit im Boden, und das andere durch ausgedehnte Trockenperioden und fehlende Bodenfeuchtigkeit ausgezeichnet ist. Der Boden wurde während der Monate März und April 2012 untersucht und Proben hinsichtlich der physikalischen und chemischen Eigenschaften analysiert.

Die Böden des trockenen Untersuchungsgebietes waren Tonböden nicht-vulkanischen Ursprungs und zeigten eine sehr geringe Wasserleitfähigkeit und eine moderate Verdichtung. Des weiteren waren sie im Vergleich zu den Böden des feuchten Standorts weniger sauer, hatten höhere Gehalte an austauschbaren Basen und einen geringeren Gehalt an organischem Material. Die Böden beider Standorte zeigten ein Kalium defizit. Zur Verbesserung der Situation im trockenen Gebiet können eine ergänzende Bewässerung während lang anhaltender Trockenperioden sowie Maßnahmen zur Erhaltung der Bodenfeuchte und Nährstoffrecycling eingeführt werden. Im feuchten Gebiet könnte eine Optimierung von Entwässerungs- sowie Hügelanbautechniken gefördert werden.

1 INTRODUCTION AND OBJECTIVES

In Papua New Guinea (PNG), 81% of the population lives in rural areas (Bourke R.M. et al, 2009a). Most of them are smallholder farmers who practice subsidence farming and are therefore very vulnerable to extreme climatic events and changing weather patterns. The occurrence of periods with extreme climatic conditions such as the El Niño and the la Niña phenomenon are expected to increase in the future. The result is an arising need of smallholder farmers to adapt their agriculture to the changing conditions in order to be capable to supply themselves with food.

To attend to this problematic, the EU funded project *Generation and adaptation of improved agricultural technologies to mitigate climate change-imposed risks to food production within vulnerable smallholder farming communities in Western Pacific countries* was launched in 2011. The aim of the project is to achieve food security for smallholder farmers of Papua New Guinea, Solomon Islands and Vanuatu in areas where precipitation deficits or excess precipitation are significant threats to food production. The main causes of food insecurity in local rural areas are:

- Very low or insufficient soil moisture for crop production during prolonged droughts (El Niño)
- Too much precipitation and hence excessive soil moisture for crop production during extended wet seasons (La Niña)
- Sea water inundation of farmland due to rising sea levels and cyclones
- Inappropriate livestock and fish production systems capable of coping with changing climatic conditions

During the project, the farming systems in high risk areas shall be adapted to cope with the extreme and changing climatic conditions. Amongst other things that can be achieved through the identification of appropriate types of water and soil management technologies, the introduction of more suitable crop varieties and alternative livestock feeding systems.

In Papua New Guinea, five study sites in high risk areas have been selected during the initial phase of the project (Table 1). In those communities pilot actions will be conducted to develop and provide smallholders with new or adapted technology options.

Table 1: The Papua New Guinean study sites of the project

Study Site	District	Province
Hisiu & Yule Island	Kariuku	Central
Kopafo	Bena Bena	Eastern Highlands
Murukanam Sum	kar	Madang
Kiripia & Alkena	Tambul	Western Highlands
Derin Transgogol		Madang

The investigations for this thesis include two out of the five Papua New Guinean study sites. One is the Kopafo community, and the other includes the two communities Kiripia and Alkena (Figure 1). Kopafo is located in the Bena Bena district of the Eastern Highlands Province and was chosen for pilot actions because of its deficit soil moisture conditions. The communities

Kiripia and Alkena are situated in the Tambul district of the Western Highlands Province and suffer from excess soil moisture.

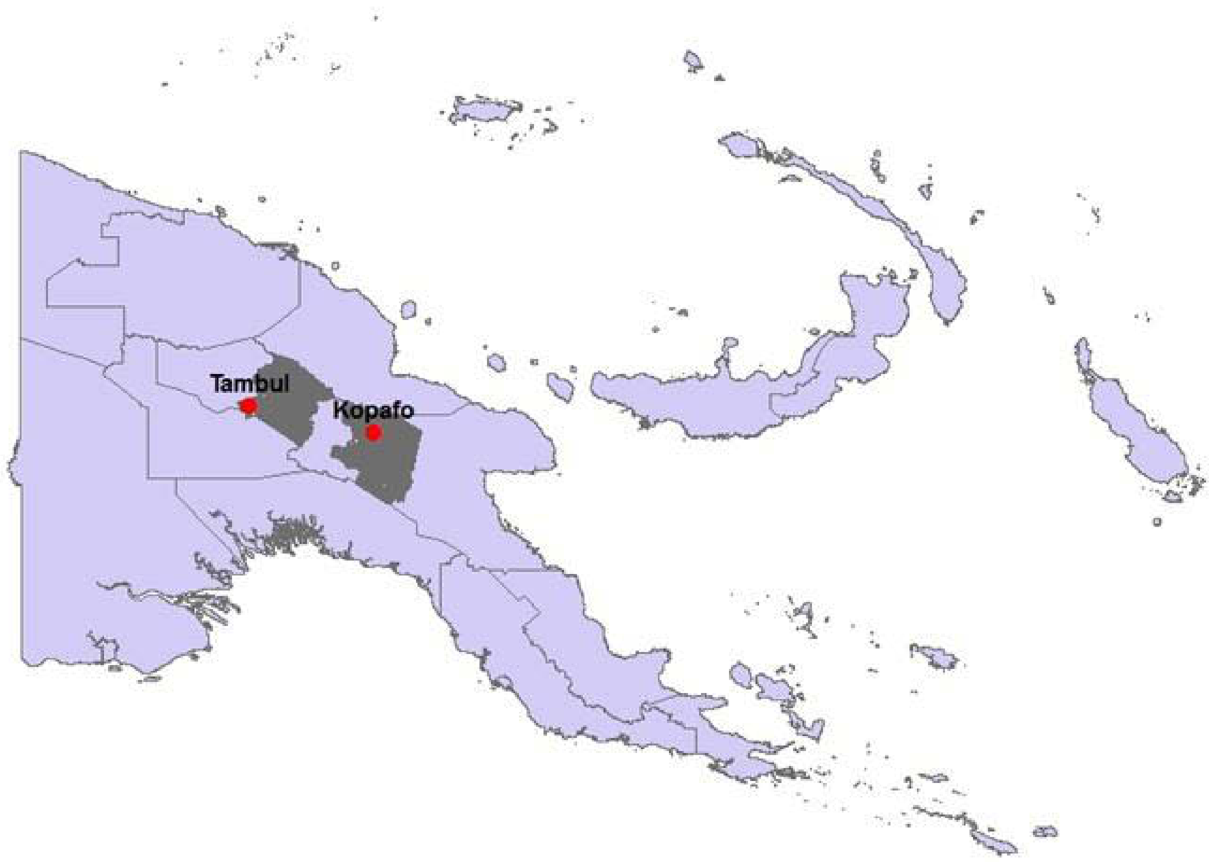


Figure 1: The two study sites Tambul (Western Highland Province) and Kopafo (Eastern Highland Province)

Objectives

The aim of this thesis is to provide the basic information and data that is necessary for further actions in the course of the project. The research objectives are:

- to identify the possible impact of climate change on agriculture and the consequences for smallholder farmers
- to provide an integrated description of the study sites and their problems concerning the availability or the excess of water, including
    - the acquisition of climatic as well as topographic data
    - the identification of locations of water sources and water infrastructure
- to analyse the soils of the food gardens of smallholder farmers in order to gain knowledge about the prevalent soil fertility status as well as the soil water dynamics

Specific research objectives for the Tambul study sites are:

- to identify the influence of the prevalent excess of soil moisture on soil conditions
- to identify specific locations with problems related to excess water such as water logging and flooding
- to determine currently used farming techniques used to cope with periods of excess rainfall and to mitigate excess soil moisture

Specific research objectives for the Kopafo study site are:

- to identify the influence of the prevalent seasonal deficit of soil moisture on soil conditions
- to identify locations that are especially dry
- to determine currently used farming techniques used to cope with periods of drought and to preserve soil moisture

With the information gained through the research and the field investigations, a first approach of how to cope with the prevalent problems is given.

2 GENERAL BACKGROUND

Papua Niugini, as it is called by its inhabitants, is a very diverse country in many ways. A large mountain range divides the country into various valleys with different environments and people and consequently creates a great diversity of languages, traditions and cultures. Papua New Guinea lies at the east end of Indonesia just south of the equator and north of the Australian continent. It has a total area of 465,000 km^2 with a population of 5.2 million people including the many islands. 81% of the population lives in rural villages where most people practice subsistence farming. Hence the agriculture, which depends a lot on climatic and environmental circumstances, is very important (Bourke R.M. et al, 2009a, pp.28).

The so-called highlands of PNG contribute with 16% to the total land area and cover the Eastern Highlands, Chimbu, Western Highlands, Enga and Southern Highlands Provinces (Figure 2). The landscape is a diverse high plateau of faults and deep dissections with its altitude ranging between 1500 and 3000 meters above sea level. About 37% of the population inhabits the highlands and 98% of them live in rural areas, which also emphasises the importance of the highlands agriculture (Benjamin A.K et al., 2000).

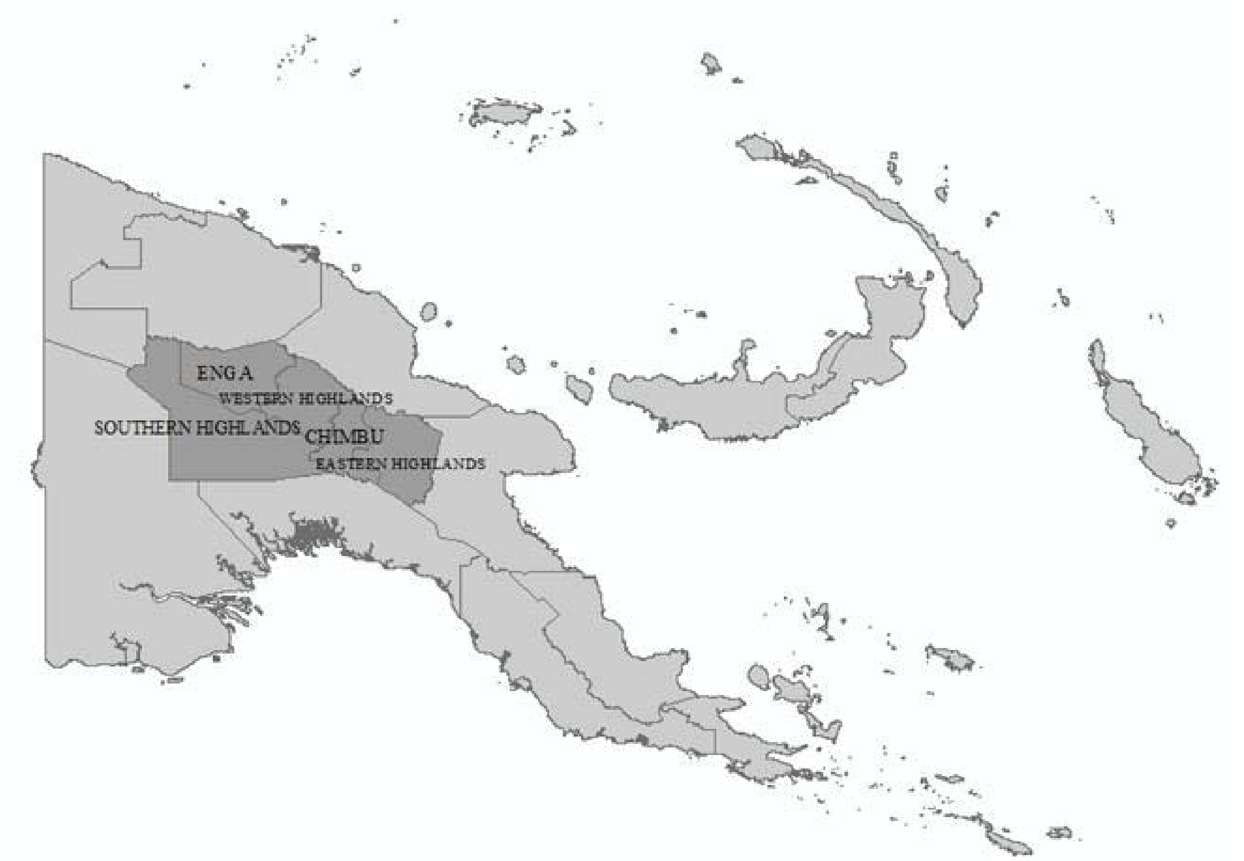


Figure 2: Highlands districts of Papua New Guinea

2.1 Climate of Papua New Guinea

The climate of Papua New Guinea is mainly influenced by the following factors: The *location* of the country between Australia and the equator implicates a tropical climate with plenty of rainfall and excess heating because of solar radiation. The *east- west or walker circulation* accounts for a year to year variability as it is regularly disrupted by El Niño /La Niña years (see Chapter 2.1.1). Local climate patterns are also influenced by the *topography*, especially the height and orientation of the mountain ranges (Saulei S. et al, 2000).

Generally, Papua New Guinea is characterised by a high amount of rainfall, high temperatures and high humidity. While the rainfall varies significantly across the country, the temperatures are relatively steady. The average rainfall in PNG lies between 2000mm and 4000mm per year in most of the country, while some regions receive up to 7000mm and others less than 1500mm (Bourke R.M. et al, 2009a, p.56). On the mainland the areas with the highest amount of rainfall are along the north, south and west end of the main highlands valleys (Figure 3). There are two monsoonal seasons, one occurring from December to March being the northwest monsoon and the other from May to October being the southwest monsoon.

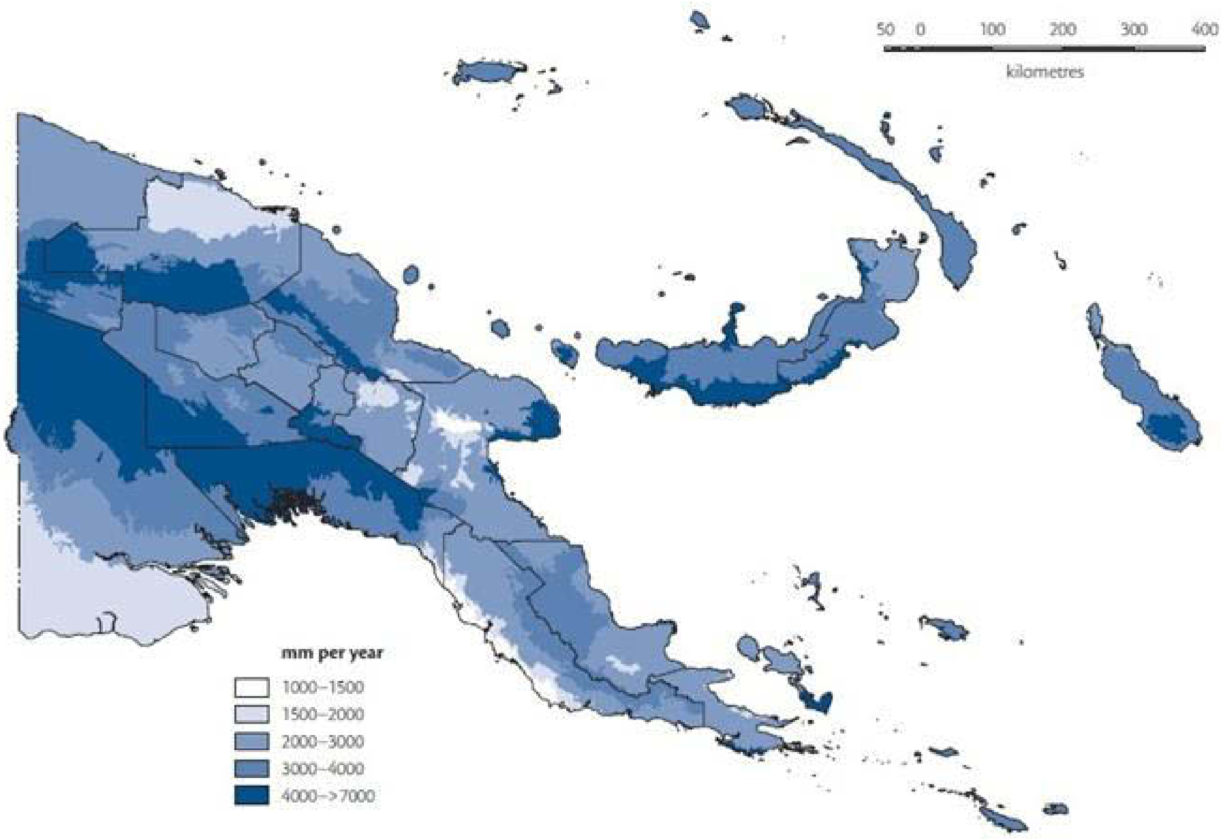


Figure 3: Rainfall in Papua New Guinea, Source: Bourke R.M. et al, 2009a, p.57

BOURKE (2009a) states that the climate in Papua New Guinea is changing as the global climate is. It is believed that the impacts of climate change in PNG are mainly related to the ENSO phenomenon, which is explained in the following chapter (Saulei S. et al, 2000).

2.1.1 El Niño Southern Oscillation (ENSO)

In a normal year the water temperature of the sea surface in the western pacific (Indonesia, PNG) is higher than in the eastern pacific (South America). The high water temperature in the western pacific leads to a convergence of humid air, which rises to a depression and causes clouds. The air is carried along the equator and descends again in the areas of high pressure along the eastern pacific ("The Walker Circulation", Figure 4). The following dissolution of the clouds implicate that these areas only receive little rainfall. Eventually the air flows back towards the Papua New Guinean depression.

In an El Niño year the water temperature of the eastern pacific rises and is no longer colder than the water temperature of the western pacific. This causes the Walker Circulation to reverse (Figure 5), and therefore air of high pressure which is cooler and drier is brought to Papua New Guinea. As a result fewer clouds are developed. The El Niño phenomenon occurs approximately once in ten years and has a big influence on rainfall in Papua New Guinea. It causes moderate to severe droughts and as a consequence of little cloud cover and clear night skies frosts can occur in areas above 2000masl. A severe ENSO event happens approximately every 50 - 100 years and can cause a serious degree of damage. The most severe ENSO event of the past 70 years took place in 1997 and caused serious food shortages all over the country (Allen B.J. et al, 2000a).

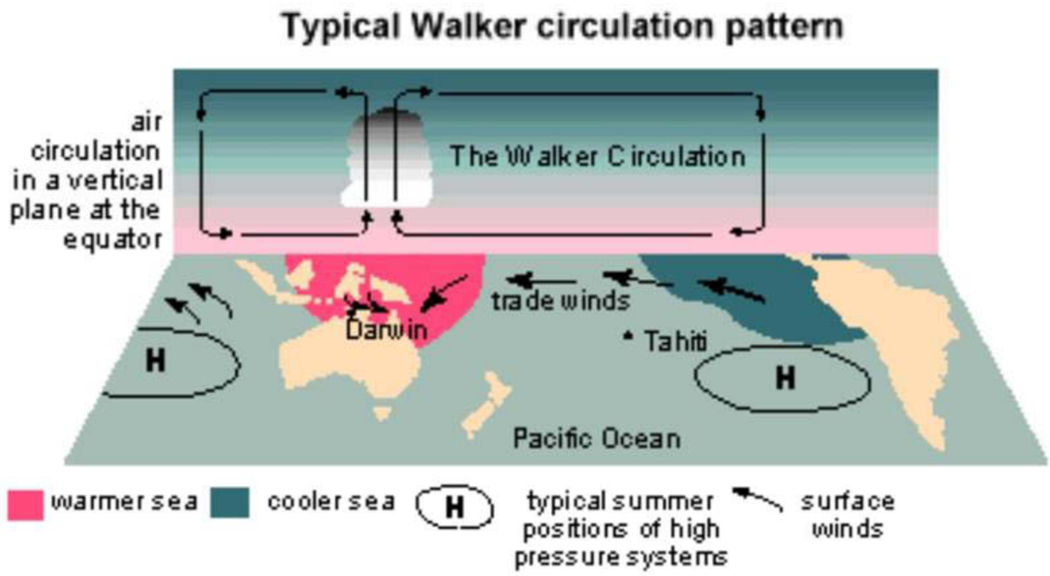


Figure 4: The Walker Circulation in a normal year, Source: BOM, 2012

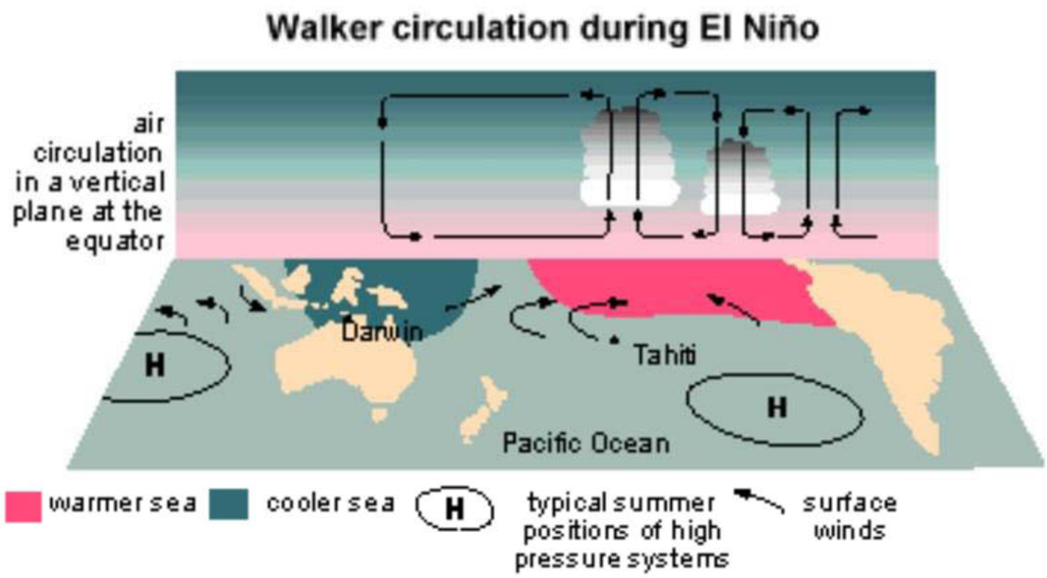


Figure 5: The Walker Circulation in an El Niño year, Source: BOM, 2012

The phase called La Niña is opposite to the El Niño phenomenon and occurs when the sea surface temperatures in the eastern pacific are colder than normal. A La Niña year is often subsequent to an El Niño year and is connected with higher rainfall in Papua New Guinea.

2.1.2 CLIMATE CHANGE IN PAPUA NEW GUINEA

The effects of climate change have an influence on life everywhere in the world. The most important effect is the rise of the world average temperature due to increasing concentrations of greenhouse gases, but there are several other impacts that possibly go on the account of climate change. For example natural hazards, especially floods, droughts and the sea-level rise are expected to increase in frequency, magnitude and intensity due to climate change. In Papua New Guinea the ENSO phenomenon has by far the most important influence on climate variability and has already been found to cause more intensive drought and flood events (Saulei S. et al, 2000).

According to BOURKE (2009a), studies show that the *temperature* in PNG has increased during the 20th century with a bigger increase of minimum and a lesser increase of maximum temperatures (Figure 6). In El Niño years temperatures tend to be lower, and in following La Niña phases higher than the average. In the highlands only little long-term data exists, but one can deduce a trend from the altitudinal growing limits of certain crops. Plants like coconut or pandanus now grow at altitudinal levels where they either did not grow before, or grew, but did not bear fruits before. Observing this, BOURKE (2009a) points out that the increase of temperatures in the highlands was 0,7°C over 20 years. This is in accordance with measurements in Aiyura (Eastern Highlands Province), where the maximum temperature shows an increase of 0,75°C over the years 1977 - 2001 (Bourke R.M et al., 2009a, p.75). In opposition to the national trend, the Aiyura station shows no change of minimum temperatures.

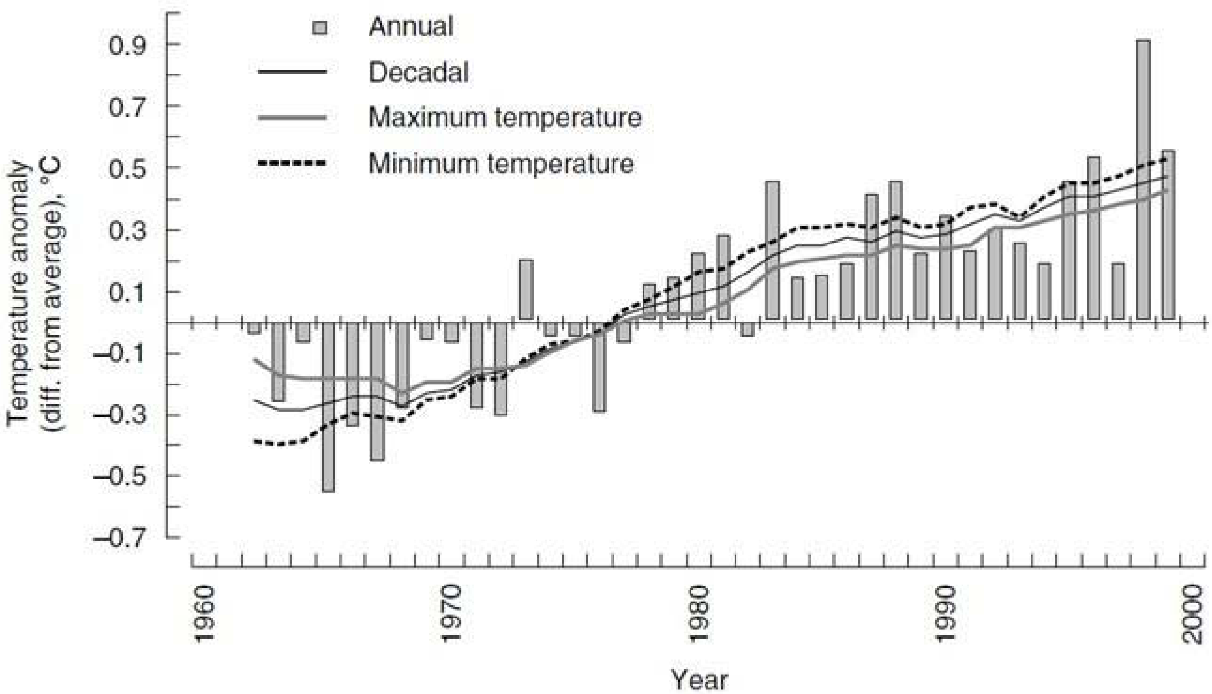


Figure 6: Temperature trend 1960 - 1999 in Papua New Guinea, Source: Inape K. et al, 2000

The change of *rainfall* patterns is more difficult to tell since most rural rainfall recording stations have stopped recording around 1980. In Goroka (Eastern Highlands Province) a shift to longer, but less distinctive rainy seasons was found during 1946 and 2002. People of both, lowlands and highlands say that seasonal rainfall patterns are changing or are less predictable now (Bourke R.M. et al, 2009a, p.77). SAULEI (2000) writes about a significant overall reduction of rainfall, but due to discontinuous records no conclusive precipitation trends for recent years can be drawn. Figure 7 shows the rainfall trend over the years 1959 - 1999 for PNG.

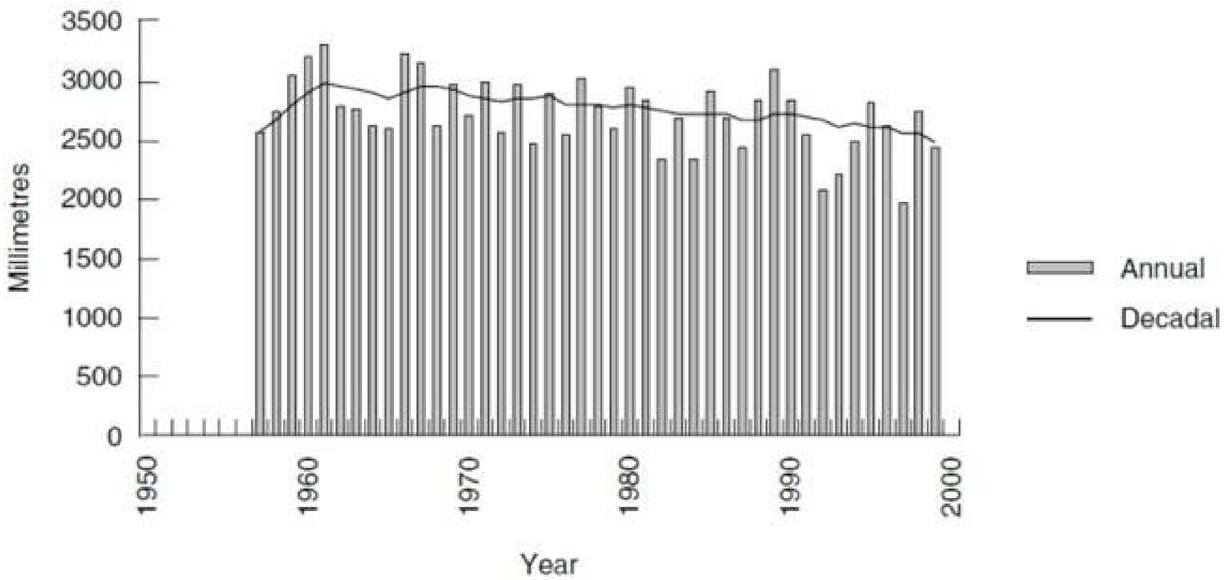


Figure 7: Rainfall trend 1950 - 1999 in Papua New Guinea, Source: Inape K. et al, 2000

2.1.3 IMPLICATIONS OF CLIMATE CHANGE FOR RURAL FARMERS

Climate Change already affects the agriculture in Papua New Guinea, but as its impacts are diverse, the consequences are difficult to tell. As most of PNGs population are subsistence farmers, they depend on the yield of their food gardens or cash crops, which are highly vulnerable to strong climatic fluctuations (Inape K. et al, 2000). In the following, the implications for smallholder farmers resulting from a change of the factors temperature and rainfall will be discussed.

Temperature

Due to the increase of minimum and maximum temperatures, the altitudinal limits of some crops will change and consequently they can be grown at higher altitudes which means that the growing area of a crop expands. In addition, temperatures above 34°C significantly decrease the tuber formation of sweet potato, which is the most important food crop in PNG (see Chapter 2.2.4.1). This could reduce sweet potato production especially in the lowlands. Further, a decrease of the diurnal temperature range could also reduce crops yields. Temperature also has an influence on some crop diseases like taro blight or coffee rust, which are sensible to low temperatures and therefore only occur up to a certain altitude. A rise of temperature due to climate change could result in an expansion of some crop diseases to higher altitudes. If there is an increase of ENSO events due to climate change, farmers will have to expect more or longer droughts and more frosts at high-altitude locations, which also would have a big impact on agricultural production. Overall, one can say that the productivity in the lowlands and in the main highland valleys will probably be reduced slightly, while it will be increased at high altitude locations due to temperature increase (Bourke R.M. et al, 2009a, p.78).

Rainfall

In areas with usually low rainfall, an increase of precipitation and a decrease of seasonality of distribution would be positive for agriculture. On the other hand this would be negative for most areas of PNG as they already receive high amounts of rainfall. With an increase of ENSO events there would be more episodes of droughts as well as periods of very heavy rainfall, which again has a negative impact on agriculture. But it is difficult to predict the changes of the patterns of ENSO events as they are not very well understood (Bourke R.M. et al, 2009a, p.78).

On the contrary, if there is moderate ENSO activity a sequence of heavy rainfall with an adjacent one- to two-year period of lower rainfall is expected. This can lead to a reduction of sweet potato production, but due to a four to eight month delay of this event the correlation between ENSO activity and lower sweet potato production is often unknown to villagers (Allen B.J. et al, 2000a).

These are just some of the many possible impacts of climate change. Others concern water supply, fish availability, sea level rise, malaria occurrence in the high lands and changes in the global economy, which also have an impact on PNG. These effects will not be discussed in detail. An idea of the effects of climate change that are important for smallholder farmers in PNG can be given by looking at the impact of the 1997 drought.

The 1997 drought

Between 1876 and 2005 there were four ENSO events with severe impacts to farmers in PNG: 1902, 1914, 1941 and 1997 (Bourke R.M. et al, 2009a, p63). The event in 1997 was by far the strongest and caused a prolonged drought which lead to severe food shortages for almost 40% of the population. Another big problem was the supply of drinking water for rural villagers. About 400.000 people were supplied inadequately, which means that they only had limited access to water or that it was of bad quality or at great distances (Allen B.J. et al, 2000a).

The respond of rural people to the drought was diverse. They started to eat food which normally is not eaten in large amounts and as the drought got more severe even famine food was consumed. People moved to areas closer to water sources, started to plant close to riverbanks or in drying swamps and fed less food to their domestic animals. In areas above 2000m asl heavy droughts are also associated with frosts as a result of the clear night sky. There, people reacted with migration to lower areas, but moved back as soon as food relief was provided because lower lying areas were also affected by the impacts of the drought. Farmers who had access to markets where they could sell goods to make money or had relatives who could do so, were able to reduce the impacts of the drought by buying imported food like rice and flour. The most affected people were those without any income, savings or relatives who could support them. They could mostly be found in remote areas where education and health standards are low. Relief food was provided by the local Government, the Australian Government and other organisations, but 75% of the imported extra rice during the drought was purchased by the PNG population itself (Allen B.J. et al, 2000a).

2.2 AGRICULTURE IN PAPUA NEW GUINEA

The agriculture in PNG is about 10.000 years old and still the most important occupation for the majority of the Papua New Guineans today (Bourke R.M. et al, 2009a, p.6). About 85% of the population is sustained by cash crops as well as subsistence food production (Saulei S. et al, 2000). That makes subsistence farming the most important part of Papua New Guinean agriculture, especially in the highlands.

This chapter first provides a brief overview about the history of agriculture and then shows the soils found in this country. Furthermore the most important agricultural techniques are explained and some important crops for subsistence agriculture are described. A special focus is given to the highlands of Papua New Guinea as both of the later discussed study sites are situated there.

2.2.1 HISTORY OF AGRICULTURE

The first humans are estimated to have arrived in PNG about 50.000 years ago. At that time the world climate was different from now with lower temperatures and a lower sea level. By then the current island of New Guinea was still connected to Australia and Tasmania by land, forming a continent called Sahul. People supplied themselves with food by gathering, fishing and hunting. The first signs of agriculture come from the Whagi valley in the Western Highlands Province of PNG and are dated about 10.000 years ago. People used stone tools to cultivate plants in small gardens and to dig drains to make swamplands arable for cultivation. The arrival of the Austronesians about 3500 years ago brought new crops and already domesticated animals like dog, chicken and pig to New Guinea. The first contact of New Guinea with European explorers was in the 1500s, but there is no evidence that new plant species were introduced. Before 1800 the Europeans brought species like sweet potato, tobacco, cassava, lima bean and bixa to Indonesia and from there they spread to PNG. The main staple food before that time was taro, yam, banana and sago (Bourke R.M. et al, 2009a, pp.13).

The first foreigners settled down permanently at the coasts of PNG in 1870. Since then the agriculture has gone through a lot of changes. Hundreds of cash crops, fodder plants, weeds and other plants were introduced. A lot of different types of cash crops like oil palm, coffee, tea, copra, cocoa, rubber and tobacco were produced and exported. Since 1950 the cash crop production on village level increased while the one on plantation level decreased and by now it is dominated by smallholder farmers (except for palm oil).

Since 1940 the agriculture has again changed a lot. Reasons for these changes were population growth and the associated pressure of land, alienation of land, cash cropping by smallholder farmers and plant diseases. This lead to the adaption of new crop species like sweet potato and cassava, more intensive land use, practice of soil fertility preservation techniques and the integration of cash crops in the food crop system.

2.2.2 AGRICULTURAL TECHNIQUES

There is a wide range of different agricultural techniques that are practiced in PNG, depending on the location and environmental circumstances. Some of these techniques are very old, like burning to clear land, drainage and mounding, while others have developed more recently. Most of the techniques are strongly connected with the intensification of agriculture and are supposed to maintain soil fertility.

Common agricultural practices are (Bourke R.M. et al, 2009a, p.232):

- Fallowing
- Crop rotation
- Tillage and construction of mounds and beds
- Green manuring (composting)
- Drainage
- Soil erosion control

Some other agricultural techniques include fencing, irrigation, mixed cropping, the support of crops with stakes, growth of yam tubers in deep holes and the usage of animal manure, inorganic fertilizer or silt from floods. These techniques will not be described more closely as they are either of minor importance or not used in the highlands region.

2.2.2.1 Fallowing

When a land is left uncultivated during several weeks to 40 years and the natural vegetation is left to grow freely, it is called a fallow. Shifting cultivation with long fallowing periods is practiced by most farmers in the lowlands to restore soil fertility. When the land is believed to be ready for cultivation again, the fallow vegetation is cleared by burning or slashing and new crops are planted (Bourke R.M. et al , 2009a, p.235). In the agricultural systems of the highlands long fallow periods do not exist and people practice rather semi- permanent cultivation than shifting cultivation (Wood A.W., 1987). In these agricultural systems only very short fallow periods are used, which is probably because the population density and hence the land use intensity is very high. In some regions of the highlands there is a practice to plant trees in sweet potato gardens as a fallow management strategy. The most important tree is the Casuarina tree, which is planted mainly in sweet potato gardens towards the end of a cropping phase (Bourke R.M., 2001).

2.2.2.2 Crop rotation

In PNG this technique is practiced by cultivating leguminous crops alternating with food crops. It is normally practiced in sweet potato based systems with the leguminous crops being mostly peanut and sometimes winged bean. Most legumes host bacteria in their roots who are able to fix nitrogen and therefore increase the nitrogen level of the soil. Another advantage of this technique is the reduction of a number of sweet potato pests and diseases (Bourke R.M. et al, 2009a, p.249). This form of crop rotation is commonly used in parts of the highlands as well as the Gazelle Peninsula of New Britain. In the highlands sweet potato is normally planted as first crop and replanted until yields decline. The second crop is peanut, which is followed by one or more cycles of sweet potato. After the 2nd cycle most probably a short fallow period will follow (Bourke R.M., 2001, p.229).

2.2.2.3 Tillage and construction of mounds and beds

Mounds

The construction of mounds is a very common practice in the highlands and already exists since about 7000 years (Bourke R.M. et al, 2009a, p.21). The soil is tilled to mounds that can be small (10–40 cm high and 40–100 cm in diameter), medium sized (40–70 cm high and 100–250 cm in diameter) or large (more than 70 cm high and more than 250 cm in diameter) and the crops are planted on top of it (Bourke R.M. et al, 2009a, p.251). The great advantage of this method is that the soil is drained very well, which means that the water can run off freely in-between the mounds and the crop does not suffer from excess moisture. Another positive effect is that the depth of the topsoil is increased by putting it to a mound. Agricultural systems with mounds are mostly sweet potato based and can be mixed with other crops (Figure 8).

Figure 8: Sweet potato cultivated on mounds in Kiripia/Western Highlands Province; single cultivation (left) and mixed cultivation with sugar cane (right), pictures: Agnes Ulreich, 2012

Small mounds have become more and more common since sweet potato has spread over PNG. The reason is, that saturated soils decrease sweet potato yields which can be avoided by constructing small mounds and thereby raising the crop above the wet soil. Small mounds are sometimes also used for other crops like cassava, yam and green vegetables. They are not only important in Chimbu and Eastern Highlands provinces, but also in Bougainville, Oro, Central and Milne Bay provinces (see Figure 9).

Medium sized mounds are often constructed subsequent to an initial sweet potato crop on small mounds. Several planting cycles of medium sized mounds follow with the break down and reconstruction of the mounds after each cycle. They are reconstructed in a way, that either one-third of the nearest three mounds or one-quarter of the nearest four mounds are put together to a new one. Medium sized mounds are used in large parts of the Southern Highlands- and Enga Province (see Figure 10).

Large mounds differ from medium sized mounds by their way of reconstruction. When broken open, the mound forms a depression in the middle which will be filled with green manure later on (Figure 13). Large mounds are always constructed in combination with composting and are rebuild on the same place as the old one after a short fallow period. Large mounds are only used by five percent of the rural population who mostly live in the western part of the Western Highland Province and parts of the Enga Province (see Figure 11) (Bourke R.M. et al, 2009a, p.252).

Figure 9 to Figure 12 show the distribution of small, medium sized and large mounds. One can see that the use of medium sized mounds as well as large mounds is restricted to the highlands provinces while small mounds are build in many parts of the country.

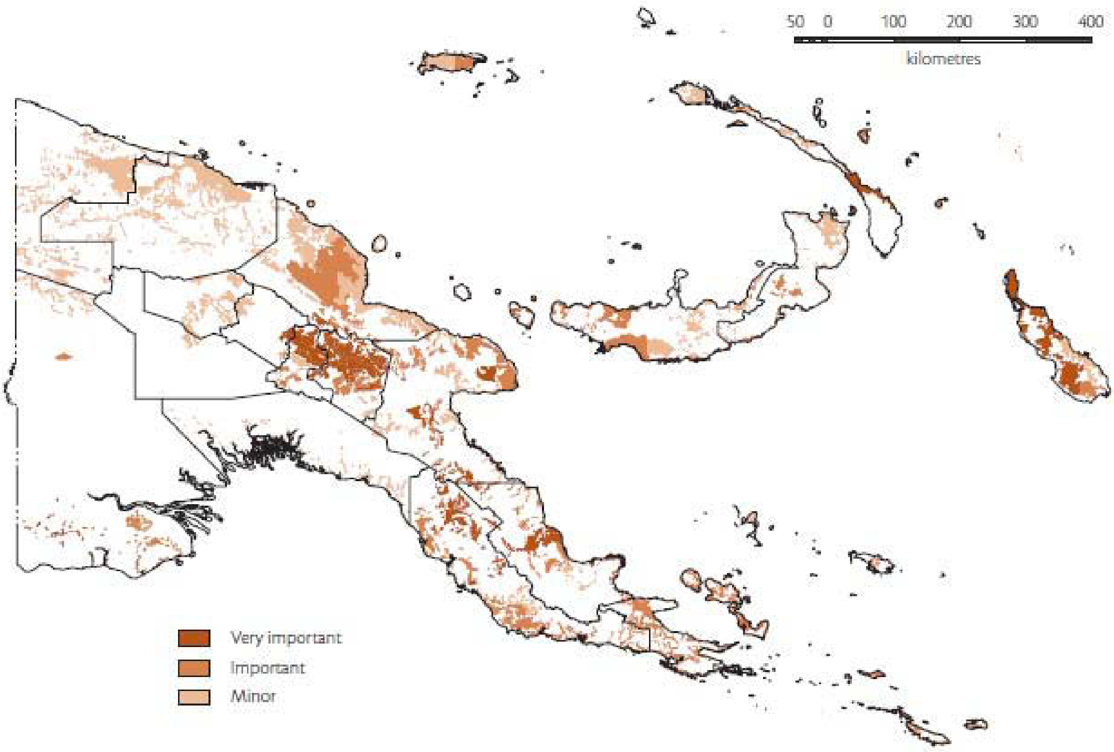


Figure 9: Distribution of small mounds, Source: Bourke R.M. et al, 2009a, pp.252

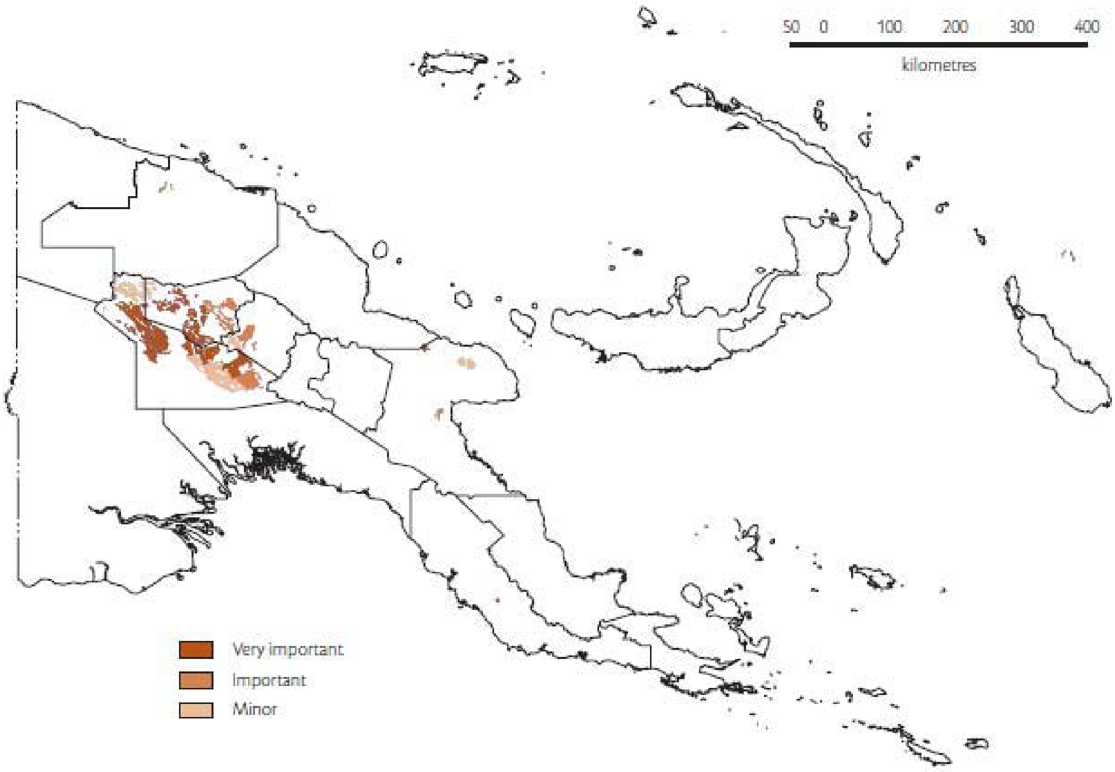


Figure 10: Distribution of medium sized mounds, Source: Bourke R.M. et al, 2009a, pp.252

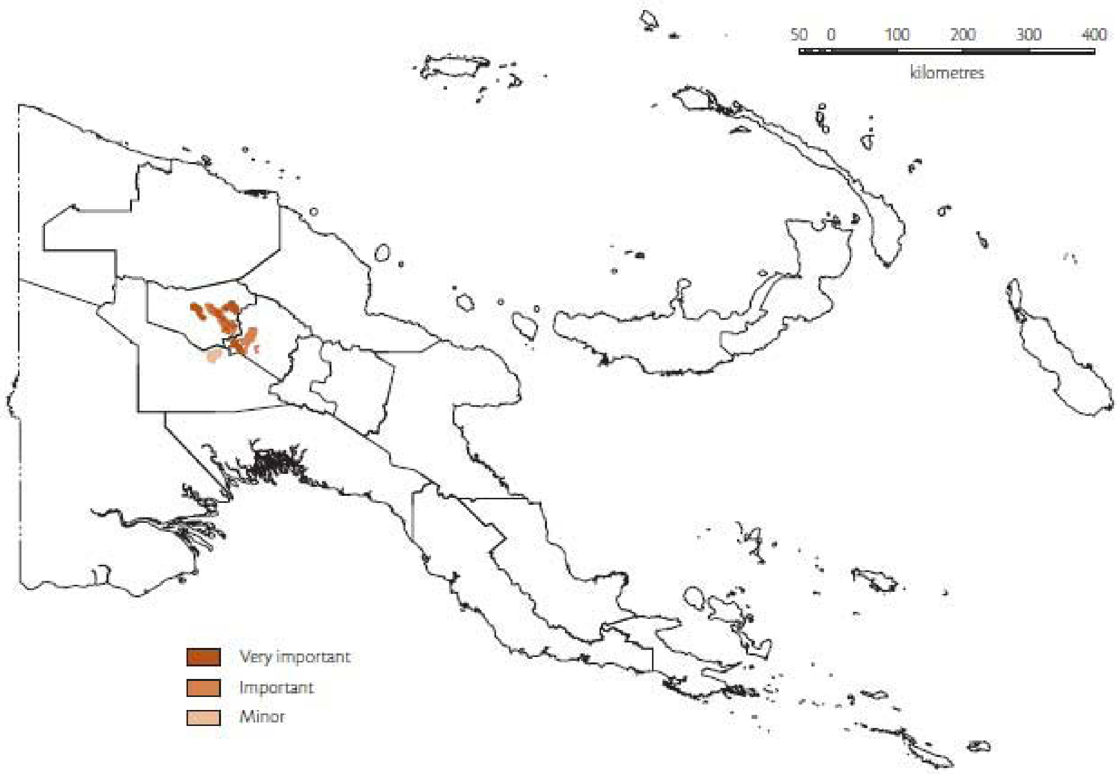


Figure 11: Distribution of large mounds, Source: Bourke R.M. et al, 2009a, pp.252

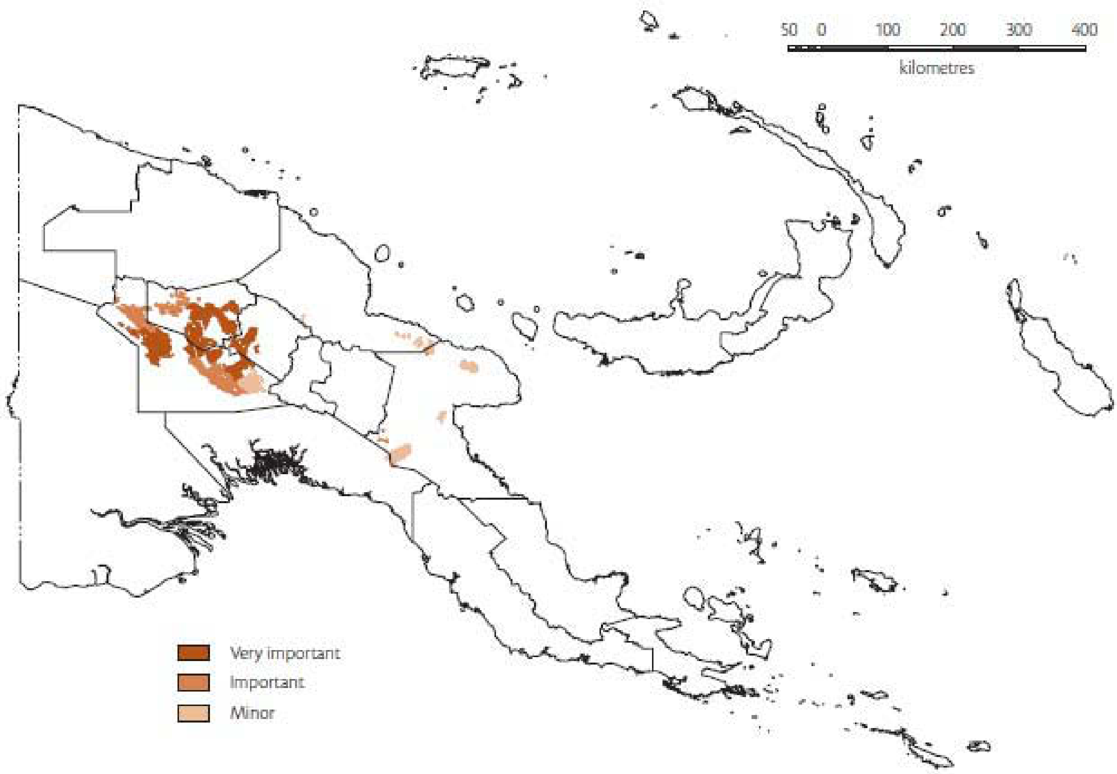


Figure 12: Distribution of composting, Source: Bourke R.M. et al, 2009a, pp.252

Beds

Beds can be divided into two kinds: square beds and long beds. To build square beds, farmers dig a grid of shallow drains through the garden while throwing the excavated earth in the space between the drains. Cleared grass is normally left on the field and after a harvest and a short fallow period, the new drains are dug. Those drains are constructed staggered to the previous ones and the old drains are filled with earth. Square beds lower the water table so that crops don't suffer from excess soil moisture. Long beds are not build as regular as square beds and have the function of letting the surface water pass through the garden with a minimum loss of topsoil. In the Southern Highland -, Western Highland - and Chimbu Province both, long and square beds are practiced, but in the Eastern Highland Province long beds are more common. In the areas where both kinds of beds are used, square beds are mostly constructed on gently slopes or flat land while long beds are found on steeper slopes. In the southern part of the Western Highland Province square beds are often used to decrease the water table and drain the excess water to be able to plant crops on very poorly drained soils. In the western part of the Western Highland Province large mounds are practiced rather than square beds (Bourke R.M. et al, 2009a, p.253).

Tillage

Tillage is mostly used in combination with mounds or beds, but in rare cases it can also be used with grass fallows. It has an influence on soil particle size, soil temperature, water infiltration and water retention (Bourke R.M. et al, 2009a, p.251). Through tillage the soil is well aerated and the decomposition of organic matter is increased.

2.2.2.4 Green manuring (composting)

Composting is mostly practiced in areas of high altitude, with very high rainfall and lower temperatures. This can be found in the Southern Highland Province, Enga Province and the western part of the Western Highland Province. The practice of composting was probably developed by villagers of the Enga Province about 150 to 200 years ago (Bourke R.M. et al, 2009a, p.255). Usually grass, weeds and crop residues are dried and then put in the garden to be covered with soil. The green manure decomposes and thereby increases soil organic matter, adds nutrients to the soil and reduces the bulk density. (Wood A.W., 1987). Composting is strongly connected to the construction of mounds and beds and nearly always associated with sweet potato cultivation. Composting is always used in combination with large mounds, sometimes with middle sized mounds and never with small mounds. When *middle sized mounds* are composted, the ground between the old mounds is covered first with green manure and consequently with soil and thereby forms a new mound in-between the old ones. When composting *large mounds,* they are already broken open in a way that there is a depression in the middle of the mound (Figure 13) which is filled with green manure during a short fallow. Afterwards the mound is rebuilt by putting the soil from outside of the mound on top of the green manure (Bourke R.M. et al, 2009a, pp.252).

Figure 13: Opened up large sweet potato mound prepared for composting in Kiripia/Western Highland Province, picture: Agnes Ulreich, 2012

2.2.2.5 Drainage

Drainage has a long tradition in Papua New Guinea since it was already used 4500 - 5000 years ago (Bourke R.M. et al, 2009a, p.21). However, drainage systems were not very widespread until the introduction of sweet potato, because the high percentage of agricultural land on slopes made them unnecessary (Bourke R.M. et al, 2009a, p.260). Today they are widely used to remove excess water and thus to increase the production in poorly drained soils or enable crop production in saturated soils. Drains are mostly dug downhill to remove excess rain fall, but in some areas a raster of drains is constructed across the garden to lower the water table. Especially in the Highlands drainage systems with regular spaces (width typically 3 - 5m and depth 20 - 40cm) and with irregular spaces (deeper than regular spaced drainage systems) are very common (Bourke R.M., 2001). Drainage systems are very important throughout the Highlands and in swamps of other regions.

2.2.2.6 Erosion control

Erosion control is not very common, but is practiced at some places of higher altitude where slopes are steeper and the intensity of agriculture is lower. Retention barriers and terraces are used to hold back the soil that would be carried downhill and out of the garden (Bourke R.M., 2001).

2.2.3 SOILS

Soils in PNG are generally young soils which can vary a lot within short distances due to the change of the factors climate, vegetation, slope or parent material. Human activity also has a big influence on soils as they are altered by tillage, composting, mounding or erosion caused by cultivation (Bourke R.M. et al, 2009a, p.81). Good information about soils in PNG based on black and white vertical air photographs is provided by the Papua New Guinea Resource Information System (PNGRIS). PNGRIS uses the soil taxonomy classification of the United States Department of Agriculture (USDA).

2.2.3.1 Soil types

The soil types of Papua New Guinea are shown in Figure 14. According to PNGRIS, the most common soils in PNG are *Inceptisols* (Figure 14, yellow area). They are moderately weathered and have no strong contrast of horizons. Soils derived from volcanic ash belong to the order of *Andisols*, which are especially important in the highlands (Figure 14, red area). Inceptisols together with Andisols cover nearly half of the total land area of PNG (Bourke R.M. et al, 2009a, p.81). Other soil types that can be found are Entisols, Histosols, Vertisols, Mollisols, Alfisols, Ultisols and Oxisols. For further description of these soils see BOURKE (2009a).

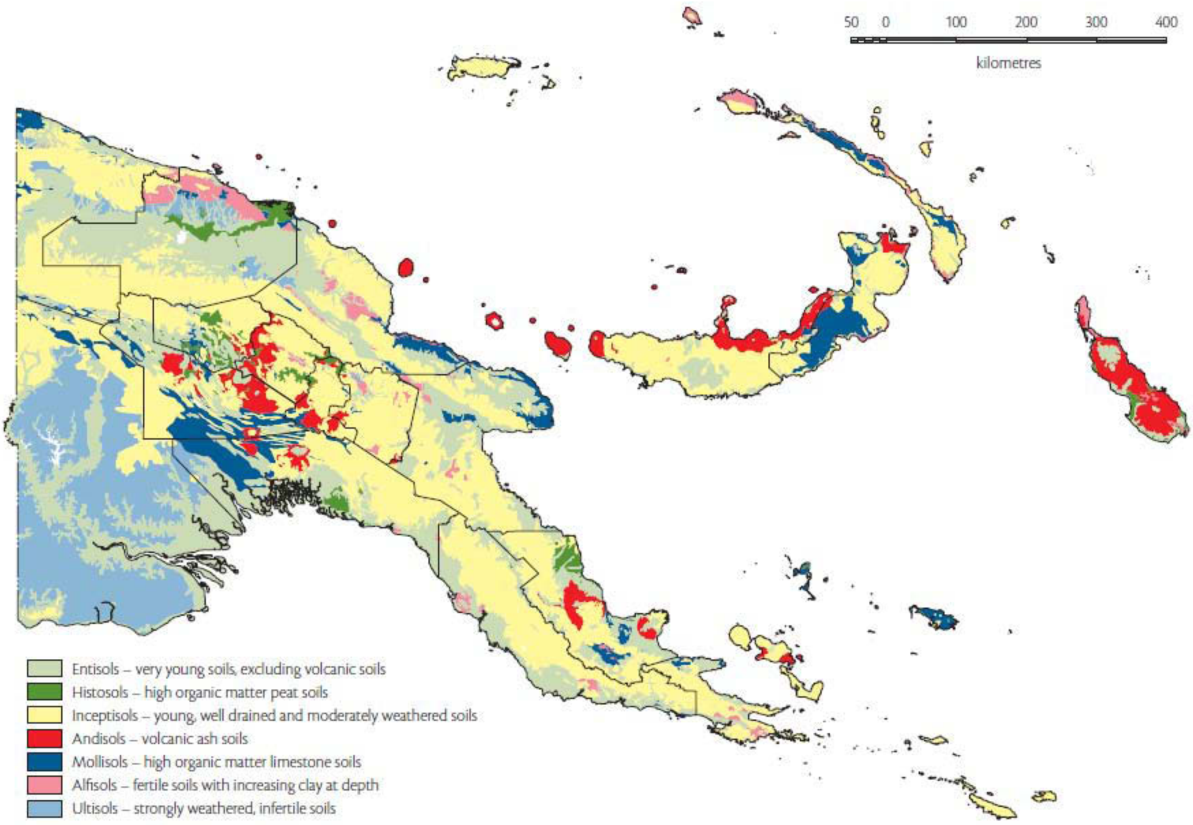


Figure 14: Orders of soils according to the USDA soil taxonomy classification derived from PNGRIS, Source: Bourke R.M. et al, 2009a, p.83

Soils of the Highlands

The importance of soils in the highlands becomes apparent when looking at the rural population. The valleys of the highlands accommodate the greatest density of rural population in Papua New Guinea, accounting to one third of the total population of the country. Most of these people depend on the soils for cultivation as they are subsistence farmers (Wood A.W., 1987).

The most common soil types of the highlands are Inceptisols and Andisols. Andisols are commonly used for cultivation, but they have a low content of available phosphorous despite their high organic matter content. Other soil types are Entisols, Ultisols and Mollisols, the most fertile ones being among the Mollisols, whereas Ultisols are normally less fertile. (Benjamin A.K et al., 2000)

The formation of the highland soils is mostly determined by two factors: parent material and climate. The dominating soil parent material is volcanic ash material, which comes from several large volcanic centres that erupted in the past. Only on steeper slopes and river floodplains or other places where the volcanic ash material has been removed, other parent material can be found. The soils formed on volcanic ash material are the true humic brown soils and differ from alluvial and colluvial soils by their chemical and physical properties.

According to a study of soils from sweet potato gardens in the highlands of PNG, volcanic soils are more acid than non-volcanic soils and generally show lower contents of exchangeable bases (Table 2). Additionally the study shows, that volcanic soils contain significantly less potassium, and the content of total carbon is significantly higher compared to non-volcanic soils (Bailey J., 2009). According to BAILEY (2009), potassium deficiency is a widespread problem in the highlands of PNG, and therefore potassium is the most limiting factor to sweet potato cultivation in this region. Another finding of the former mentioned study was the unusual negative correlation of the CEC and the soil organic C in volcanic soils (Bailey J.S. et al., 2008).

Table 2: Mean concentrations of soil variables in non-volcanic and volcanic soils of the PNG highlands, Source: Bailey J., 2009

Soil variable	Non-volcanic soils	Volcanic soils
pH	6,2 5,6	
P (mg/kg)	43 67	
exch. K (meq/100g)	0,31 0,26	
exch. Ca (meq/100g)	9,73 4,87	
exch. Mg (meq/100g)	3,73 1,54	
total C (g/kg)	48 97	

Beside the great influence of the soil parent material, climatic factors also play an important role for soil formation. This can clearly be seen by examining soils of different altitudes. Above 2000masl, soils are exposed to lower temperatures and more rainfall. As a consequence they lose more nutrients by leaching, are less weathered, have more organic matter in the surface horizons and more gley in the subsoil (Wood A.W., 1987).

The upland valleys of the highlands are dominated by humic, yellow brown clay soils. According to the USDA soil taxonomy classification most humic brown soils of the highlands are classified to be Hydrandepts, which belong to the Order of Inceptisols (Wood A.W., 1987).

2.2.3.2 Important soil parameters

For an assessment of the soil fertility a number of parameters can be used. In this chapter important soil parameters and their optimum ranges for agriculture are given.

2.2.3.2.1 Soil pH

The pH value of a soil expresses the activity of the hydrogen ions and hence the acidity or alkalinity of a soil. It has an effect on many processes taking place in soils and influences the availability of mineral nutrients to plants (FAO, 2006). It therefore provides information about the chemical environment and the chemical processes of a soil. The pH-value for mineral soils in humid regions commonly ranges between 5 and 8 (Peverill K.I. et al., 1999). The knowledge of the soil pH gives information about the availability of essential elements or their toxicity for plant growth and hence the suitability of the soil for crops. Most of the crops prefer soils with pH-values between 5,5 and 7,0. A soil with pH-values below 5,5 will accumulate excessive aluminium (Al), iron (Fe) and manganese (Mn), which can be toxic to plant growth. Coffee, tea and sweet potato are tolerant to acid soils (Thiagalingam K., 2000). A general rating of the soil pH according to HAZELTON (2007) is given in Table 3.

Table 3: Rating of pH-value measured in a 1:5 soil/water ratio, Source: Hazelton P. et al, 2007, p.64

Rating pH	
very strongly alkaline	> 9
strongly alkaline	9,0 - 8,5
moderately alkaline	8,4 - 7,9
mildly alkaline	7,8 - 7,4
neutral	7,3 - 6,6
slightly acid	6,5 - 6,1
moderately acid	6,0 - 5,6
strongly acid	5,5 - 5,1
very strongly acid	5,0 - 4,5

2.2.3.2.2 Cation Exchange Capacity (CEC)

The Cation Exchange Capacity expresses the amount of negative charges in the soil that are present on the surface of clay and organic matter. These negative charges attract cations (positively charged ions), which are often essential plant nutrients like potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and ammonium (NH^{4+}) but can also be detrimental like Sodium (Na^+), Hydrogen (H^+) and Aluminium (Al^{3+}) . Hence the CEC shows the potential productivity of a soil, which is demonstrated by its capacity to retain and supply plant nutrients. It not only buffers fluctuations in nutrient availability, but also of soil pH, which gets more difficult to change with an increasing CEC. The most important factor for the determination of the CEC is the clay and organic matter content of the soil. The higher the quantities of clay and organic matter are, the higher is the CEC (Camberato J. J., 2001). A general rating of the cation exchange capacity according to HAZELTON (2007) is given in Table 4

Table 4: Rating of cation exchange capacity, Source: Hazelton P. et al, 2007, p.64

Rating CEC	**[me%]**
very low	< 6
low	6 - 12
moderate	12 - 25
high	25 - 40
very high	> 40

The interpretation of the Cation Exchange Capacity of soils dominated by variably charged components (most tropical and highly organic soils) depends on the pH conditions and the ionic strength of the soil at the time of the measurement (Peverill K.I. et al., 1999, p.149). PEVERILL (1999) states, that the estimation of the CEC for soils with variable charge by a method involving NH_4^+ saturation can lead to large overestimates.

2.2.3.2.3 Base Saturation

The base saturation (BS) gives information about the nutrient status of a soil compared to its potential fertility (Hazelton P. et al, 2007, p.66). It reflects the part of the CEC that is occupied by the basic cations Ca^{2+}, Mg^{2+}, K^+ and Na^+. It therefore is a function of the CEC and is used to manage soil properties and nutrient availability, especially detrimental levels of Na^+ and Mg^{2+} (Camberato J. J., 2001). A low base saturation signifies a high amount of other exchangeable cations such as those of micronutrient elements (Cu^{2+}, Co^{2+}, Zn^{2+},..), ammonium ions NH_4^+, aluminium (Al^{3+}), iron (Fe^{2+}) or H^+. Those other exchangeable cations are normally not present in significant amounts, so that the sum of the basic cations mostly has similar values to the CEC. In acid soils the there is a discrepancy of these values which is mainly due to the presence of exchangeable aluminium ions (Peverill K.I. et al., 1999, p.148). If soils have a low base saturation, it normally means that they are acidic. A general rating of the base saturation according to HAZELTON (2007) is given in Table 5.

Table 5: Rating of base saturation, Source: Hazelton P. et al, 2007, p.66

Rating B	S [%]
very low	0 - 20
low	20 - 40
moderate	40 - 60
high	60 - 80
very high	> 80

The base saturation may also be consulted for conclusions about the extent of leaching that a soil is exposed to. The rating is based on the extent of depletion of the exchangeable bases expressed through the base saturation. HAZELTON (2007) rates the indication of the base saturation on leaching as followed (Table 6).

Table 6: Rating of the indication of the BS on leaching, Source: Hazelton P. et al, 2007, p.66

Rating Range	(% BS)
very weakly leached	70 - 100
weakly leached	50 - 70
moderately leached	30 - 50
strongly leached	15 - 30
very strongly leached	0 - 15

2.2.3.2.4 Exchangeable Bases

Many cations present in the soil are important plant nutrients. In their exchangeable form they are bound to negative charges of organic matter or clay minerals, but can easily pass on into the soil solution, where they are available for plant uptake. The excess presence of one cation can lead to the obstruction of another cation (Thiagalingam K., 2000). The basic cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) normally constitute the majority of exchangeable cations present in soils (Peverill K.I. et al., 1999, p.148) and were here measured as "exchangeable bases". A general rating of the exchangeable bases according to HAZELTON (2007) is given in Table 7.

Table 7: Rating of exchangeable bases, Source: Hazelton P. et al, 2007, p.65

Rating	Na [me%]	K [me%]	Ca [me%]	Mg [me%]
very low	0 - 0,1	0 - 0,2	0 - 2	0 - 0,3
low	0,1 - 0,3	0,2 - 0,3	2 - 5	0,3 - 1,0
moderate	0,3 - 0,7	0,3 - 0,7	5 - 10	1 - 3
high	0,7 - 2,0	0,7 - 2,0	10 - 20	3 - 8
very high	>2	> 2	> 20	> 8

Another way of interpreting the results for the exchangeable bases is to look at the proportion of the CEC occupied by a specific cation (e.g. %Ca of CEC). Deficiencies of a specific nutrient are often specified by its saturation percentage. Following, the importance and the effects of the particular exchangeable bases are explained and their quantitative existence in the soils of the study sites presented.

Calcium

Calcium (Ca) is normally present in soils in sufficient quantities. Deficiencies occur in very acid soils with low effective CEC in high rainfall areas. The calcium level in soils comes from weathering, dissolution or fertilizers and is is removed from soils by plant uptake, leaching or soil erosion. The level of exchangeable calcium normally exceeds the levels of exchangeable magnesium, potassium and sodium (which is also desirable). In soils of humid regions the proportion of exchangeable magnesium relative to calcium increases. The saturation of exchangeable calcium is closely related to the base saturation and the pH and inversely related to aluminium saturation (Peverill K.I. et al., 1999, p.247).

Magnesium

Magnesium (Mg) is an essential plant nutrient and one of the most common elements of the earth's solid surface. The magnesium reserve in soils mainly comes from rain, fertiliser and the breakdown of minerals. Soil magnesium is lost by crop removal or leaching (Peverill K.I. et al., 1999, p.255). The exchangeable fraction of magnesium is most important to plant growth and has, after exchangeable calcium, the second highest level of the exchangeable bases in neutral to acid soils. According to PEVERILL (1999), critical levels of exchangeable magnesium for crop production depend on the texture of the soil as well as the soil pH. The dependence on the acidity of the soil is due to its higher availability to plants in acid soils (Peverill K.I. et al., 1999, p.258).

Potassium

Potassium (K) is one of the most abound elements in soils and is required by plants for many important processes. Potassium has to be provided to the plant by the soil in high amounts. Soils with a higher clay content or high organic matter content generally have higher contents of total K. In soils with a low organic matter and clay content, K might be lost by leaching. Deficiencies of potassium can be due to generally low levels in soils, but also because of potassium-removal by agricultural crops. The amount of potassium removed by the plant depends on the type of crop. Potato as well as sugarcane can remove a relatively high amount of potassium (200kg/ha), while grain crops remove only little (10kg/ha) (Peverill K.I. et al., 1999, p.230). The exchangeable fraction of potassium is immediately available to plants, while non-exchangeable available potassium is available more slowly. The interpretation of soil test levels of K depends on soil texture, since the extractants might also remove non-available potassium in soils of heavier texture (Peverill K.I. et al., 1999, p.234).

Sodium

Unlike Ca, Mg and K, Sodium (Na) is no plant nutrient and hence not needed for plant growth. As a consequence of very high sodium levels, the clay particles of the soil can swell or disperse and the physical structures of the soil may be damaged. Therefore sodicity of soils can be detrimental to plant growth. Other consequences can be water logging, crusting, hard-setting and erosion (Peverill K.I. et al., 1999, p.153). A common way to assess the sodicity of a soil is the calculation of the exchangeable sodium percentage (ESP), which is the proportion of the CEC that is occupied by sodium. Soils are said to be sodic at ESPs above five to six (Peverill K.I. et al., 1999, p.253).

2.2.3.2.5 Soil Nutrients

Organic matter consists of organic material derived from plant residues and animals. It accounts much to the chemical and physical fertility of a soil and is an important storage reservoir for carbon (C), nitrogen (N), phosphor (P) and sulphur (S). Mineral soils usually have organic matter contents of one to ten percent and contain about 58% C, 5% N, 0.5% P and 0.5% S. The total organic matter of the soil can be estimated by measurements of soil carbon- and nitrogen contents. The carbon- nitrogen ratio (C/N ratio) is used to assess the state of decomposition of organic matter (Thiagalingam K., 2000).

Organic Carbon

Soil Organic Carbon (SOC) is a very important property as it is a key factor for soil fertility and contributes to soil erosion resistance (Meersmans J. et al, 2009). It has a great influence on how chemicals react in a soil and therefore plays an important part in its characterisation. SOC is often used as an indicator for soil organic matter and is expressed as percentage of the total soil (Schumacher B.A., 2002). To estimate the content of organic matter of the soil, the level of organic carbon is multiplied by a conversation factor of usually 1,72, which is derived from the assumption that the content of organic carbon in organic matter is 57% (Hazelton P. et al, 2007). General ratings of the levels of organic matter and organic carbon according to HAZELTON (2007) are given in Table 8.

Table 8: Rating for organic matter and organic carbon, Source: Hazelton P. et al, 2007, p.78

Level of organic matter % (g/100g)	Level of organic carbon % (g/100g)	Rating
< 0,70	<0,40	extremely low
0,70 - 1,00	0,40 - 0,60	very low
1,00 - 1,70	0,60 - 1,00	low
1,70 - 3,00	1,00 - 1,80	moderate
3,00 - 5,15	1,80 - 3,00	high
> 5,15	> 3,00	very high

Total Nitrogen

Total Soil Nitrogen (TSN) is closely associated to SOC and is also important for soil fertility and the enhancement of soil productivity. The attention on those two factors has increased lately, since the emission of their gases into the atmosphere contribute to global warming. Therefore the sequestration of carbonate and the conservation of nitrogen in soil are important management options for the mitigation of greenhouse gas emissions.

The measure of TSN includes all organic and inorganic forms of nitrogen in the soil. Most of the nitrogen is held in the organic matter of a soil and hence cannot be used by plants. Therefore the measure of total nitrogen does not provide information about plant available forms of nitrogen (NO_3^-, NH_4^+) (Hazelton P. et al, 2007). Plant available forms are generated through mineralisation processes, which are highly dependent on climatic conditions and thus on soil moisture, temperature and soil pH. Reduced soil mineral nitrogen levels can occur at waterlogged soils or on slow draining soils after heavy rainfall due to denitrification processes (soil nitrate is conversed to gaseous forms N_2 and N_2O). Soil nitrogen can be lost by leaching in soils with high internal drainage and especially in high rainfall areas (Peverill K.I. et al., 1999, p.173). A general rating of total nitrogen levels according to HAZELTON (2007) is given in Table 9.

Table 9: Rating for total nitrogen, Source: Hazelton P. et al, 2007, p.67

Rating	Total Nitrogen (%)
<0,05 very	low
0,05 - 0,15	low
0,15 - 0,25	medium
0,25 - 0,50	high
>0,50 very	high

C/N ratio

The carbon /nitrogen ratio (C/N ratio) expresses the relative content of nitrogen in organic material. It provides information about the decomposition of organic material and demonstrates the role of crop residues on their breakdown rate and on the level of soil nitrogen (Hazelton P. et al, 2007). The higher the C/N-ratio is, the lower is the amount of available nitrogen. Therefore a very low C/N ratio is a sign of excess nitrogen in soil. A general rating of the exchangeable bases according to HAZELTON (2007) is given in Table 10.

Table 10: Rating for the C/N ratio, Source: Hazelton P. et al, 2007, p.68

Rating C/N	ratio
< 10	very low
10 - 15	low
15 - 25	medium
25 - 70	high
70 - 100	very high
> 100	extremely high (very nitrogen deficient)
860	approximate end point (essentially having cero nitrogen)

Soils used for agriculture normally possess C/N-ratios of ten to twelve. Higher ratios suggest a slower decomposition process, and values above 25 mean that the organic matter will not break down quickly. Ratios below ten indicate a rapid break down of organic material. If the ratio is above 20, nitrogen will be locked up while decomposing, which makes it unavailable to crops. The presence of resistant organic structures and organic compounds also has an influence on the decomposition rate (Hazelton P. et al, 2007).

2.2.3.2.6 Bulk density

The bulk density describes the relation of the soil mass and its volume and therefore expresses the state of compaction of a soil. One can generally say that soils with low bulk densities are in porous conditions, whereas high bulk densities display higher compaction which means worse settings for root growth, reduced aeration and reduced water infiltration (FAO, 2006). Agricultural soils typically have bulk densities of 1,4 g/cm³ (Hazelton P. et al, 2007, p.18). In clay soils bulk densities of 1,4 g/cm³ and in sandy loams of 1,8 g/cm³ are very probable to be restrictive to plant root growth. A general rating of the bulk density according to HAZELTON (2007) is given in Table 11.

Table 11: Rating for the bulk density, Source: Hazelton P. et al, 2007, p.20

Rating	Bulk density (g/cm^3)
very low	< 1
low	1 - 1,3
moderate	1,3 - 1,6
high	1,6 - 1,9
very high	> 1,9

2.2.3.2.7 Hydraulic conductivity

The hydraulic conductivity (k) is the rate at which a fluid moves through a porous medium. The saturated hydraulic conductivity of a soil describes the velocity of the water movement through the saturated soil. It depends on the porosity of the material and on the size and shape of the grains (Rizema H.P., 1994).

Table 12 shows a general rating of the saturated hydraulic conductivity according to HAZELTON (2007). Soil layers with extremely low hydraulic conductivities could be used for water storage whereas soils with very high hydraulic conductivities are vulnerable to contaminations of their water tables (Hazelton P. et al, 2007, p.14).

Table 12: Rating of the saturated hydraulic conductivity, Source: Hazelton P. et al, 2007, p.14

Rating	Saturated hydraulic conductivity (mm/h)
extremely low	< 0,5
very low	0,5 - 10
low	10 - 20
moderate	20 - 60
high	60 - 120
very high	> 120

2.2.4 CROPS

A huge number of different types of cash crops and food crops are grown in Papua New Guinea. This chapter provides only a short description of those, which are essential for food security in the highlands. In this thesis only the soils with regard to food crops were investigated, but since cash cropping is an important component for most of the smallholder farmers and accounts for food security (especially in times during droughts - see Chapter 2.1.3) it cannot be left completely unattended.

2.2.4.1 Food crops

Food crops are grown either for subsistence consumption or for sale at local food markets and include root crops, sago, banana, maize and green vegetables. Sweet potato is thereby the most important food crop and constitutes the staple food for more than 60% of the rural population (Hartemink A.E. et al, 2000). Other staple food crops for rural villagers are: sago, banana, yam, taro, Chinese taro, cassava, Irish potato and corn (Allen B.J. et al, 2000b).

Figure 15 shows the most important crops by province. It can clearly be seen that the Highlands Provinces nearly exclusively depend on sweet potato.

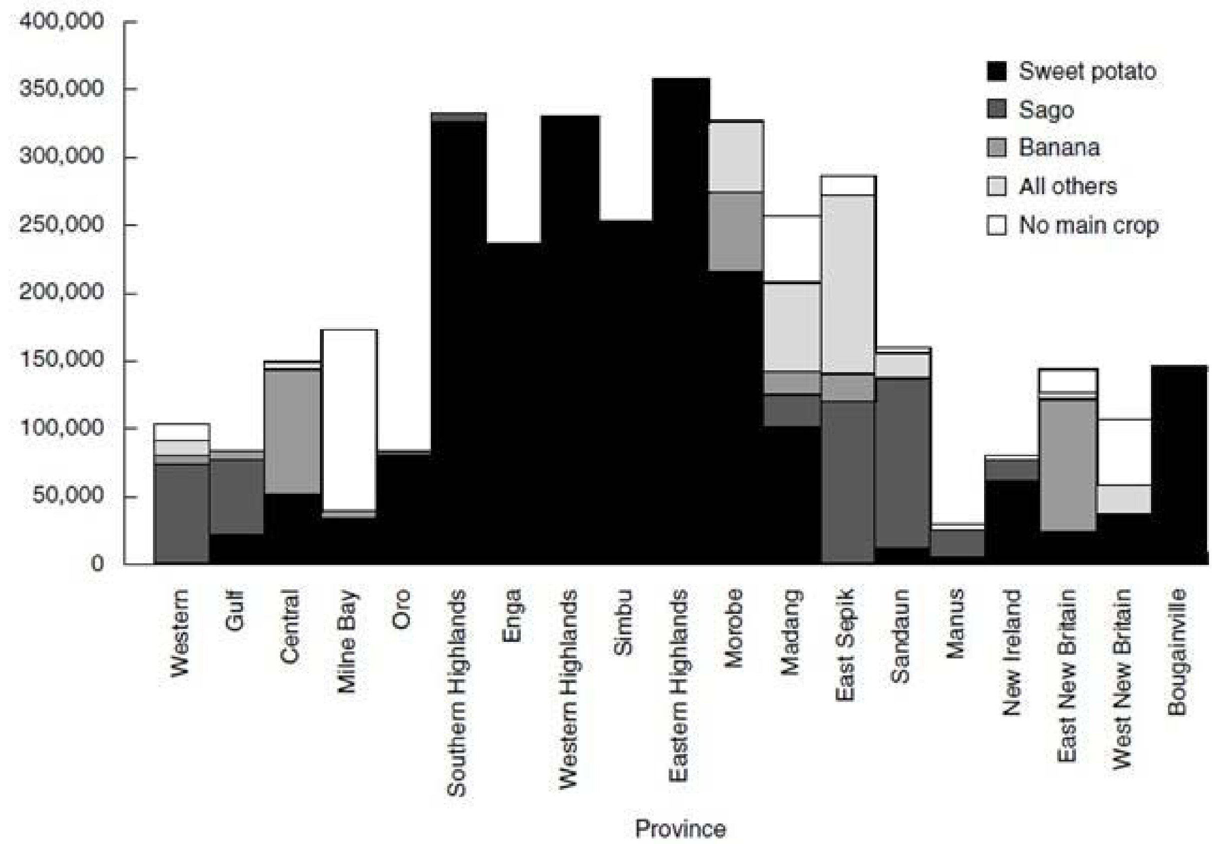


Figure 15: Most important crops by province; the ordinate shows the number of people cultivating the crop and the abscissa the province in which it is planted, Source: Allen B.J. et al, 2000b

Sweet potato

Sweet potato was introduced from eastern Indonesia to the highlands of Papua New Guinea about 300 years ago. By the time of the first contact with European explorers it dominated the highlands agriculture and has replaced taro as the most important staple food. Now it is grown by 99% of the rural villagers and represents an important food for 80% of the rural population, especially at locations above 1500masl (Bourke R.M. et al., 2009a, p.194). The introduction of sweet potato lead to significant changes in agriculture and in social and economic conditions, since it allows settlement at higher altitudes and utilisation of poorer soils. It also provides excellent pig fodder. About one-third of the sweet potato produced in the highlands is fed to pigs, which is the most important domestic animal (Bourke R.M. et al, 2009b).

The most common farming practices for sweet potato based systems are mound tillage, composted mounding and fallow rotation. Sweet potato is often intercropped with other food crops and sometimes planted in rotation with leguminous crops.

The most important environmental factor for sweet potato production is altitude. The altitudes where it is grown in Papua New Guinea range from the sea level up to approximately 2700masl. The crops grown in the highlands are exposed to lower temperatures and therefore need more time to mature than those grown in the lowlands. Crops planted at the sea level only mature after 13 - 22 weeks, while crops at altitudes of 1500 - 2000masl need 20 - 35 weeks and crops above 2000masl need 35 - 50 weeks. At altitudes higher than 2200masl frost can occur and damage the sweet potato tubers. The mean annual rainfall of the regions in which sweet potato is grown ranges between 1000mm and 6500mm. Sweet potato is very vulnerable to water logging, but can tolerate dry periods to a certain extend. The most critical period in terms of water supply is during the first 21 days when the roots of the plants are developed. Excessive moisture during this time leads to minor root growth and water stress to reduced yields (Hughes M.J. et al, 2009). Apart from swamps or waterlogged areas sweet potato is cultivated on nearly all landforms and soil types of PNG. It can be grown on soils from strongly acid to neutral and has moderate requirements of Nitrogen (N), low requirements for Phosphorus (P) and high requirements of Potassium (K) (Hughes M.J. et al, 2009). In the humic brown soils of the highlands potassium and phosphorous are the most limiting factors for sweet potato cultivation (Wood A.W., 1987). In areas above 2000m asl symptoms of P deficiency can often be found, especially on volcanic ash soils which have very low potassium levels (Hughes M.J. et al, 2009). The practice of removing old sweet potato vines from the garden exacerbates the problem of nutrient depletion as high quantities of K and S are stored there (Bailey J., 2009).

Taro

Taro was the most important staple food crop in the highlands until the introduction of sweet potato and is now grown in most of PNG as a supplementary crop. Colocasia taro is grown by 95% of the rural population throughout the country up to 2400masl. The production has declined since 1940 due to loss of soil fertility, virus infection and taro beetle damage. Chinese taro is grown by half of the rural population and up to an altitude of 2000masl.

Cassava

Cassava was introduced to PNG in the 19th century and is now grown by over 50% of the rural population. It can be found within a wide range of rainfall and is more important in the lowlands since it doesn't grow at altitudes higher than 1800masl (Bourke R.M. et al., 2009a, p.197).

Banana

Banana is grown by 96% of the rural population in PNG. The exception are people living at very high altitudes, because it doesn't grow in locations higher than 2150m asl. Its importance has declined as the one of a number of foreign crops has increased (sweet potato, cassava,..).

Yam

Yam is grown throughout the country by 60% of the rural population. Greater yam grows up to an altitude of 1900m asl and lesser yam up to 1550masl. Yam is important in seasonally dry climates and sometimes in areas with well distributed rainfall over the year.

Corn

Compared to the main root crops, banana and sago corn is no important food crop, but it is still grown by 94% of the rural population. It was introduced to PNG in the 19th century and can be found up to an altitude of 2450m asl. It is grown in seasonally dry areas (for example in the Eastern Highland Province around the study site Kopafo) because it matures faster than other crops (Bourke R.M. et al., 2009a, p.200).

2.2.4.2 Cash crops

Rural people consume about one sixth of their total calories in form of imported food that they buy at supermarkets or local markets. This includes rice, flour, tinned meat, tinned fish and oil. The money for this additional food is made by cash cropping, which is practiced by many smallholder farmers.

The most important agricultural source of cash is Arabica coffee. Especially in the valleys of Eastern- and Western Highlands Provinces coffee is planted by villagers on their own land and harvested by themselves. On the other side palm oil, which is another important source of income, is produced on big, privately owned palm tree plantations and needs factories to be processed. Other important cash crops are cocoa and betel nut. While Arabica coffee grows in an altitudinal range of 1400 - 2000m asl, cocoa, betel nut and the oil palm are restricted to the lowlands. When looking at the number of people involved, the most important income generating activity is the sale of fresh food. This practice can be found everywhere in the country, usually on a very small scale, and is sometimes the only source of income. However, the majority of smallholder farmers is not restricted to one, but rather practice a combination of income generating activities. A crucial factor for their ability to earn money from agricultural activities is the quality of their land and its location relative to a market. (Allen B.J. et al, 2000b)

2.2.5 FOOD SECURITY IN THE PNG HIGHLANDS

Since the drought in 1997 people have realized that their farming systems are very fragile to extreme climatic events and food security is not given at those times. The cause for the food insecurity is said to be poverty and urbanization, which leads to a reduced number of farmers and at the same time an increased number of people that consume but do not produce food (Benjamin A.K et al., 2000).

The food insecurity and its magnitude depends a lot on the location and a large part of the rural people live in areas with disadvantageous conditions. In these areas the population grows and so does the food demand. Farmers have to expand to marginal areas and to intensify the agriculture, leading to resource degradation and poverty. At the same time areas of high potential are being supported with infrastructures and agricultural technologies by donors and governments (Benjamin A.K et al., 2000).

To improve food security, different farming systems suitable for small scale agriculture have to be developed and adapted. This way external inputs are used most efficiently and at the same time have no, or only little negative environmental impact. To achieve that, the knowledge and the application of traditional technology combined with scientific research into the biological processes of agricultural production is required (Benjamin A.K et al., 2000).

3 METHODOLOGY

In this chapter the methods that were used to write this thesis are described. First, relevant literature was obtained through an intensive literature research, later secondary data was collected in Papua New Guinea and finally the primary data was obtained through field work in the study sites.

3.1 SECONDARY DATA COLLECTION

As far as available, secondary data was collected from different institutions of Papua New Guinea. The collection of the data presented some difficulties, especially as there either is no data, or it is incomplete.

Weather data is often not recorded continuously and therefore long-time series have large gaps. Another problem is that the climate varies a lot from valley to valley and even if data is obtained from a nearby weather station, it might not be representative for the research area. During the field stay weather data including rainfall and temperature series could be obtained from the NARI weather station in Tambul.

Digital maps of Papua New Guinea including the factors altitude, geology, inundation, land form, radiation, rainfall, seasonality, slope, soil, temperature, topographic position have been provided by NARI in the form of GIS data (PNGRIS). Unfortunately the data has a rather rough scale and the study sites which are very small are not represented in detail.

With this data as background-information the primary data collection was conducted.

3.2 PRIMARY DATA COLLECTION

The primary data was collected during a three months stay in Papua New Guinea. Several weeks were spent in the selected study sites named Alkena, Kiripia and Kopafo. The field work was conducted with the help of employees from NARI and respectively a member of each community familiar with the locality, language and people. The following actions were undertaken to investigate the general and soil specific features of the study sites.

3.2.1 MAPPING

The study sites were represented in a map, using a computer based geographic information system (GIS). The GIS data obtained from the secondary data collection served as basic information for the more detailed maps generated during the field stay. They were created through transect walks using a GPS device of the type Magellan eXplorist 310. With this device the tracks from the walks were recorded, additional GPS points were set at important locations and both were inserted in the GIS program.

The route for the site inspection was chosen on the basis of a hand drawn map of the area and the information of a local guide. The goal was to get a digital map of the study sites with specific information concerning its soil and water conditions. Thereby locations with problems related to soil and water issues such as water logging, flooding and soil erosion should be identified. A focus was laid on sites with either excess soil moisture or deficit soil moisture.

During the transect walks the following indicators were observed and recorded:

- roads, ways and tracks
- rivers
- villages and central places such as schools, churches, hospitals
- water providing facilities such as water tanks and sources
- sampling spots of the soil survey
- location of the profile pits

3.2.2 Soil and Site Description

The soils present in the study sites were described and analysed to assess the quality of soil conditions, to learn about its suitability for agriculture and to assess potential problems with respect to the respective soil excess and deficit water scenarios. The land form and plant cover of the sites was also recorded as these factors can easily be recognized in the field and have a great influence on the characteristics of a soil. A high slope for example can lead to excessive runoff and accordingly to erosion, loss of nutrients and reduced water availability in the soil. The condition of the soil surface like the existence of cracks, erosion, hard setting or self mulching was also recorded.

The description of the soil itself was conducted by three methods. At first the whole area was surveyed with a soil core auger, providing an overview of the soils found on site. On the means of this information the locations for profile pits were selected and consequently dug. At last, undisturbed soil samples were taken from each profile pit and sent to a laboratory for analysis. In this chapter those three methods and the indicators used for soil characterisation are described.

Additional information about the study sites was gathered during discussions with key informants from the respective communities.

3.2.2.1 Soil morphological descriptors

The following soil morphological descriptors derived from PEVERILL (1999) were used to characterise the soil in the field:

Soil colour and internal drainage

Soil colour is one of the most important soil properties determined in the field and plays an important role in soil classification. The following indicators for good and poor soil conditions were derived from PEVERILL (1999):

good soil conditions:

- *dark brown colours near the surface are often associated with high organic matter levels, well-aggregated soil, above-average nutrient levels;*
- *bright yellowish and reddish colours in sub-soils usually indicate iron (goethite and hematite) under oxidised conditions, suggesting good drainage; these iron oxides also contribute to good aggregation which are porous and contain sufficient air and water for root development*

poor soil conditions:

- *mottles with dull yellow and orange colours in a grey, bluish or olive coloured material indicate prolonged lack of soil aeration; possibly seasonal or permanent water logging*

- *rust coloured specks and iron precipitates along fine roots indicate prolonged permanent water logging*
- *very pale grey or white colours may indicate considerable leaching and low organic matter status and fertility status*
- *pale coloured dense sub-surface layers overlying dense clays (usually with mottled colours) indicate a perched water table on the clay*
- *black mottles with the smell of hydrogen sulfide or mercaptene gases develop through anaerobic decay of organic matter and indicate severe water logging*

Soil colour also provides information about the drainage conditions of a soil. A soil that has uniform red, brown or yellow colours within the first meter is *freely drained*. It does not have grey layers or rusty mottles. If there is a layer that restricts the water movement downwards within the first meter, the soil has *impeded drainage* conditions. This layer can be grey with rusty mottles and concretions, or yellow or pale brown with distinctive rust coloured mottles. A soil is *poorly drained* when the subsoil is dominant grey, green or blue and has lots of rust coloured mottles or concretions. Hence soil colour is a good indicator for the identification of waterlogged soils when the monitoring of the water table is too expensive and not viable.

Texture

The soil texture describes the proportion of sand, silt and clay in the soil. It can be estimated in the field by the following method (Peverill et al., 1999, p.59):

A small amount of soil is taken, moistened with water and worked until there is no apparent change in the ball anymore. Subsequently a ribbon is made by shearing the soil between thumb and forefinger. The length of the ribbon and the behaviour of the worked soil characterise the soil texture as specified in Table 13.

Table 13: Field assessment of soil texture, Source: Peverill et al., 1999, p.60

Texture	Code	Ribbon length [mm]	Ball
Sand	S	nil	coherence nil to very slight
Loamy sand	LS	5	coherence nil to very slight
Clayey sand	CS	5-10	coherence very slight
Sandy loam	SL	15-25	coherence slight
Loam	L	25	coherent, rather spongy
Silty loam	ZL	25	coherent, rather spongy
Sandy clay loam	SCL	25-40	strongly coherent
Clay loam	CL	40-50	coherent, plastic
Light clay	LC	50-75	plastic
Medium clay	MC	>75	smooth plastic
Heavy clay	HC	>75	smooth plastic

Soil structure

The soil structure describes the way soil particles are located to each other. A soil is called *well structured* if it consists of naturally formed aggregates (peds) with irregular spaces in between. If those peds are coarse, large and firm, the soil has a reduced water storage capacity and restricts the root growth to a certain extent. Fine and friable peds on the contrary make it easier for roots to spread and they have a greater storage capacity of water available for the plant. A *structureless* soil has no or very little peds.

If two thirds of the soil consist of loose and individual particles it is said to be in *single grains*, but if it is in a block composed of particles that are bound together it is called *massive*.

A shearing fault in the soil that appears like a shiny plane is called a *slickenside*. It occurs in clay soils when they shrink or swell and can stretch across the soil mass in any direction. A soil that exhibits slickensides is highly impermeable to water movement, especially when it is in a moist state, and has restricted root growth.

The soil structure can easily be determined in the field if the soil is in a dry to slightly moist state. This is done by a visual observation of the presence or absence of peds and slickensides, and the identification of the soil matrix as structureless, well structured, single grained or massive.

Segregations
The accumulation of other particles in the soil is called segregation. Those particles can occur in various sizes, shapes and forms and can be of iron, calcium carbonate, gypsum or other materials. They can have an important influence on soil physical and chemical properties and hence should not be let out during the field soil inspection.

Presence of roots
The observation of the presence of roots provides information about either water availability, existing restrictive layers or toxicity to plant root growth.

3.2.2.2 Soil survey

3.2.2.2.1 Soil core auger

The area of the study sites was surveyed taking various soil samples with a soil core auger. The soil was abstracted until a depth of one meter and the core of soil inspected. Thereby the different soil horizons were identified and their depths measured. Each horizon was described on the basis of the soil morphological descriptors (Chapter 3.2.2.1). The samples were not retained for further analysis, but pictured and then left on site.

In Kopafo, the soil samples were taken systematically at regularly distributed points given by a coordinate system. For this purpose a uniform grid was laid over the area of the study site. The interceptions formed twenty points that were arranged in four rows. During the field work those points were located with a GPS device and consequently sampled with the soil core auger.

In Kiripia ten and in Alkena eleven soil sampling spots randomly distributed over the area were chosen. The selection of the sampling spots took place on the basis of the personal judgement of the author. Thereby places of different sub environments were taken into account and unusual spots like tracks and headlands avoided. The exact location of the spots was recorded with the GPS device and the information was inserted in a map.

3.2.2.2.2 Profile pit

A profile pit is an open hole in the ground that is dug to look at a soil profile and inspect the soil in its natural state. During the field work seven profile pits were dug, three of which were located in the study site Kopafo, two in Kiripia and two in Alkena. The sites for the profile pits were selected on the basis of the information gotten during the soil survey. The places had to be representative for the area, in accordance with the owners of the land and suitable for further actions in the course of the EU ARD project.

The pits were dug with the help of local villagers mostly in their own gardens and had an approximate size of 1m x 1m x 1m, depending on the conditions on site. Important was, that the sides of the pit were straight and wide enough to see to the bottom and that the upper part was wider, forming a step (see Figure 16). After the finalisation of the pit, a side which was well exposed, had a straight and clean cut, and could be seen clearly was examined. Thereby the different soil horizons were identified and their depths measured. The soil of each horizon was described by means of the soil morphological descriptors specified in Chapter 3.2.2.1. At the end two undisturbed soil samples were taken from each soil horizon.

When groundwater is found before reaching the final depth of the pit, it is not possible to continue digging. In this case the samples were taken as low as possible at the bottom of the pit.

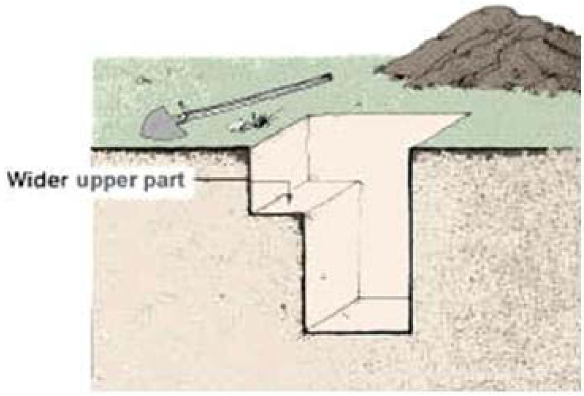


Figure 16: Scheme of a profile pit, Source: FAO, 2012

3.2.2.2.3 Soil samples

Undisturbed soil samples were taken from every profile pit dug in the study sites. Thereby each soil horizon with a minimum thickness of 10cm was sampled two times, using sampling rings of stainless steel that had a height of 8,5cm and a diameter of 12,5cm. In most cases the samples were taken at depths of 30cm, 60cm and 90cm. One of the samples of each horizon was brought to the laboratory in Aiyura to estimate the bulk density, and the other one was sent to the soil chemical laboratory in Port Moresby.

For the sample taking, a step was prepared in the profile pit (see Figure 16), having a straight, clean cut. The sampling rings were driven in the soil with extreme precaution to preserve the natural state of the soil of the sample. To drive them in evenly and without cracking, a wooden block and a hammer was used. Once the samples were hammered down completely, the soil around the samples was removed carefully, leaving only the ring filled with soil on the step. After cleaning the outside of the rings from the redundant soil, the soil samples were packed in plastic bags. To avoid the evaporation of the wet soil, the samples should be covered with plastic caps and sealed with tape on the interfaces. However, as there were no caps available, each sample was wrapped in a banana leave before packing it in the plastic bag. The plastic bag then was labelled with the date, the place, the number of profile pit and depth from which the sample was taken. The transport to the laboratory has to be arranged so that the samples are not altered in any way.

3.3 LABORATORY ANALYSIS

The analysis of the soil samples took place at two different laboratories. One set of undisturbed soil samples (21 samples) was sent to the laboratory of the NARI Highlands Centre in Aiyura, where the bulk density was determined.

The second set of undisturbed soil samples was analysed in the NARI Chemistry Laboratory in Kila Kila/Port Moresby, which is situated in the National Capital District of Papua New Guinea. A determination of the soil texture was conducted for all soil samples send to the laboratory, i.e. three soil samples per profile pit. An analysis of the soil chemical parameters (pH, CEC, BS, SOC, TSN) was only conducted for the soil samples taken from the topsoil layers, i.e. one soil sample per profile pit. The nutrient status of deeper lying soil layers is not relevant for crop production, which is why a chemical analysis of the soil from these layers was not needed.

In this chapter the analysed physical and chemical parameters are specified. The methods explained are conform to the methods used in the NARI laboratories.

3.3.1 PHYSICAL PARAMETERS

3.3.1.1 Particle Size Distribution Analysis (PSDA)

The soil is made of particles of different sizes and shapes, which can be grouped into different texture classes, according to their size. The particle size analysis determines the relative proportion of different size ranges by weight. The method used to estimate the proportions of particle sizes employs sieving for the coarser fractions and the hydrometer for the finer fractions. The hydrometer method is based on Stokes' law, which states that particles with a higher density sink faster than particles with a lower density when they are suspended in a liquid (Carter M.R. et al., 2008).

The classification of the particle sizes into texture classes varies slightly between different countries, but the upper limits of sand and clay size usually are the same. Table 14 shows the International standard which is used in Papua New Guinea in opposition to the USDA/FAO system.

Table 14: Opposition of the international and USDA/FAO standards for classification into texture classes, Source: Minasny B. et al., 2001

	International system [mm]	USDA/FAO system [mm]
clay	< 0,002	< 0,002
silt	0,002 - 0,02	0,002 - 0,05
sand	0,02 - 2	0,05 - 2

The soil from the analysed soil samples was classified according to the Australian (=International) system for division into soil fractions.

3.3.1.2 Bulk Density

The bulk density of a soil is the quotient of its mass and its volume. The mass includes all the solid components of the soil and is measured by weighting the oven-dry sample. The volume includes the solids and pores and is given by the volume of the soil sampling ring.

$$\text{bulk density} = \frac{\text{mass of the oven-dry soil}}{\text{volume}}$$

3.3.1.3 Derived Parameter - Hydraulic Conductivity

The saturated hydraulic conductivity was calculated with the program "ROSETTA" which uses hierarchical pedotransfer functions to estimate the hydraulic properties of a soil. Input parameters of the model are soil texture and bulk density.

Since the program uses the FAO/USDA system for classification of texture classes, the texture data had to be converted from the Australian system to the FAO/USDA system. That was done by a formula derived from MINASNY (2001), that assumes a lognormal distribution of particle sizes.

$$P_{20–50} = 48.4593 – 0.2225\ P_{20–2000} – 0.0029\ (P_{20–2000})^2 – 0.6952\ P_{<2} + 0.0018\ (P_{<2})^2$$

Thereby the increment of particles of the fraction 20µm - 50µm was calculated and consequently the fractions of the FAO/USDA system could be determined (Minasny B. et al., 2001).

3.3.2 CHEMICAL PARAMETERS

3.3.2.1 pH

The pH value was determined by a potentiometric measurement of the activity of hydrogen ions of a 1:5 soil-water (H_2O) suspension using a pH meter (Code 4A1 in Rayment G.E. et al., 2011).

3.3.2.2 Cation Exchange Capacity (CEC) and Exchangeable Bases

Before determining the exchangeable bases (K^+, Ca^{2+}, Mg^{2+} and Na) or the CEC, the soluble salts have to be removed during a pre-treatment. This has to be done because the dissolution of hardly soluble salts could change the relative proportions of individual exchangeable cations (Peverill et al., 1999, p.148). For non calcareous soils dominated by permanent charge the method used is an exchange with 1 M ammonium acetate (NH_4COOCH_3) at pH 7 with manual leach (Code 15D2 in Rayment G.E. et al., 2011). The Cation Exchange Capacity is indicated in milliequivalents of negative or positive charges (Camberato J. J., 2001).

3.3.2.3 Base Saturation (BS)

The base saturation was calculated by determining the quotient of the sum of exchangeable bases and the Cation Exchange Capacity.

$$BS = \frac{\text{sum of exchangeable bases (Ca, Mg, K, Na)*100}}{\text{cation exchange capacity}}$$

3.3.2.4 Soil Organic Carbon (SOC)

The method used to estimate the content of the soil organic carbon is the one of Walkley and Black (Code 6A1 in Rayment G.E. et al., 2011). It is a wet oxidation procedure, in which an oxidant is used to convert the organic carbon in CO_2 (Peverill K.I. et al., 1999, p.160). Therefore potassium dichromate and concentrated sulphuric acid are added to the finely milled air dry soil sample. Through the heat of this reaction the organic carbon is oxidised and the remaining dichromate is determined by redox titration with ferrous ammonium sulphate (Meersmans J. et al, 2009).

This is a commonly used method because organic carbon can be determined simply and fast with little equipment. However, the oxidation is incomplete since the recalcitrant fraction of organic carbon is not detected, which leads to an underestimation of the total SOC content. Therefore a correction factor of 1,33 is used to adjust the results (Schumacher B. A., 2002). If the soil is heated during the oxidation process the oxidation can assumed to be complete and no correction factor is needed (Peverill K.I. et al., 1999, p.160).

3.3.2.5 Total Soil Nitrogen (TSN)

The method used to estimate the total soil nitrogen is the semi micro Kjeldahl-steam distillation (Code 7A1 in Rayment G.E. et al., 2011). The sample is finely milled and air dried before the semi micro Kjeldahl digestion is conducted. Consequently Sodium Hydroxide (NaOH) is added and effects the release of NH_3 by steam distillation, which is then absorbed in dilute bordic acid. The total soil N is subsequently determined through titration with standard acid and is indicated as % N (Rayment G.E. et al., 2011).

4 THE STUDY SITES - ASSESSMENT AND RESULTS

This chapter provides a detailed assessment of the study sites Tambul and Kopafo. The communities Kiripia and Alkena, which are both included in the Tambul study site, as well as the Kopafo community are first described in terms of their climatic, environmental and agricultural conditions. Later the results of the soil survey with the soil core auger and the description of the soil profiles from the profile pits are presented, and finally the results of the laboratory analysis for each study site are summarised and discussed.

However, the results of the laboratory analysis have to be regarded with caution, because the soil samples were not send to the laboratory immediately after sample taking. Due to organisational difficulties it took about one month until the soil samples could be analysed. Considering that the samples were under very wet and in some cases under completely saturated conditions, an alteration of the soil chemistry during that time cannot be ruled out. Furthermore, the soil sampling sites in the study sites were chosen to be especially dry locations in Kopafo and especially wet locations in Tambul. A final conclusion about the general state of the soils in the study sites, and about the differences of the soils between Tambul and Kopafo can therefore not be made. Finally it has to be mentioned that the soil samples from the study sites were all taken at the end of the rainy season, which means that the soils in Kopafo haven't been under the supposed dry conditions at the time of soil sampling.

Additionally, soil data for the relevant areas was abstracted from the GIS map of PNGRIS and compared with the results of the analysis. But the data derived from PNGRIS is not very detailed in the small scale. At locations with a rapid change of soil characteristics within a small range, not every soil type is captured by the database. For detailed soil surveys of smaller areas, the PNGRIS data can only be consulted to a limited extent.

4.1 KIRIPIA / TAMBUL

4.1.1 GENERAL INFORMATION

Kiripia is one of the communities belonging to the study site Tambul in the Tambul/Nebilyer District of the Western Highlands Province. Both communities (Kiripia and Alkena) are situated along one of the main roads to Tambul (Figure 17) at an altitude of about 2300masl. To the south lies Mt. Giluwe, the second largest mountain of the country (4200m). The whole Province is diverse with many mountains covered with rainforests or grasslands which experience a continuous depletion due to population growth and economic activities.

Kiripia comprises a total population of 1703 people (PNG 2000 census, data source: Mike Bourke, Australia National University) and a catholic mission, a school and a health centre (Figure 18). The inhabitants are mostly subsistence farmers who live in traditional houses. Some of them own livestock (mainly pigs but also goat, sheep, chicken and ducks) or practice fish farming. There is a central place, where women eventually sell surplus food from their gardens to other villagers. Some people practice other income generating activities such as owning a PMV, buying goods in Tambul and selling it at the local market or participating in livestock projects such as piggery or aquaculture.

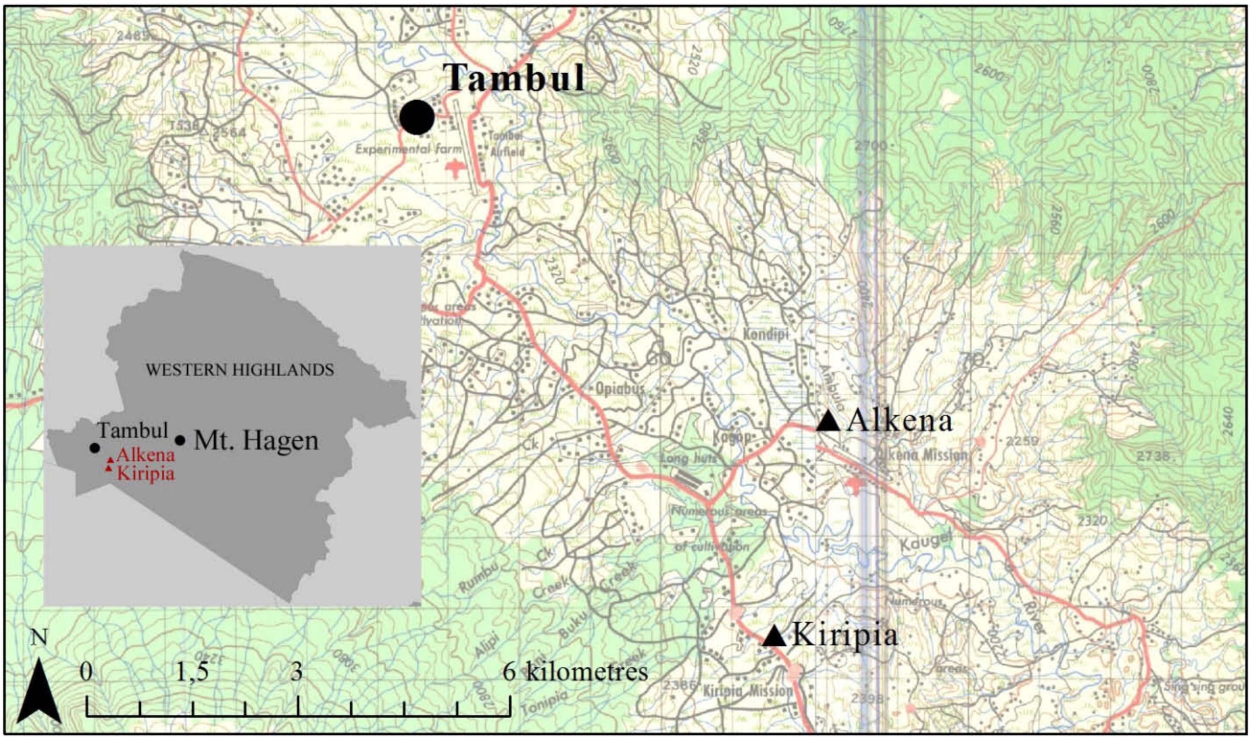


Figure 17: Location of the two communities Kiripia and Alkena of the study site Tambul

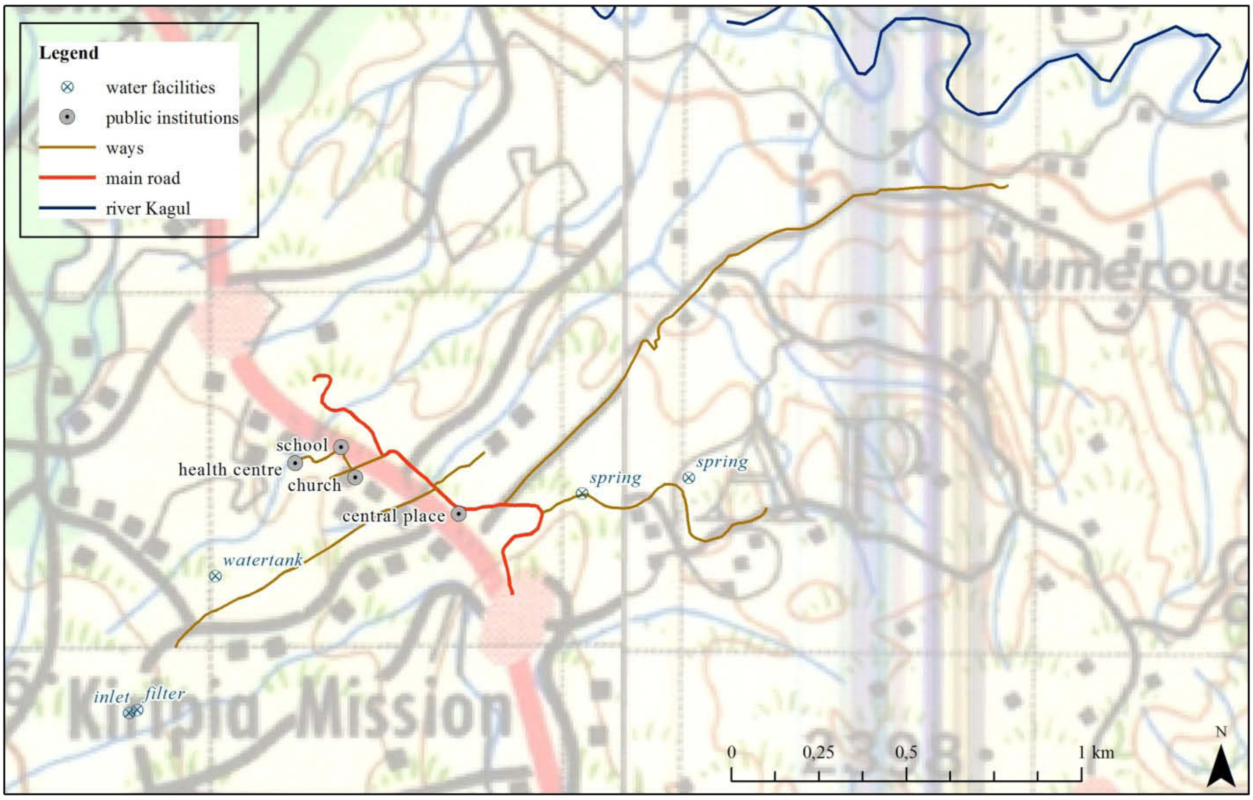


Figure 18: Map of the Kiripia community

4.1.1.1 Climate

One important characteristic of this place is its high altitude of about 2300 metres above sea level which regularly leads to low temperatures at night. Figure 19 shows the average monthly minimum and maximum temperatures recorded by the NARI weather station in Tambul. It is obvious that the maximum temperature varies only slightly over the year, while the minimum temperature drops close to 0°C during the late dry period and frosts occur regularly.

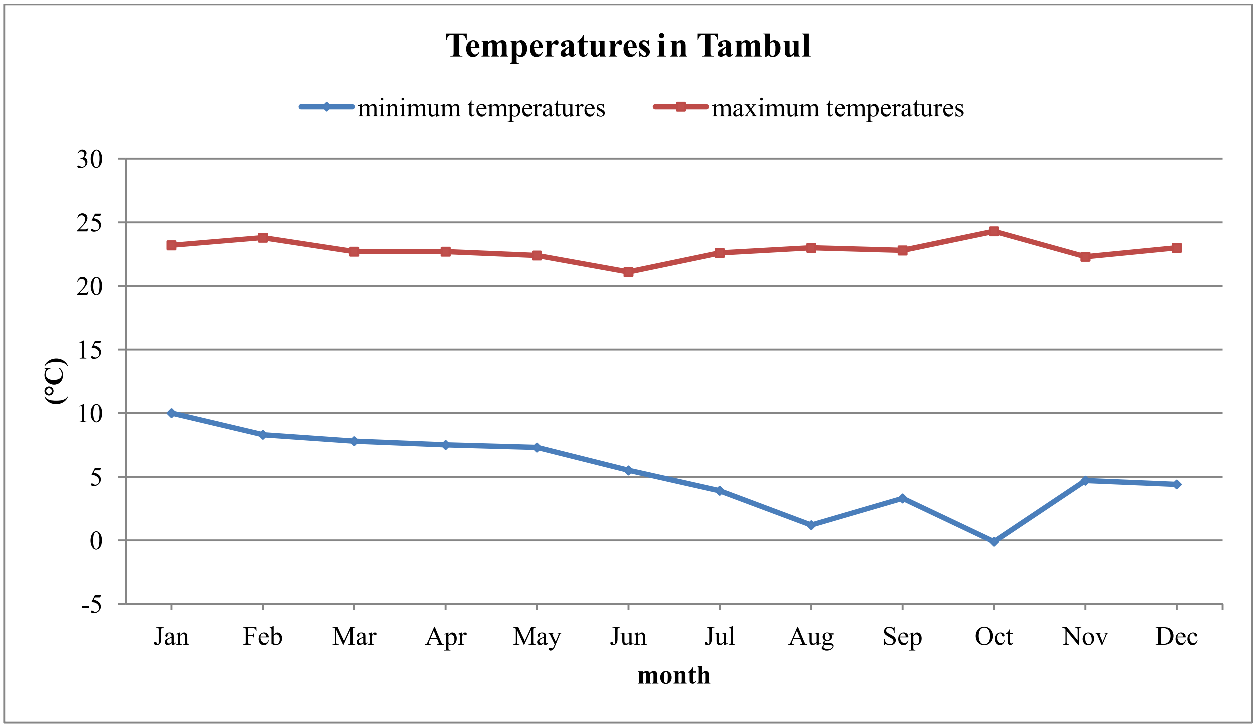


Figure 19: Average minimum and maximum temperatures recorded by the weather station Tambul in the years 2003 - 2009

Another characteristic of this area is its rather high rainfall with an annual mean of 2580mm. Although the seasonality of distribution of rainfall is not as high as in the Eastern Highlands Province, there is still a distinction between a dry and a wet season. The rainy season lasts approximately from October till March, and the dry season from April till September (Figure 20). Even in the months of the dry season of a normal year the rainfall doesn't fall below 100mm.

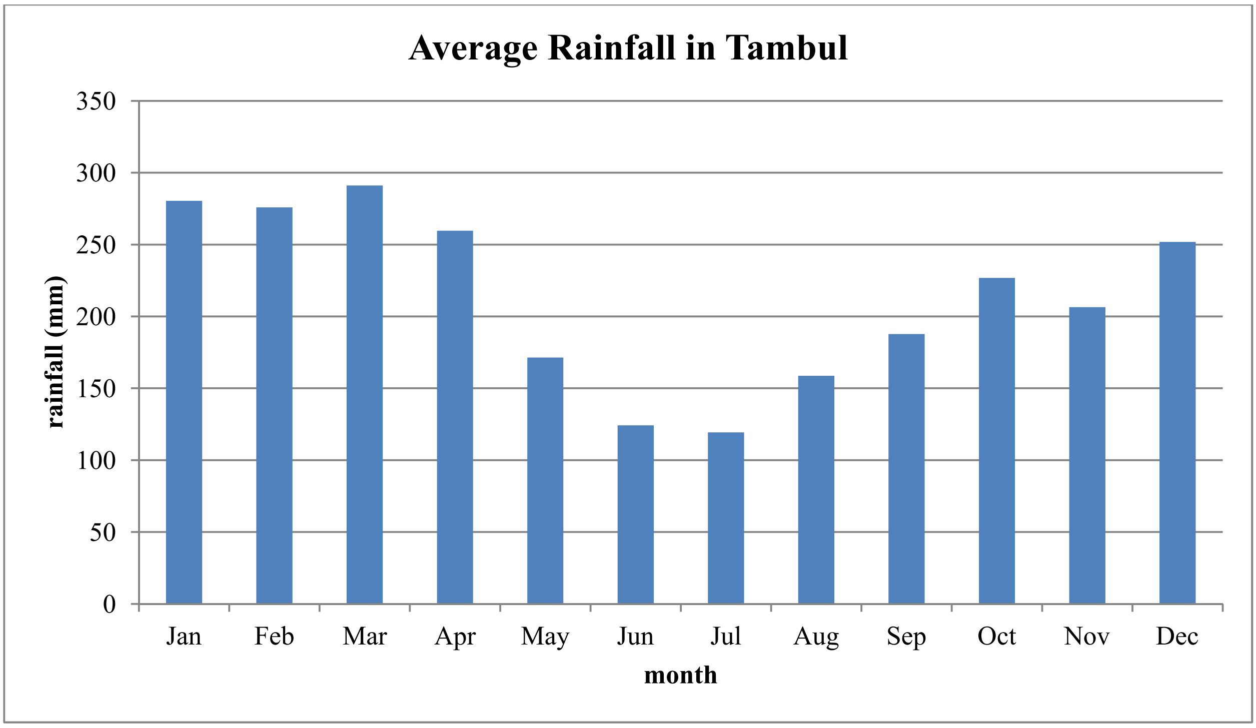


Figure 20: Average monthly rainfall at Tambul weather station over the years 1957 - 2008

In Figure 21 the m onthly average rainfall data of Mt. Hagen is plotted ag ainst evaporation data calculated by HAANTJENS (1970). Since the evaporation never exceeds the rainfall, the balance is positive over the whole year of an average year.

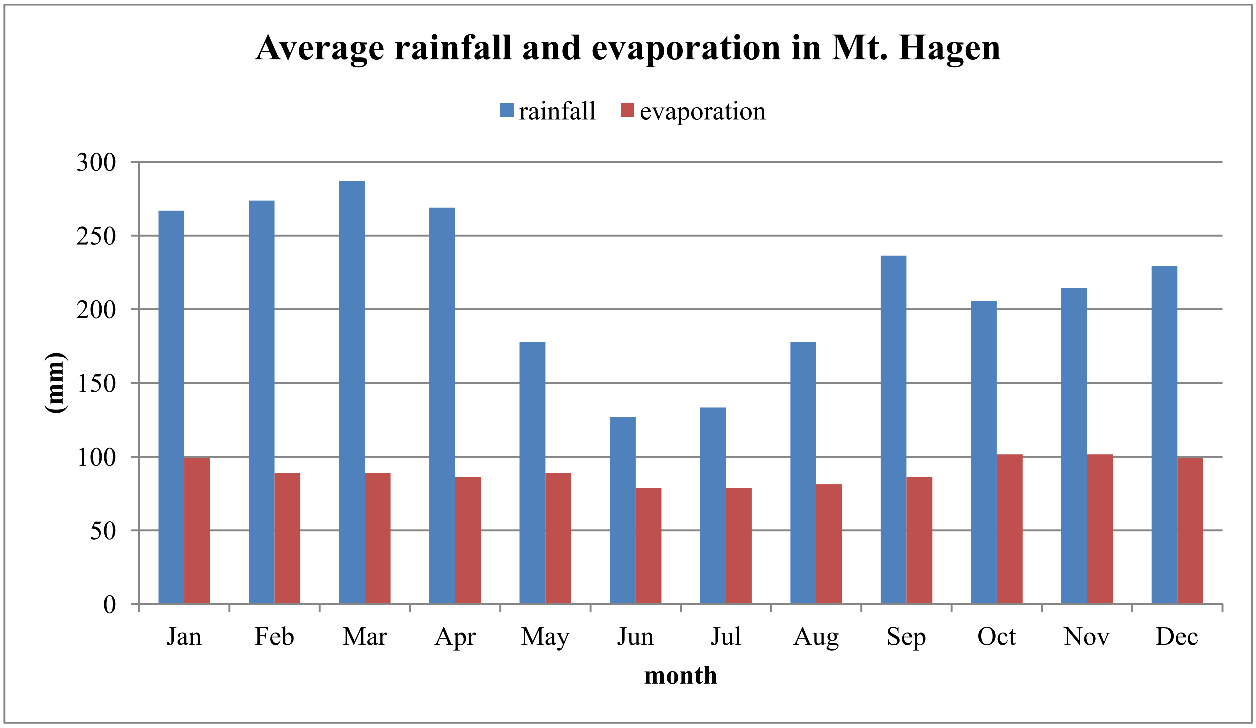


Figure 21: Average monthly rainfall and evaporation in Mt. Hagen, created with data from Haantjens H.A. et al., 1970

The daily rainfall data of the years 2004 and 2 005 shows that the dry season in T ambul was characterized by periods without rain which were in terrupted by days of slight to heavy rainfall.

In July and August 2004 those dry periods lasted one to two weeks, while during the months of June and July 2005 rainfall was completely absent (Figure 22).

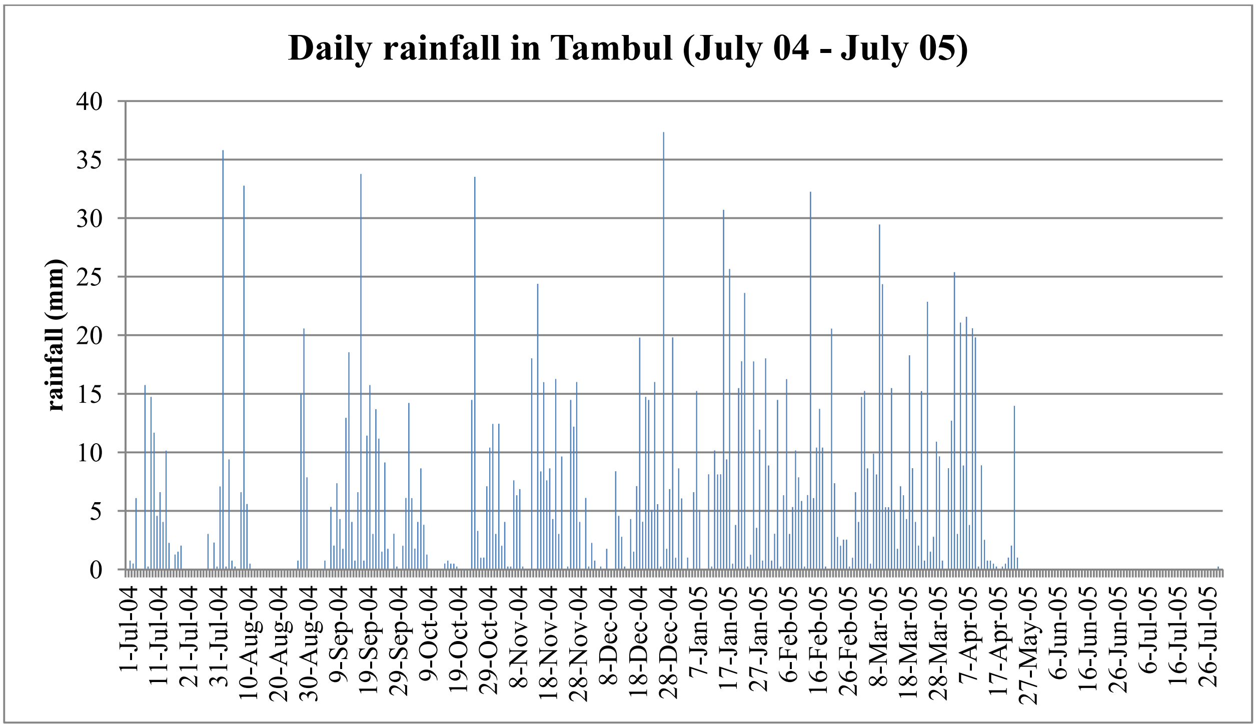


Figure 22: Daily rainfall at Tambul weather station from July 04 until July 05

During the 1997 drought, the area around Tambul was hard hit and depended on food relief from NGO's. There was very little rainfall (Figure 23) and no cloud cover, which resulted in burning sun during the day and clear sky with frosts at night.

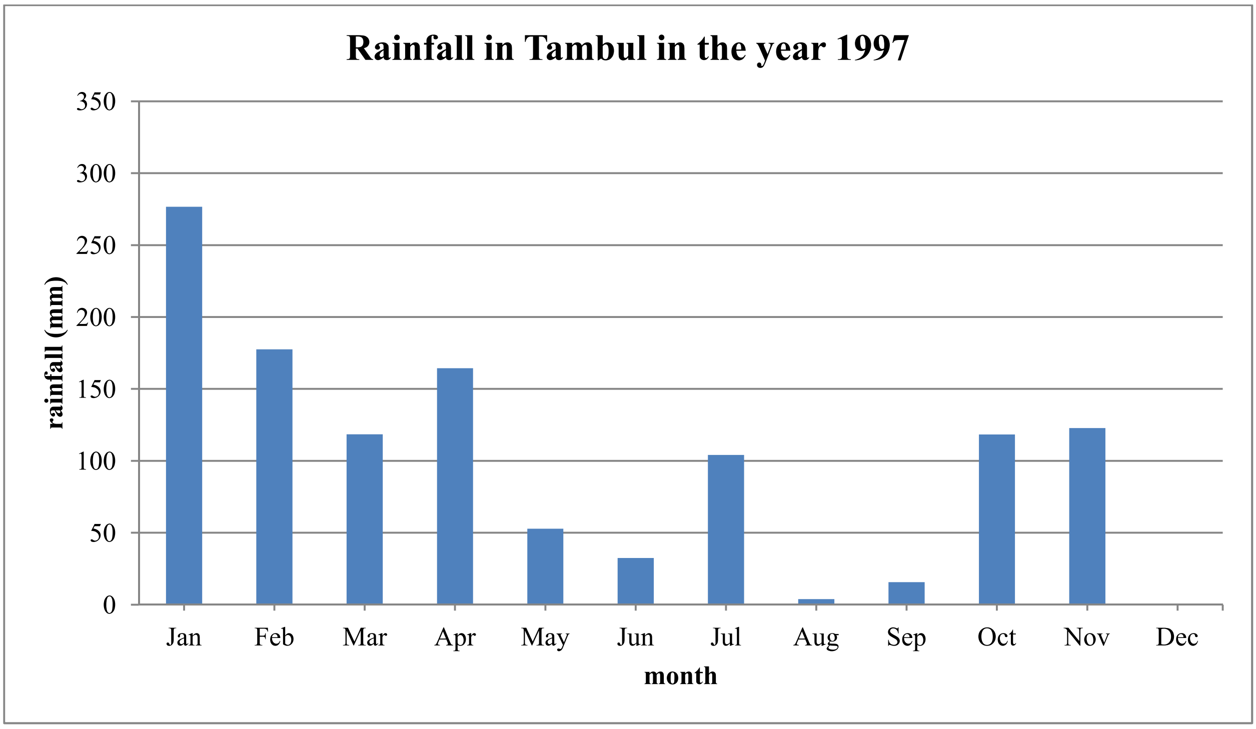


Figure 23: Rainfall at Tambul weather station in the year 1997 during the big drought

4.1.1.2 Agriculture

The high altitude of this area and the consequently low temperatures lead to a reduced variety of crops that can be cultivated compared to the lowlands. Most of the people are subsistence farmers, who have small food gardens and are not able to produce cash crops. The food gardens mainly consist of large sweet potato mounds, usually cultivated in a mono cropping system. Mixed cropping is sometimes practiced in a way, where sweet potato is intercropped with other crops like sugar cane, corn, cabbage or beans. Taro is sometimes cultivated in swampy areas. Most of the gardens are additionally interspersed by deep drains to discharge the excess water from the soil. Farmers cultivating in lowland areas have problems with soil excess water in times of heavy rains or a high groundwater table that is related to the discharge of a nearby river. Farmers with fields in higher lying areas don't have problems with excess soil water and therefore do not use drains.

According to local farmers in Kiripia, the sweet potato plants suffer from dry leaves. A reason could be soil fertility depletion due to the overuse of the fields. The increasing population and the increasing amount of domestic pigs forces the people to shorten or omit the fallowing periods of their fields and cultivate more intensively. Farmers also state, that they have observed changes in the climatic patterns. Climatic conditions that used to be predictable are now becoming unforeseeable for them. For example, the maturing period of sweet potato has changed from nine to six months and weeding has to be done four times instead of two times during a specific period. During the wet season heavy rain and sun normally alternate at a two- to three-day period. During heavy rains the mounds are saturated with water, but during the following sunny days the soils dry out completely by the intense sun. According to the farmers, water logging can be a problem after heavy rains, because the sweet potato tubers start rotting. This could be because the residual soil moisture in the mounds is heated up during the period of intense sun and "cook" the tubers. During the dry season frost occurs regularly, mostly if there is intense sunlight and dry, cold weather on the previous day.

4.1.1.3 Water supply

The community of Kiripia possesses one water tank (Figure 24, left), constructed by the Canadian International Development Agency (CIDA). With a height of 2,2m and a perimeter of 16,4m the tank is capable of supplying about 300 people including the catholic mission, the health centre and the school. The source for the water tank is at the Wapelga river, where a pipe leads from the inlet (Figure 24, right) to a filter and later to the tank. The school of Kiripia is equipped with flush toilets and a septic tank. The majority of the villagers are not connected to the water supply system and have to fetch water from nearby creeks or springs. According to the local population the water quality of those sources is often not good because of pollution from livestock. As most of the people live in traditional houses with rooftops made out of grass (pitpit), water harvesting from rooftops can only be practiced at the public buildings.

Figure 24: Water tank (left) and inlet (right) of the water supply system in Kiripia, pictures: Agnes Ulreich, 2012

The valve that controls the water supply of the tank is controlled by the catholic mission and can be closed completely during times of water shortage. At that time only the school, the catholic mission and the health centre are still supplied with water, while the pipes leading to the villages are closed. Villagers are only allowed to fetch water during certain time frames each day. During the dry season water is only used for drinking and cooking and the gardens cannot be watered.

In times of severe drought, the springs and wells that are normally used to fetch water, dry out and the villagers have to go to the river Kagul for water. The water of the river is normally not used for dinking purposes as it is too dirty because of human pollution. During the drought the water from the Kagul river had to be fetched early in the morning when the water quality was still relatively good. Methods to purify and treat the water before drinking are not practiced.

4.1.2 Soil

The geology of Kiripia is mainly characterized by ingenous consolidated extrusive rocks. The central area of the community consists of volcanogenic gravel, sand, silt and some lava flows. To the southwest basalts, dolerites and andesites dominate, which are fine grained volcanic rocks with relatively low silica content. The northeast of Kiripia is dominated by unconsolidated sedimentary rocks from alluvial deposits. In this area there is clay, silt, sand, gravel and peat from lake deposits. Along the river Kagul, gravel, sand, silt, clay and organic remains from alluvium and swamp deposits can be found (PNGRIS, 2008).

The prevalent great soil group around Kiripia is the Hydrandept, which belongs to the soil order of Inceptisols and to the suborder of Andepts . The Hydrandept is a moderately weathered soil that is formed on volcanic ash and has "clays which dehydrate irreversibly into aggregates of silt, sand and gravel size" (PNGRIS, 2008). Andepts are normally freely drained, have low bulk densities (<0,85g/cm³) and contain plenty allophane which implies a high CEC (PNGRIS, 2008). Furthermore soils of the great groups Tropofolists and Troporthents can be found in Kiripia. Tropofolists (order: Histosol, suborder: Folists) are peat soils, alpine peat and humus soils that are freely drained and are never saturated for more than a couple of days. Troporthents (order: Entisol, suborder: Orthents) are soils that are recently formed on erosional surfaces on slopes greater than 25% and are under moist conditions during most of the year (PNGRIS, 2008).

Generally the area is not affected by flooding or inundation, but periodic, brief flooding can occur along the two springs in the eastern part of the community and along the river Kagul in the north there is a waterlogged area (PNGRIS, 2008).

4.1.2.1 Soil survey

The primary data collection in Kiripia was conducted between April 11 th and April 15 th, 2012. The soil survey included the characterisation of nine soil samples taken with a soil core auger ($P_{KIR}1$ - $P_{KIR}9$) and of two soil profiles through digging of profile pits ($P_{PROF}1$ & $P_{PROF}2$) with subsequent abstraction of undisturbed soil samples. Figure 25 shows a map of the great soil groups prevalent in Kiripia as described in chapter 4.1.2, and the location of the of the sampling spots with the soil core auger as well as the profile pits.

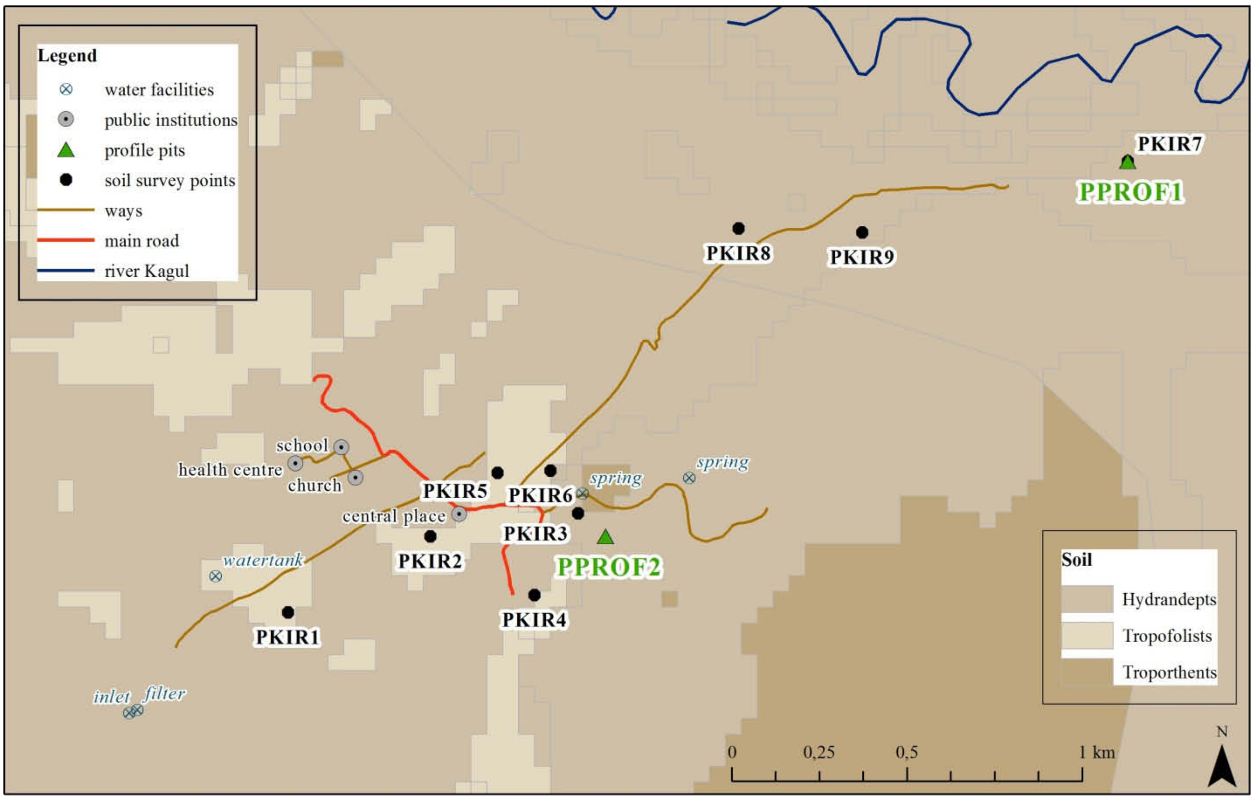


Figure 25: Great soil groups (Source: PNGRIS, 2008) and location of soil sampling spots in Kiripia

4.1.2.1.1 Soil core auger

Table 15 shows the coordinates of the sampling spots from the soil core auger, their elevation and the type of land use at the sampling site. All soil samples were taken from sweet potato gardens at elevations between 2200 and 2337masl.

Table 15: Sampling spots from the soil core auger in Kiripia

Sample	Date	Latitude	Longitude	Elevation [m]	Landscape
$P_{KIR}1$	11.04.2012	-5,951712469	143,9923025	2337	sweet potato field
$P_{KIR}2$	11.04.2012	-5,949760385	143,9959545	2317	sweet potato field
$P_{KIR}3$	12.04.2012	-5,949172236	143,9997507	2278	sweet potato field
$P_{KIR}4$	12.04.2012	-5,951267791	143,9986296	2272	sweet potato field
$P_{KIR}5$	12.04.2012	-5,94812907	143,9976832	2296	sweet potato field
$P_{KIR}6$	12.04.2012	-5,948072407	143,9990378	2309	sweet potato field
$P_{KIR}7$	13.04.2012	-5,940127689	144,0138586	2201	sweet potato field
$P_{KIR}8$	13.04.2012	-5,941848205	144,0038697	2232	sweet potato field

$P_{KIR}9$	13.04.2012	-5,941951918	144,0070465	2255	sweet potato field

The soils found during the soil survey with the soil core auger were mostly clays with sometimes sandy layers from alluvial deposits. $P_{KIR}3$ and $P_{KIR}9$ (Figure 26) showed a constant dark brown layer throughout the whole profile and the soil of $P_{KIR}3$ was completely saturated. $P_{KIR}9$ was on a steep slope and showed big erosion gullies.

Figure 26: Soil profile of $P_{KIR}9$ taken by the soil core auger (left) and its location (right), pictures: Agnes Ulreich, 2012

The other profiles had dark brown top soil layers of different thicknesses and mostly yellow, ochre and reddish colours in deeper layers. At the points of $P_{KIR}4$ and $P_{KIR}7$ grey soil was found in the bottom layers. $P_{KIR}4$ (Figure 27) had greenish stains in the grey matrix indicating stagnant moisture, and water logging was observed at the soil surface between nearby fields. This could be due to its location, which is in the locally lowest lying area.

Figure 27: Soil profile of $P_{KIR}4$ taken by the soil core auger (left) and its location (right), pictures: Agnes Ulreich, 2012

A detailed description of the soil profiles taken with the soil core auger according to the soil morphological descriptors (chapter 3.2.2.1) and pictures of all soil profiles are shown in Annex 1.

4.1.2.1.2 Profile pits

The location of the profile pits (Figure 25) was chosen on the basis of the information obtained during the soil survey and the explanation of local farmers. Since the study site was chosen because of its wet conditions, both pits were situated at rather wet sites. Profile pit one ($P_{PROF}1$) was located close to the river Kagul, and profile pit two ($P_{PROF}2$) was situated close to a swampy area. Infiltration tests were conducted at the sites of both profile pits, but no results could be obtained as the infiltration was nil over the whole test period (about three hours). The location details of the profile pits are listed in Table 16.

Table 16: Location of profile pits in Kiripia

Name Date		**Latitude**	**Longitude**	**Elevation [m]**	**Landscape**
$P_{PROF}1$	13.04.2012	-5,940127689	-5,94012769	2201	sweet potato field
$P_{PROF}2$	15.04.2012	-5,949760162	-5,94976016	2287	sweet potato field

Profile pit one ($P_{PROF}1$)

Profile pit one was located on the northeast end of Kiripia, in the field of a village called Kumungapul. The field was situated close to the river Kagul, but with a difference in elevation of about 5m. The field was cultivated with large sweet potato mounds and had no drains. Six undisturbed soil samples were taken from this profile pit, two respectively at a depth of 15-25cm, 60-70cm and 90-100cm. Table 17 presents the soil profile description from the field investigations.

Table 17: Soil profile description of profile pit one ($P_{PROF}1$) in Kiripia

Sample Code	**Depth [cm]**	**Colour**	**Segregations**	**Presence of roots**	**Comments**
$P_{PROF}1$ Kiripia	0 - 5	dark brown	none	few	soil has fractures until a depth of 60cm that are filled with material from the topsoil
	5 - 30	light grey	ochre	few	
	30 - 40	dark grey	none	few	
	40 - 90	light grey	ochre	few	
	90 - 110	dark grey	black (charcoal)	no	

The soil profile of $P_{PROF}1$ in Kiripia was divided in five horizons (Table 17 and Figure 28). The upper horizon had a depth of five centimetres and showed dark brown colours and few roots, which suggests high organic matter and nutrient levels. From a depth of 5cm until 90cm the soil matrix was light grey and firm with ochre or rust mottles, which can indicate impeded drainage conditions. The layer was interrupted by a dark grey layer at the depth of 30-40cm. At the bottom of the profile the soil had a dark grey colour again and black segregations that could be charcoal.

Figure 28: Soil profile (left) and location (right) of profile pit one ($P_{PROF}1$) in Kiripia, pictures: Agnes Ulreich, 2012

Profile pit two ($P_{PROF}2$)

Profile pit two was located within a low lying, swampy area called Silmalga. A spring that normally dries out during the dry season was situated close to the pit. According to the owner of the field, the water from the spring is of good quality unless pigs dig in the area of the headwater. The field that was chosen for the construction of the profile pit was located on a slope. It had no drains, because the inclination of the field already caused the rainwater to run off into the swamp. According to the owner of the field erosion exists, but the people don't care because they have enough yield either way. At the time of the field work the sweet potato mounds were opened up with grass upon them and were about to be closed and planted soon (see chapter 2.2.2.4, composting). Six undisturbed soil samples were taken from this profile pit, two respectively at a depth of 30-40cm, 60-70cm and 90-100cm. Table 18 presents the soil profile description from the field investigations.

Table 18: Soil description of profile pit two ($P_{PROF}2$) in Kiripia

Sample Code	Depth [cm]	Colour	Segregations	Presence of roots	Comments
$P_{PROF}2$ Kiripia	0 - 5	dark brown	none	few, until 30-40cm	
	5 - 55	reddish brown	none		
	55 - 80	reddish	red and small white mottles	no sm	all stones
	80 - 100	white grey yellowish	red, white and black mottles	no	stones (l=5-20cm)

The soil profile of $P_{PROF}2$ in Kiripia had four horizons (Table 18 and Figure 29). Like the soil profile of $P_{PROF}1$, the topsoil layer was only five centimetres deep and had a dark brown colour. The low thickness of this layer could be a result of erosion and the common practice of mounding, where the top-soil of the field is put together for the construction of mounds. From a depth of 5-55cm the soil horizon was reddish brown followed by a reddish horizon. Roots were present until a depth of 30-40cm. The uniform reddish and yellowish colours in the sub-layers indicate free drainage of the soil. At a depth of 80-100cm the colour of the soil changed to white, grey, yellowish with black mottles. The pale colours could indicate considerable leaching and low fertility in this layer.

Figure 29: Soil profile (left) and location (right) of profile pit two ($P_{PROF}2$) in Kiripia, pictures: Agnes Ulreich, 2012

4.1.2.2 Laboratory analysis

4.1.2.2.1 Texture

The texture of $P_{PROF}1$ in Kiripia was classified as clay to clay loam and of $P_{PROF}2$ as sand to clay loam (Table 19). $P_{PROF}2$ contained higher fractions of sand than $P_{PROF}1$, especially in the topsoil layer, which consisted to 93% of sand (Figure 30).

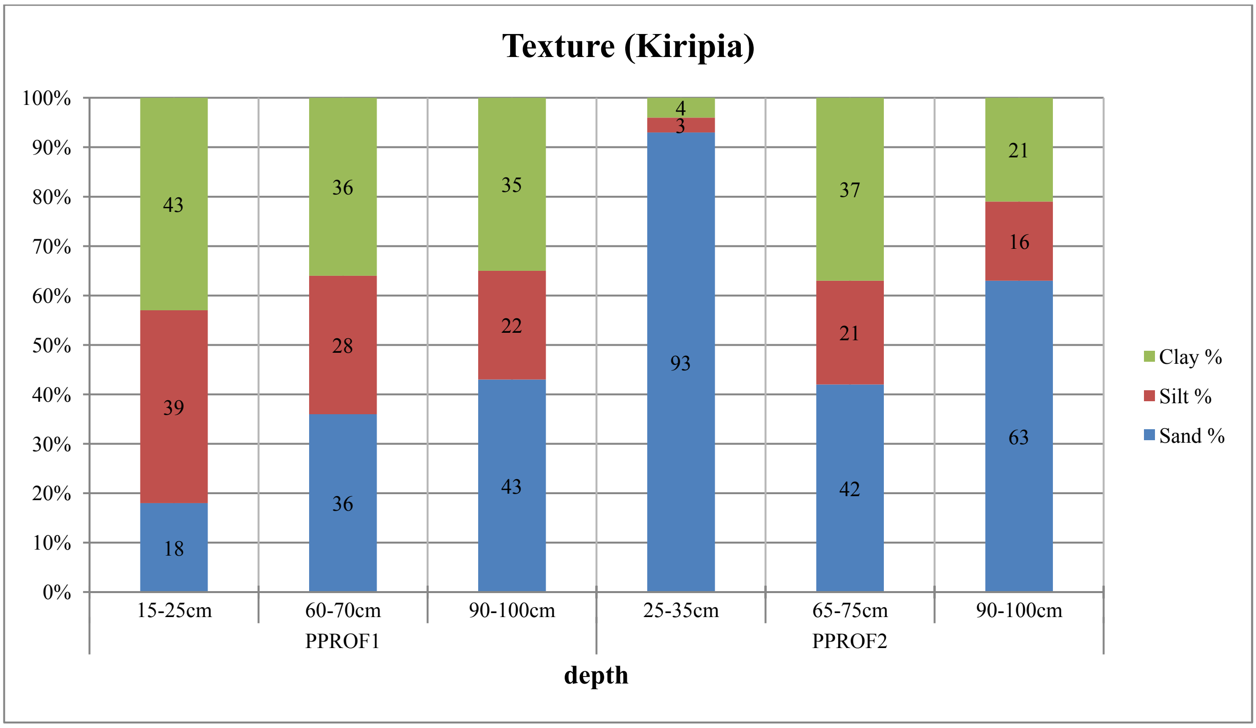


Figure 30: Soil texture of the soils from Kiripia

Table 19 shows a comparison of the soil texture determined in the laboratory and the texture information from the GIS data of PNGRIS for the areas of the profile pits. According to PNGRIS the soil is of low to moderate fertility, very low erodibility, has moderate mineral reserves and is well to imperfectly drained.

Table 19: Comparison of the soil texture specifications from the laboratory analysis and the texture data from PNGRIS at Kiripia

		laboratory analysis		PNGRIS	
		depth	texture	depth	texture
Tambul (Kiripia)	$P_{PROF}1$	15-25cm	clay	0-25cm	sandy loam, loam, clay loam
		60-70cm	clay loam	25-100cm	clay, silty clay, sandy clay
		90-100cm	clay loam		
	$P_{PROF}2$	25-35cm	sand	0-25cm	sandy loam, loam, clay loam
		65-75cm	clay loam	25-100cm	clay, silty clay, sandy clay
		90-100cm	sandy clay loam		

4.1.2.2.2 Chemical parameters

Soil pH

The soil pH of the soils from both profile pits was 4,8, which means that the soils were very strongly acid (Figure 31). The data derived from PNGRIS shows acid (pH 5,0 - 6,0) soil conditions for the locations of the profile pits.

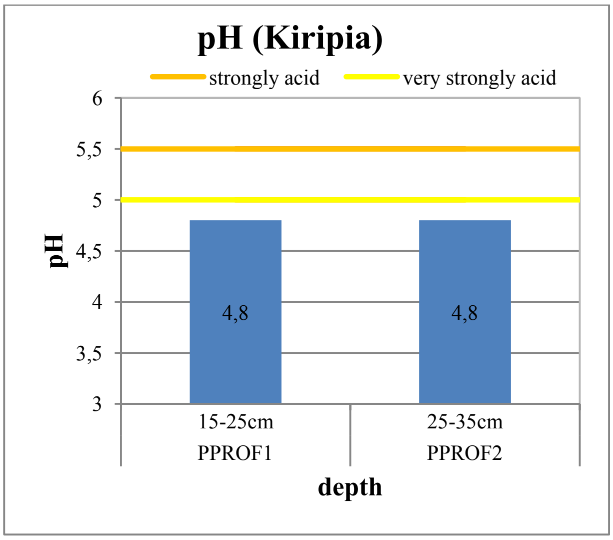


Figure 31: Soil pH values of the soils from Kiripia

Both profile pits are located in an area where the Hydrandept, which is formed on volcanic ash material, is the dominating great soil group. As shown in chapter 2.2.3.1 by means of a study from BAILEY (2009), volcanic soils are generally more acid than non volcanic soils and have mean pH values of 5,6. The soils of both profile pits from the own research were under very strongly acid conditions, which means that the pH values lie beneath the average value for the highlands soils (Bailey J., 2009).

Cation Exchange Capacity and Base Saturation

With a value of 24,1me% at $P_{PROF}1$ and 34,4me% at $P_{PROF}2$ (Figure 32, left), the CEC of the soils was rated as moderate and high according to HAZELTON (2007). Hydrandepts contain a high amount of allophane material, which has a highly reactive surface and therefore a high CEC. Normally soils with low clay contents also feature low contents of CEC. $P_{PROF}2$ has a clay content of only 4% but a high CEC, which can be explained by the high amount of organic material present in the soil. It means that the soils must be dominated by variable charge, which is not only located on the edges of clay, but also of organic matter. Soils with variable charge show a high dependence on soil pH, whereas an increase of soil pH would probably lead to an increasing CEC.

The base saturation on the other hand was rated as moderate (43%) at $P_{PROF}1$ and very low (4%) at $P_{PROF}2$ (Figure 32, right). A base saturation of over 40%, as found at $P_{PROF}1$, indicates moderate leaching, while a BS of under 15% means that the soil is very strong leached.

The data derived from PNGRIS indicates a high (>25me%) CEC and a low base saturation (<20%) for all Tambul sites. Observing the own data, only the BS of $P_{PROF}1$ differs considerably as it is rated as high.

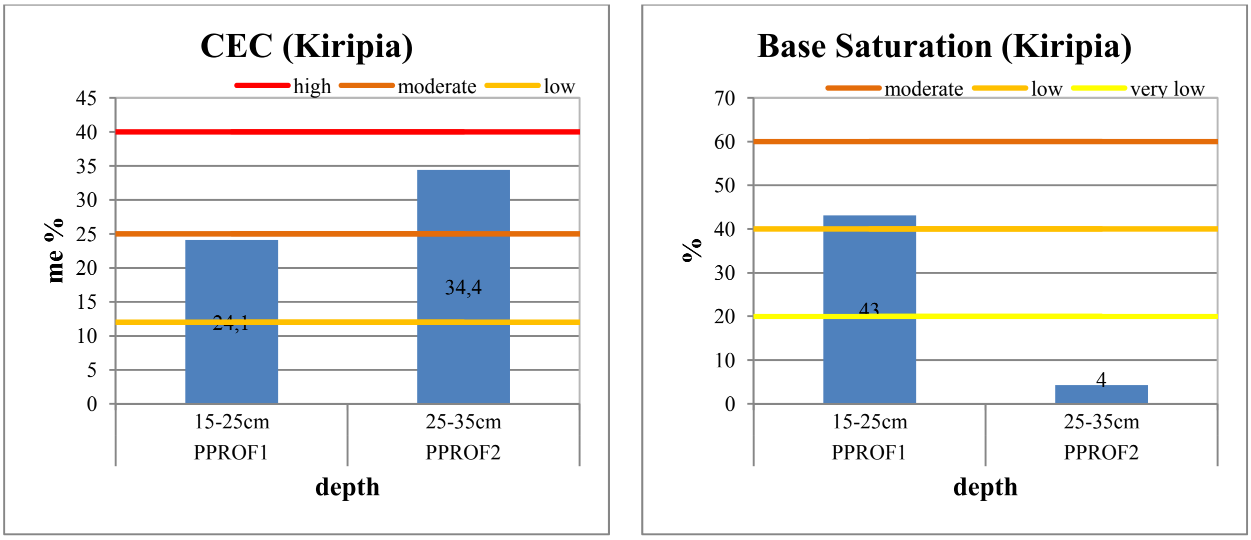


Figure 32: Cation Exchange Capacity (left) and Base Saturation (right) of the soils from Kiripia and upper boundaries of ranges according to HAZELTON (2007)

Exchangeable Bases

The levels of the exchangeable bases in Kiripia are illustrated in Figure 33 and Figure 34. According to the rating of HAZELTON (2007), the soil of $P_{PROF}1$ possessed moderate levels of exchangeable Ca (7,23me%) and Mg (2,74me%), a low level of exchangeable Na (0,27me%) and a very low level of exchangeable K (0,15me%). $P_{PROF}2$ showed very low levels of exchangeable Ca (0,38me%), Na (0,05me%) and K (0,09me%), and a low level of exchangeable Mg (0,95me%).

According to PEVERILL (1999), a Mg deficiency exists in sandy soils from concentrations below 0,2 me%, and in clay soils from concentrations below 0,5 me%. According to that, none of the analysed soils was deficient in Mg.

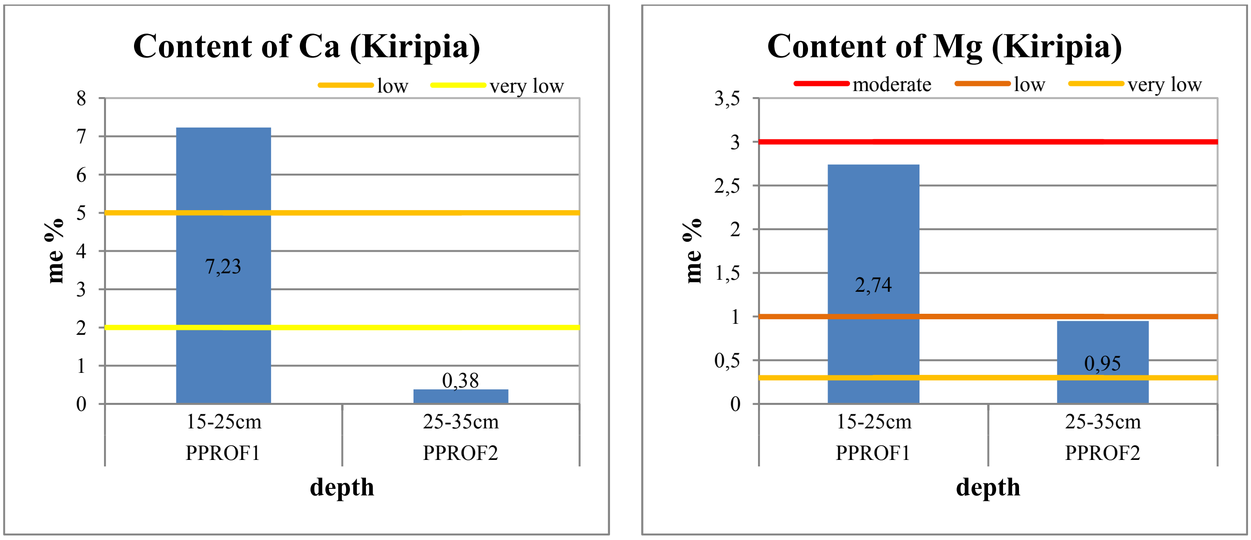
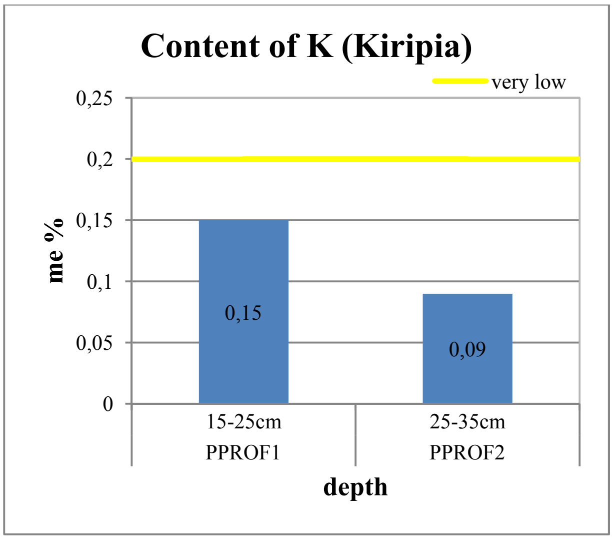


Figure 33: Content of exchangeable calcium (left) and exchangeable magnesium (right) of the soils from Kiripia and upper boundaries of ranges according to HAZELTON (2007)



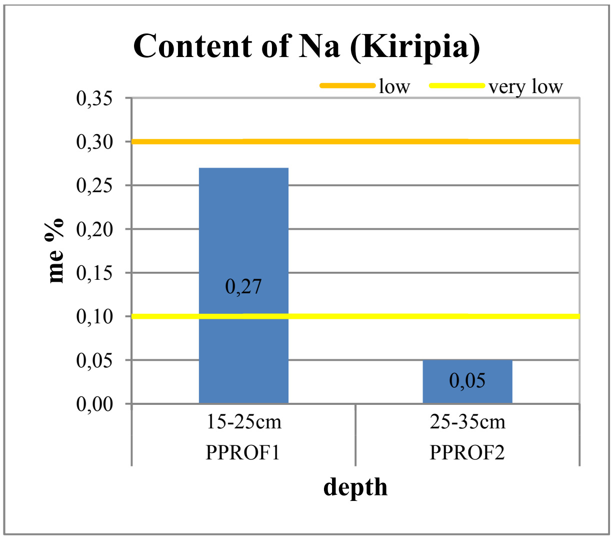


Figure 34: Content of exchangeable potassium (left) and exchangeable sodium (right) of the soils from Kiripia and upper boundaries of ranges according to HAZELTON (2007)

Figure 35 reveals, that the content of the basic exchangeable bases at $P_{PROF}2$ was very low compared to the total amount of cations that can be exchanged by the soil (CEC). That implies, that large amounts of other exchangeable bases such as Al or H+ must have been present. Large amounts of aluminium ions in soil can be toxic to plant growth and are always associated to very acid soil conditions, which applies to the soils from the profile pits. A reason for the extremely low content of basic exchangeable bases in $P_{PROF}2$ could be the high content of sand in the topsoil layer of the profile (93%), which - together with its location in a high rainfall area- leads to strong leaching of the soil and consequently the exchangeable bases are washed out.

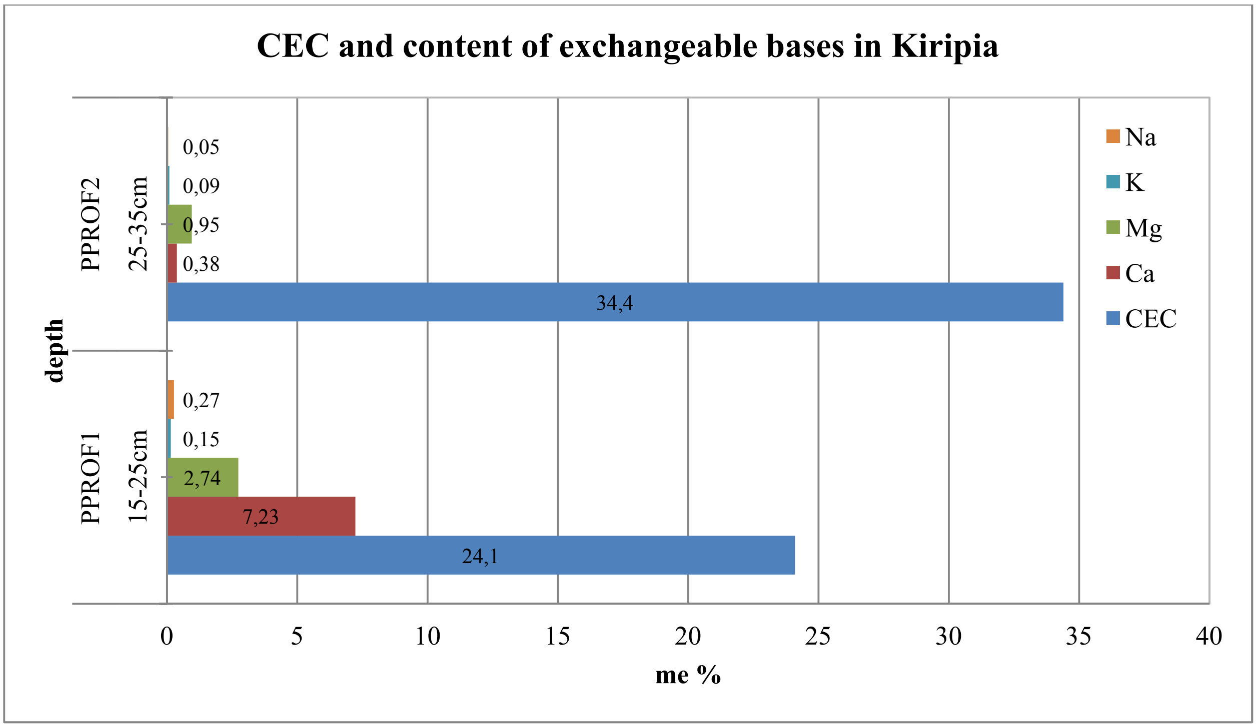


Figure 35: CEC and content of exchangeable bases of $P_{PROF}1$ and $P_{PROF}2$ in Kiripia

When looking at the saturation percentages of the soils it can be stated that only the Na-, and the Mg- saturation of $P_{PROF}1$ had saturation levels within the desirable range according to

HAZELTON (2007). With values of 30% and 1,10% (Figure 36, left), the Ca saturation percentages of both soils are much below Hazelton's lower threshold level of 65%. Other sources quote the adequate Ca saturation percentage of soils around 25-30%, which would mean that $P_{PROF}1$ was within the desirable range. The K saturation values lie beneath the threshold values of HAZELTON (2007), which signifies a K deficiency in both soils (Figure 37, left). This is also confirmed by PEVERILL (1999), who expects a deficiency at potassium levels below 0,2 - 0,5me%. The ESP values of the soils were 0,15% and 1,12%, which implies that the soils are not under sodic conditions (Figure 37, right).

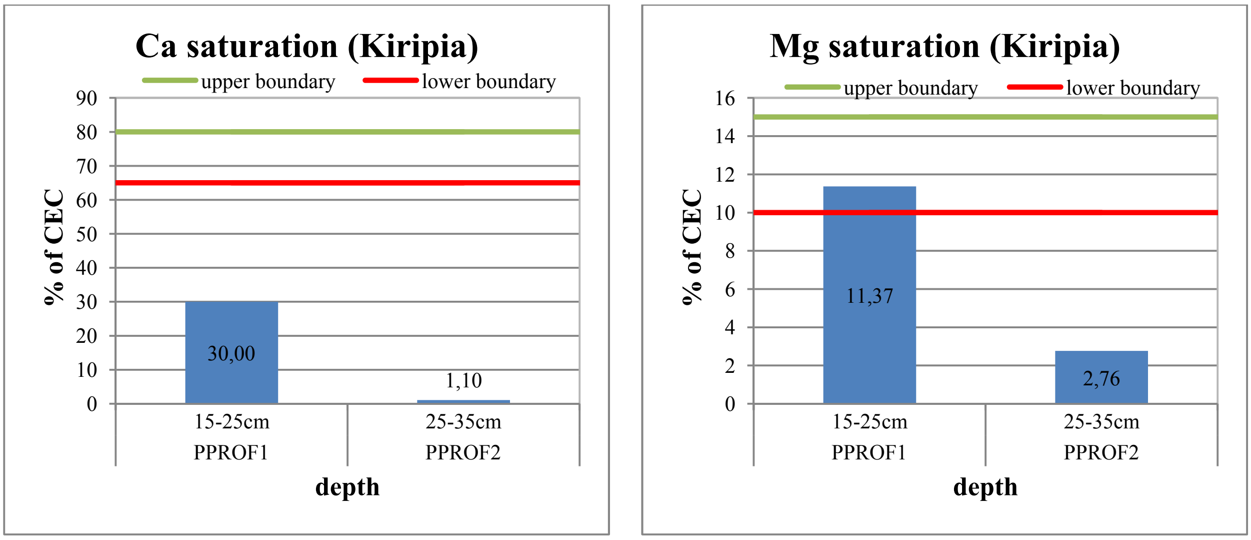


Figure 36: Calcium (left) and magnesium (right) saturation of the soils from Kiripia and desirable range for many plants according to HAZELTON (2007)

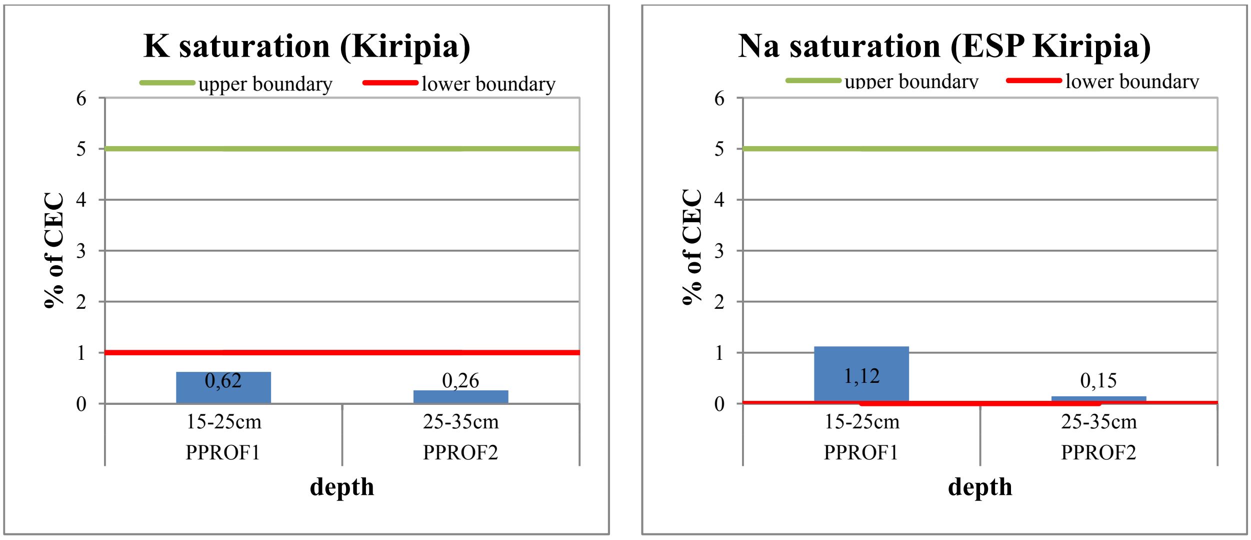
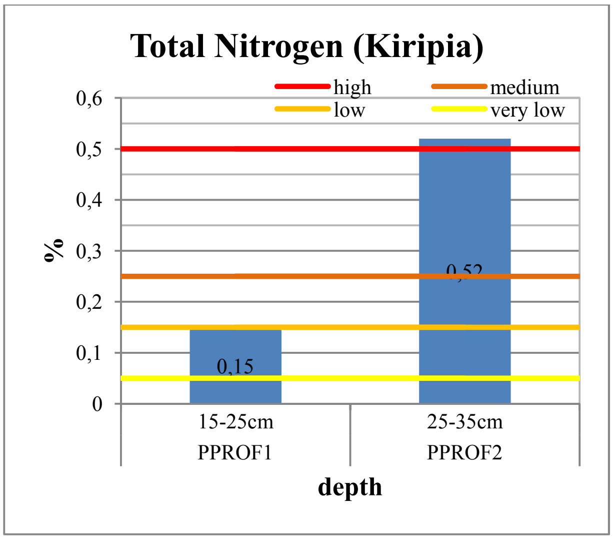


Figure 37: Potassium saturation (left) and sodium saturation (right) of the soils from Kiripia and desirable range for many plants according to HAZELTON (2007)

Nutrients

The level of total nitrogen and organic carbon was very high in the soil of $P_{PROF}2$ and medium to low in $P_{PROF}1$ (Figure 38). The PNGRIS data indicates high values (>0,5%) of total Nitrogen for all sites.



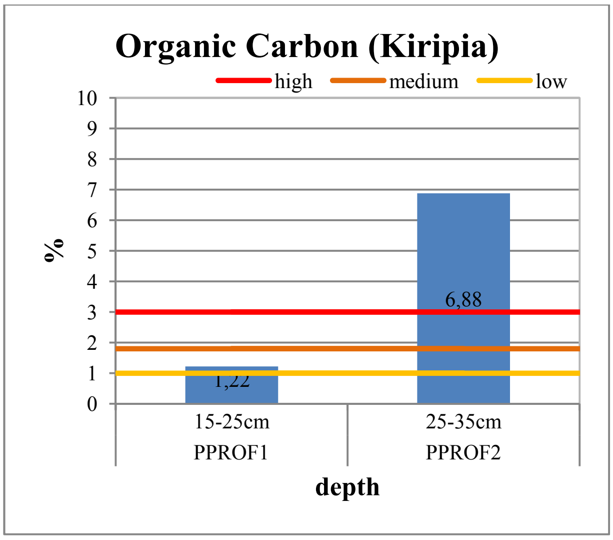


Figure 38: Total nitrogen (left) and organic carbon (right) of the soils from Kiripia and upper boundaries of ranges according to HAZELTON (2007)

The soils possessed very low to low C/N ratios (Figure 39). P$_{PROF}$1 exhibits values below 10, which indicates a rapid break down of organic material. Values around ten to twelve are normal for agricultural soils. The C/N ratio at P$_{PROF}$2 was slightly higher, which suggests a slower decomposition process.

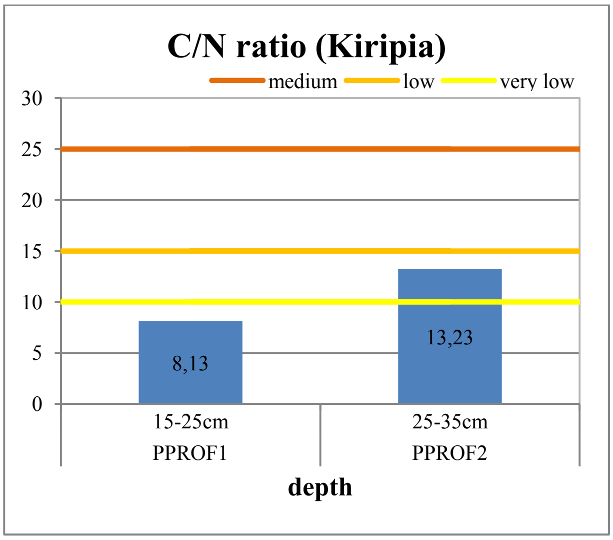


Figure 39: C/N-ratio of the soils from Kiripia and upper boundaries of ranges according to HAZELTON (2007)

4.1.2.2.3 Bulk density

A high amount of allophane in soils implicates a low bulk density because of its high porosity and water content. Hydrandepts normally have bulk densities below 0,85g/cm³ (PNGRIS, 2008). The data from the own research shows that the bulk densities at the two profile pits were indeed very low, having values of 0,9g/cm³ at P$_{PROF}$1 and 0,45g/cm³ at P$_{PROF}$2 (Figure 40). The even lower bulk density at P$_{PROF}$2 could be due to the very high content of organic matter in the soil. Further the profile pit was situated in an area which is assigned to be possibly peat from lake deposits (PNGRIS, 2008), which could also be a possible explanation for the low bulk density.

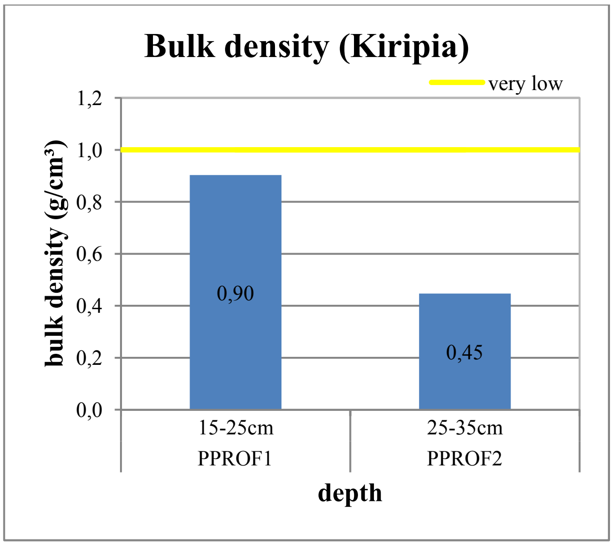


Figure 40: Bulk density of the soils from Kiripia and upper boundaries of ranges according to HAZELTON (2007)

4.1.2.2.4 Hydraulic conductivity

In order to calculate the hydraulic conductivity, the texture classes of the soils were converted to the FAO/USDA system of classification, and are shown in the following table (Table 20). The soil texture of the profile pits only differs at $P_{PROF}2$, whereas it is a clay soil according to the Australian system and a silty clay soil according to the FAO/USDA system.

Table 20: Texture of the soils from Kiripia according to the FAO/USDA system

		Texture (FAO/USDA)	Texture (Australia)
Tambul (Kiripia)	$P_{PROF}1$	Silty Clay	Clay
	$P_{PROF}2$	Sand	Sand

The hydraulic conductivity of the soils was calculated as extremely low at $P_{PROF}1$ and low at $P_{PROF}2$ (Figure 42). The extremely low hydraulic conductivity of $P_{PROF}1$ (0,45mm/h) could be explained by the higher amount of clay in the soil (Figure 41). This was also affirmed by the soil profile inspection during the fieldwork, which showed a light grey and firm soil matrix with ochre or rust mottles indicating impeded drainage conditions. Further the profile pit was located in a locally low lying area, where water is accumulated. Extremely low saturated hydraulic conductivities as found in $P_{PROF}1$ can be prone to water logging, and vegetation might be restricted to shallow rooted plants (Hazelton P. et al., 2007, p.14).

With a value of 1,13mm/h the hydraulic conductivity calculated for $P_{PROF}2$ is higher than for $P_{PROF}1$, but is still rated as very low. This is surprising considering the high content of sand (93%) in the soil sample (Figure 41).

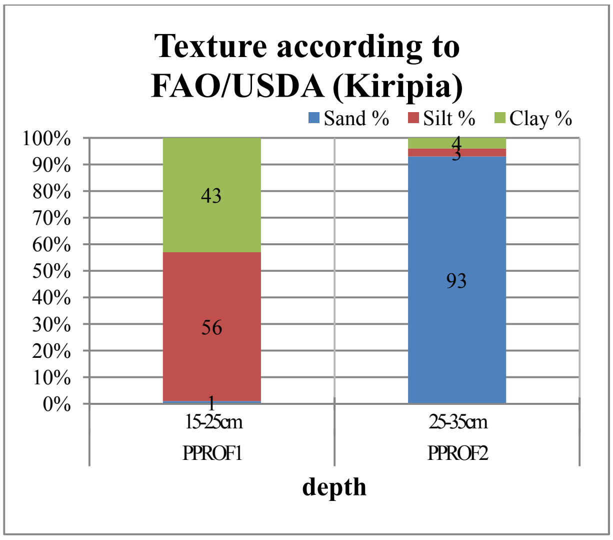


Figure 4 1: T exture of the soils fr om Ki ripia according to the FAO/USDA system

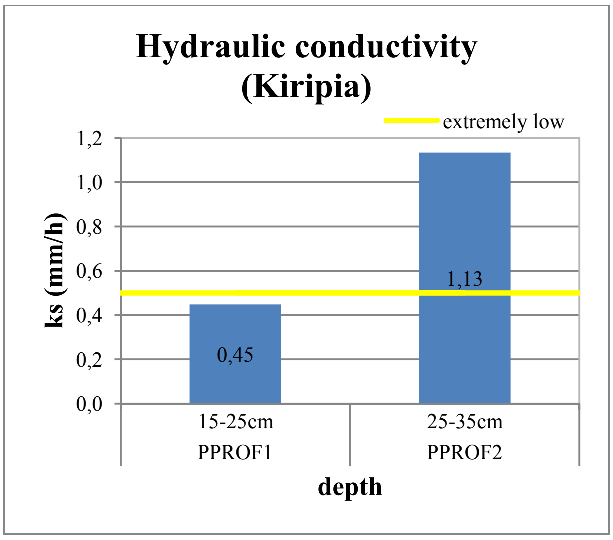


Figure 42: Calculated hydraulic conductivity of th e soils fr om Kiripia and upper b oundaries of r anges according to HAZELTON (2007)

4.2 ALKENA / TAMBUL

4.2.1 GENERAL INFORMATION

Like Kiripia, Alkena is situated at a distance of about ten kilometres from Tambul district station and can be reached by an unsealed road (Figure 17). It is located to the north of Kiripia on a hillside opposite to Mount Giluwe and is separated from Kiripia by the river Kagul. It lies at an altitude of approximately 2200 to 2300m asl and has a total population of 1945 people (PNG 2000 census, data source: Mike Bourke, Australia National University). The general conditions are similar to Kiripia, with the main staple crop being sweet potato, the villagers being subsistence farmers and some owning livestock. The Alkena district office is situated on the main road and further the community possesses a health centre, a school and various churches (Figure 43).

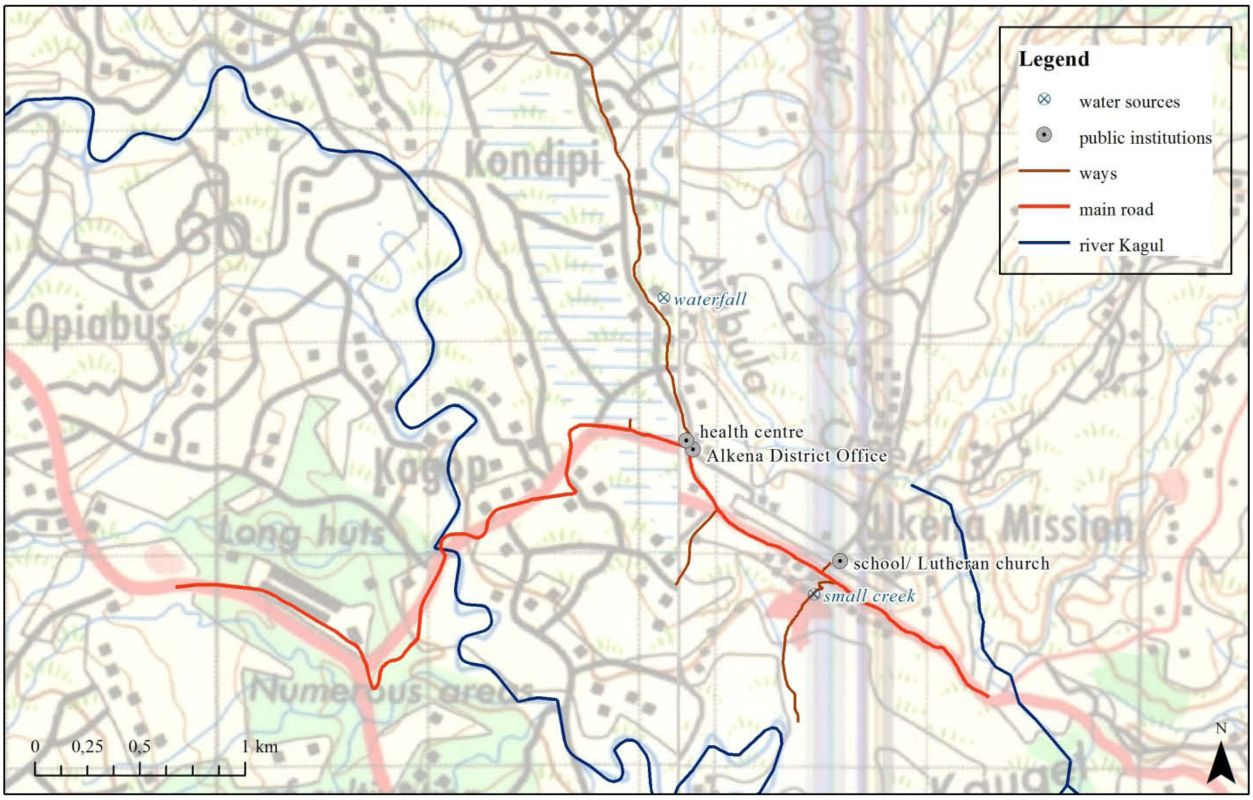


Figure 43: Map of the Alkena community

4.2.1.1 Climate

For a description of the climatic conditions of the Alkena community, the temperature and rainfall data described in chapter 0 from Tambul district station can be consulted.

4.2.1.2 Agriculture

The crops as well as the agricultural techniques used in Alkena are similar to Kiripia (see chapter 4.1.1.2).

4.2.1.3 Water supply

There is a water pipe sponsored by the red cross, which supplies few parts of Alkena with public water taps. People living in the lower lying part of Alkena don't have a water supply system and therefore fetch the water from the rainwater harvesting tanks of the Lutheran church (Figure 44, left) or small creeks (Figure 44, right). The main water sources for villagers without access to either of these water systems or during times of water shortage are the swamp Ambile and the river Kagul which can be reached in about one hour by most of the villagers.

Figure 44: Rainwater harvesting tanks of the Lutheran church (left) and small creek (right) in Alkena, pictures: Agnes Ulreich, 2012

4.2.2 Soil

The geology of Alkena is mostly determined by unconsolidated sedimentary rocks from alluvial deposits. In the western part of the community silt, sand, mud, clay and gravel from alluvium and fluvial deposits prevail, while the eastern part consists of clay, silt, sand, gravel and peat from lake deposits and the southern part of gravel, sand, silt, clay and organic remains from alluvium and swamp deposits. The bedrock of the northern part of the community is of mixed sedimentary and volcanic origin whereas green, grey, dark, thick-bedded and poorly sorted volcanic and polymict and muddy sandstone can be found (PNGRIS, 2008).

The predominant great soil group in Alkena is the Hydrandept, which is rarely interrupted by spots of Tropofolists, Tropothents and Humitropepts (Figure 45). Like Hydrandepts, Humitropepts belong to the soil order of Inceptisols and are hence moderately weathered soils. Their suborder of Tropepts implies that they are young and moderately well drained, with bulk densities above 0,85g/cm³ and a low content of amorphous clay minerals (PNGRIS, 2008).

Alkena generally doesn't feature inundation or flooding characteristics, but there are many waterlogged areas distributed over the whole community site. They especially occur near the river Kagul and in the swamp.

4.2.2.1 Soil survey

The primary data collection in Alkena was conducted between April 19th and April 21th, 2012. The soil survey included the investigation of eleven soil samples taken with a soil core auger ($P_{ALK}1$ - $P_{ALK}11$) and of two soil profiles through digging of profile pits ($P_{PROF}1$ & $P_{PROF}2$). Figure 45 shows the location of the sampling spots with the soil core auger as well as the location of the profile pits in a map of the great soil groups of the area. As shown in the figure, the soil sampling sites selected for the soil survey were all located within the area of the Hydrandept.

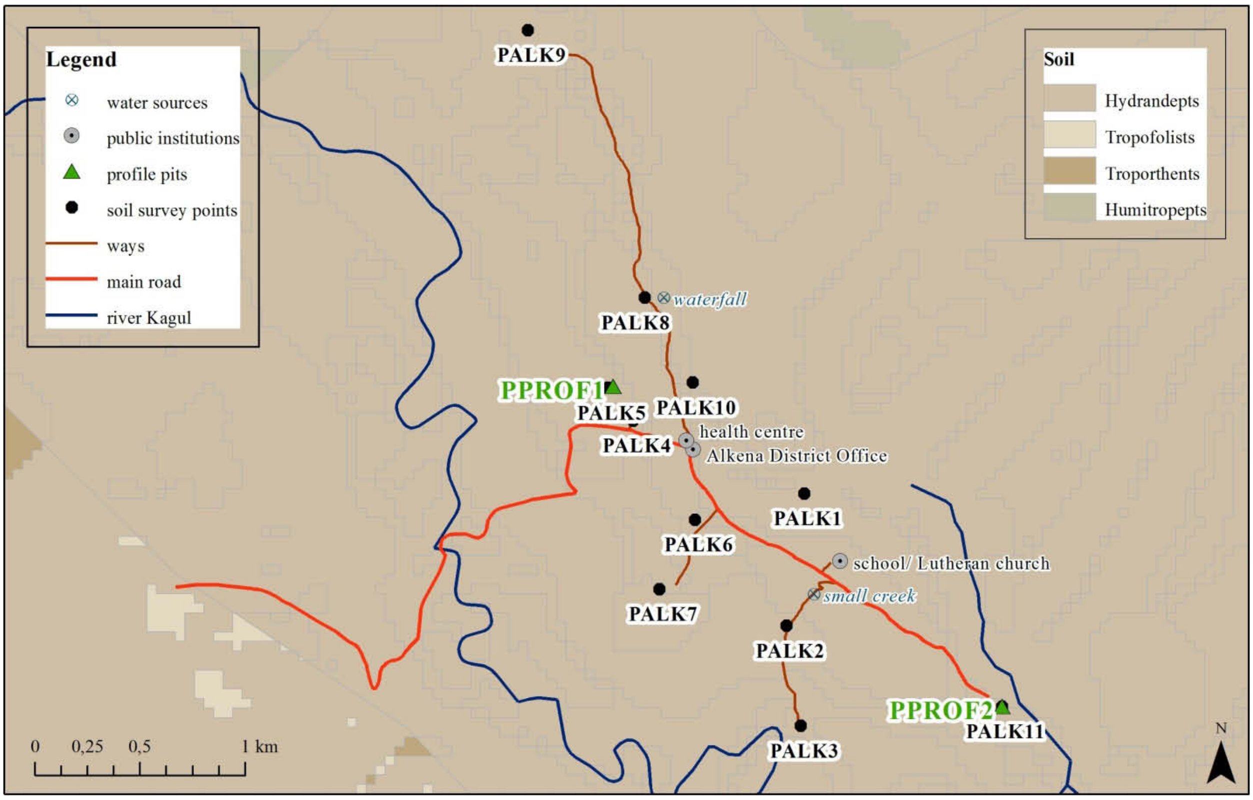


Figure 45: Great soil groups (Source: PNGRIS, 2008) and location of soil sampling spots in Alkena

4.2.2.1.1 Soil core auger

Table 21 shows the coordinates of the sam pling spots from the soil core auger, the e levation and the type of land use at the sam pling site. Most of the soil samples were taken from sweet potato fields, one respectively from english potato, ca uliflower and taro fields and two from m ixed cropping fields at elevations between 2196 and 2294masl.

Table 21: Sampling spots from the soil core auger in Alkena

Sample	Date	Latitude	Longitude	Elevation (m)	Landscape
$P_{ALK}1$	19.04.2012	-5,922806392	144,0063744	2266	english potato field
$P_{ALK}2$	19.04.2012	-5,928465821	144,0056298	2199	sweet potato field
$P_{ALK}3$	19.04.2012	-5,932753295	144,0062263	2209	cauliflower field
$P_{ALK}4$	19.04.2012	-5,91968807	143,9990515	2273	sweet potato field
$P_{ALK}5$	19.04.2012	-5,918285119	143,997971	2267	sweet potato field
$P_{ALK}6$	19.04.2012	-5,923928586	144,0017086	2265	sweet potato field
$P_{ALK}7$	19.04.2012	-5,926896777	144,0001796	2256	sweet potato field
$P_{ALK}8$	20.04.2012	-5,914426819	143,999553	2262	sweet potato field
$P_{ALK}9$	20.04.2012	-5,902975833	143,9945504	2294	taro field
$P_{ALK}10$	20.04.2012	-5,918055851	144,001596	2277	mixed cropping field
$P_{ALK}11$	20.04.2012	-5,931928223	144,0148486	2196	mixed cropping field

Most of the soil profiles taken with the soil core auger in Alkena had fertile dark brown topsoil layers with a thickness of over 30cm. Beneath them the soils showed either brown, very pale or sometimes yellowish or red coloured layers, some of them with mottled matrixes. Striking was the organic material found at $P_{ALK}2$, $P_{ALK}4$, $P_{ALK}5$, $P_{ALK}6$ and $P_{ALK}9$, which seemed to be not, or only half decomposed (e.g. $P_{ALK}2$, Figure 46). The points where organic material was found in the profiles were located in a row parallel to the main street of Alkena, in a stretched swamp (cp. Figure 45).

Figure 46: Soil profile of $P_{ALK}2$ taken by the soil core auger (left) and its location (right), pictures: Agnes Ulreich, 2012

$P_{ALK}3$, $P_{ALK}7$ and $P_{ALK}11$ held sandy or sandy loam layers from alluvial deposits (e.g. $P_{ALK}3$, Figure 47), which becomes evident when looking at their proximity to the river.

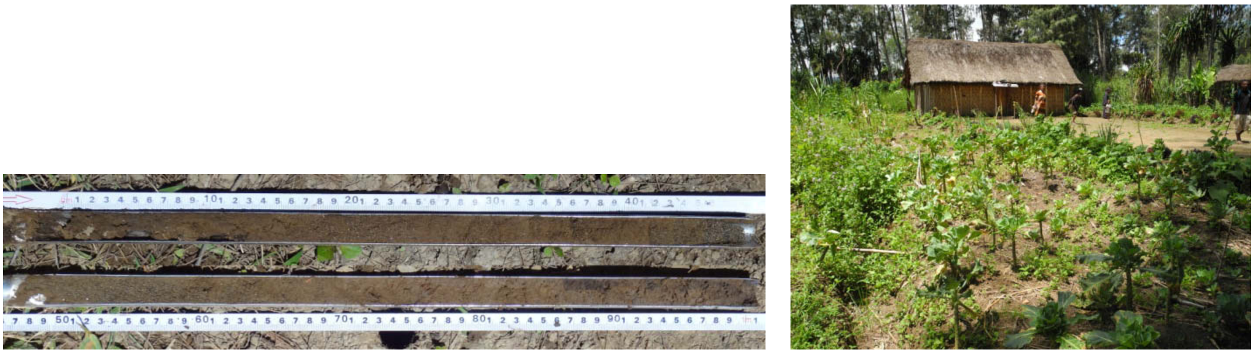


Figure 47: Soil profile of $P_{ALK}3$ taken by the soil core auger, pictures: Agnes Ulreich, 2012

Clay soils were found at the points $P_{ALK}1$, $P_{ALK}4$ and $P_{ALK}8$ to $P_{ALK}10$, which were all located at the northern part of Alkena. A detailed description of the soil profiles taken with the soil core auger according to the soil morphological descriptors (chapter 3.2.2.1) and pictures of all soil profiles are shown in Annex 2.

4.2.2.1.2 Profile pits

Both profile pits were situated in low lying areas with wet soil conditions. Profile pit one was located in a swampy area, and profile pit two close to a tributary of river Kagul. During the nights previous to the construction and investigation of the profile pits the area received heavy rainfall. Therefore the soil was highly saturated and no infiltration tests could be performed. In Table 22 the location details, the elevation and the land use of the site of the profile pits are listed.

Table 22: Location of profile pits in Alkena

Name	Date	Latitude	Longitude	Elevation [m]	Landscape
$P_{PROF}1$	20.04.2012	-5,91822673	143,9981898	2287	fallow grassland
$P_{PROF}2$	21.04.2012	-5,931928223	144,0148486	2196	mixed cropping

Profile pit one ($P_{PROF}1$)

Profile pit one was located in a swampy area close to the main road in Alkena. It was located in a field that was not cultivated during the time of the field work and had fallow grass vegetation. During the establishment of the profile pit the water table was encountered at a depth of 50cm. Six undisturbed soil samples were taken from this profile pit, two respectively at a depth of 20-30cm, 50-60cm and 80-90cm. Table 23 presents the soil profile description from the field investigations.

Table 23: Soil description of profile pit one ($P_{PROF}1$) in Alkena

Sample Code	Depth [cm]	Colour	Segregations	Presence of roots	Comments
$P_{PROF}1$ Alkena	0 - 35	dark brown	none	few	water table at a depth of 50cm
	35 - 65	light brown	ochre and dark mottles	few	
	65 - 75	dark, reddish brown, presence of organic material	none	no	
	70 - 100	light brown	ochre and dark mottles	no	

The soil profile of $P_{PROF}1$ in Alkena is characterised by four soil horizons (Table 23 and Figure 48). The dark brown topsoil layer had a thickness of 35cm indicating a highly fertile soil with a high level of organic matter and nutrients. The following layer extended until a depth of 65cm and had a light brown matrix with ochre and dark mottles. Roots were present until this depth. The third horizon (65cm -75cm) had a dark, reddish brown colour and contained a high amount of organic material. The material appeared to be grass from the swamp that has been decomposed only partially. The bottom layer of the profile was similar to the second horizon, consisting of a light brown matrix with ochre and dark mottles.

Figure 48: Soil profile (left) and location (right) of profile pit one ($P_{PROF}1$) in Alkena, pictures: Agnes Ulreich, 2012

Profile pit two ($P_{PROF}2$)

Profile pit two was located at the southeast end of Alkena within a low lying area. It lay in a field which is adjacent to a tributary of the river Kagul. The field was made up of mounds, where sweet potato was cultivated in a mixed cropping technique with corn and cabbage. During the establishment of the profile pit, the water table was encountered at a depth of 65cm. Six undisturbed soil samples were taken from this profile pit, two respectively at a depth of 30-40cm, 50-60cm and 75-85cm. Table 24 presents the soil profile description from the field investigations.

Table 24: Soil description of profile pit two ($P_{PROF}2$) in Alkena

Sample Code	Depth [cm]	Colour	Segregations	Presence of roots	Comments
$P_{PROF}2$ Alkena	0 - 50	brown	grey mottles, few red brownish mottles	few	water table at a depth of 65cm
	50 - 65	light brown	various grey and red, brownish mottles	no	
	65 - 70	transition zone	none	no	
	70 - 85	grey	none	no	
	85 - 100	dark grey	none	many	

The soil profile of $P_{PROF}2$ in Alkena consisted of four horizons (Table 24 and Figure 49). The thick brown topsoil layer had a thickness of 50cm and was interspersed by grey and a few red or brownish mottles. Roots were present in this layer. At the depth of 50cm to 65cm the soil had a light brown colour with an increasing number of grey and red or brownish mottles. The presence of the mottles indicates prolonged lack of soil aeration and hence possibly seasonal or prolonged water logging. The soil of the following horizon (70cm-85cm) had a grey, and at the bottom horizon (85cm-100cm) a dark grey colour. The soil of those layers was completely saturated and coarser grained. The sand and gravel fraction at the bottom of the profile was most probably alluvial soil from the nearby river.

Figure 4 9: Soil profile (left) and location (right) of profile pit two ($P_{PROF}2$) in Alkena, pictures: Florian Wawra (left) and Agnes Ulreich (right), 2012

4.2.2.2 Laboratory analysis

4.2.2.2.1 Texture

$P_{PROF}1$ had fractions of sand that were as high as 81% to 91% (Figure 50) and was therefore classified as sand to loamy sand (Table 25). The texture of $P_{PROF}2$ was clay loam to loam at the upper two soil horizons and loamy sand at the depth of 75-85cm. The high content of sand in this horizon (84%) is probably due to sediment from the nearby tributary of the river Kagul.

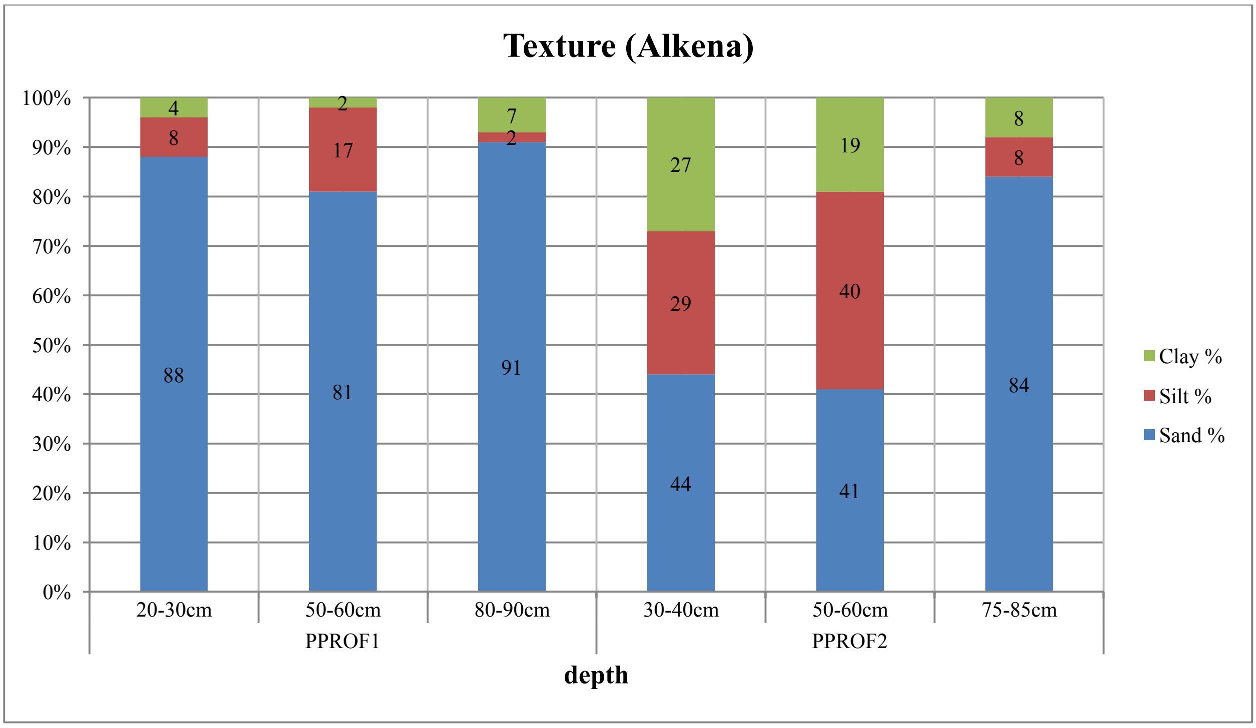


Figure 50: Soil texture of the soils from Alkena

Table 25 shows a comparison of the soil texture determined in the laboratory and the texture information from the GIS data of PNGRIS for the areas of the profile pits. According to PNGRIS the soil of this area is classified as Hydrandept, its soil fertility is moderate, the erodibility low, the soil has moderate mineral reserves and is imperfectly drained.

Table 25: Comparison of the soil texture specifications from the laboratory analysis and the texture data from PNGRIS at Alkena

		laboratory analysis		PNGRIS	
		depth	**texture**	**depth**	**texture**
Tambul (Alkena)	$P_{PROF}1$	20-30cm	sand	0-25cm	sandy loam, loam, clay loam
		50-60cm	loamy sand	25-100cm	clay, silty clay, sandy clay
		80-90cm	sand		
	$P_{PROF}2$	30-40cm	clay loam	0-25cm	sandy loam, loam, clay loam
		50-60cm	loam	25-100cm	clay, silty clay, sandy clay
		75-85cm	loamy sand		

4.2.2.2.2 Chemical parameters

Soil pH

The soil of both profile pits was very strongly acid, with a soil pH of 4,6 at $P_{PROF}1$ and 4,7 at $P_{PROF}2$ (Figure 51). The data derived from PNGRIS shows acid (pH 5,0 - 6,0) soil conditions for the locations of the profile pits.

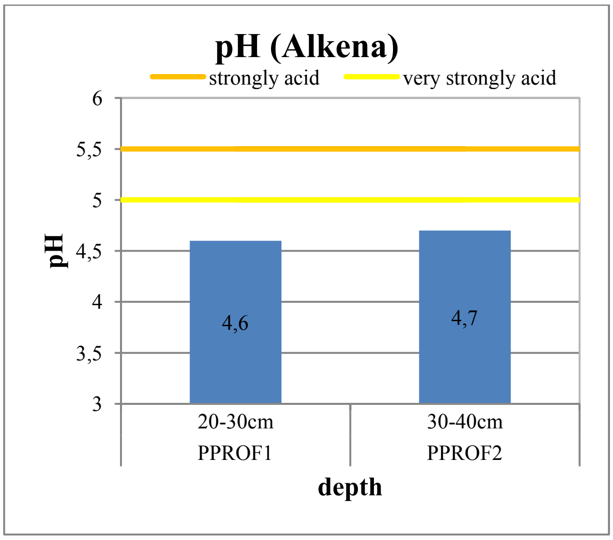


Figure 51: Soil pH values of the soils from Alkena

Like in Kiripia, the profile pits in Alkena were taken in an area whose parent material consists of volcanic ash. With very strongly acid conditions, the soils in Alkena were also more acid than the average highland soil (Bailey J., 2009).

Cation Exchange Capacity and Base Saturation

Figure 52 illustrates the cation exchange capacity and the base saturation of the soils from the profile pits. The CEC of $P_{PROF}1$ was rated as very high (52,4me%), and of $P_{PROF}2$ as moderate (18,3me%). Alike $P_{PROF}2$ in Kiripia, the high CEC in the soil of $P_{PROF}1$ in Alkena could be explained by its high amount of organic matter.

The base saturation of $P_{PROF}1$ was very low (7%) and of $P_{PROF}2$ low (23%). This implicates, that the soil of $P_{PROF}1$ is probably very strongly leached, and of $P_{PROF}2$ strongly leached.

Only the CEC of $P_{PROF}2$ differs considerably from the soil characterisation of PNGRIS for this area, which displays the CEC of the Tambul soils as high (>25me%) and the BS as low (<20%).

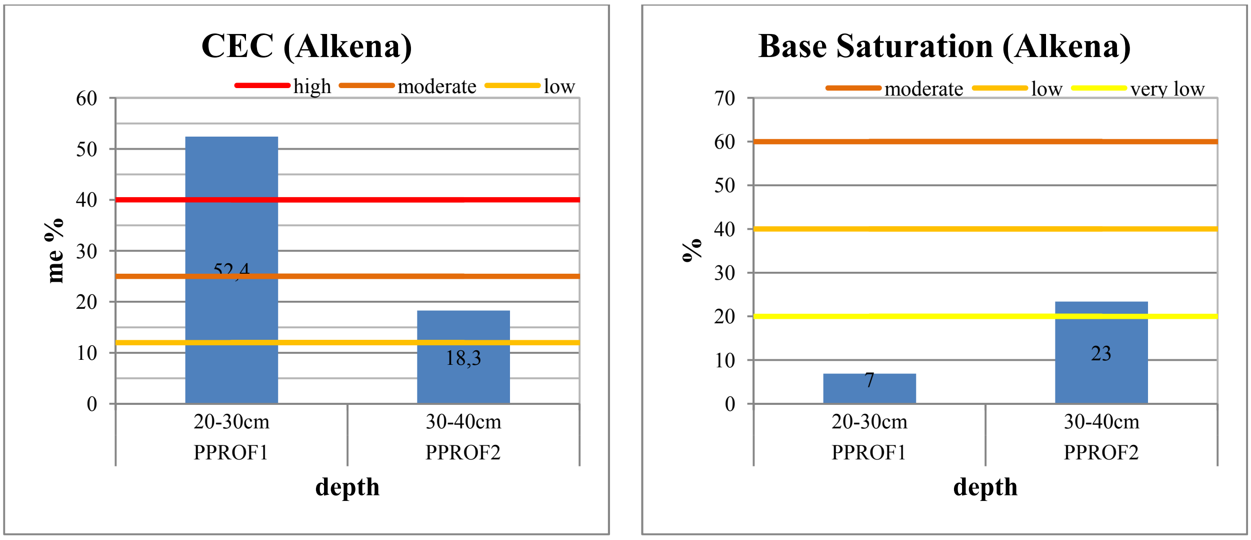


Figure 52: Cation exchange capacity (left) and base saturation (right) of the soils from Alkena and upper boundaries of ranges according to HAZELTON (2007)

Exchangeable Bases

The levels of exchangeable bases of the soils from Alkena are shown in Figure 53 and Figure 54. The content of Ca was low (2,24me%), the content of Mg moderate (1,15me% and 1,76me%), and the content of K very low (0,13me% and 0,15me%) in the soils of both profile pits. The content of Na was very low (0,10me%) at $P_{PROF}1$ and low (0,13me%) at $P_{PROF}2$.

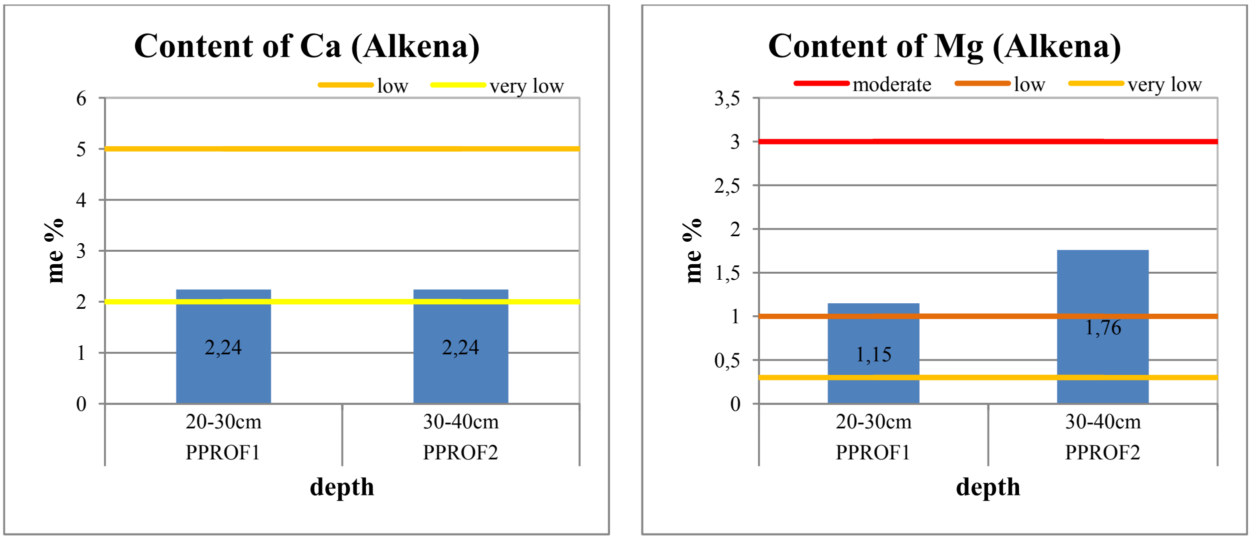
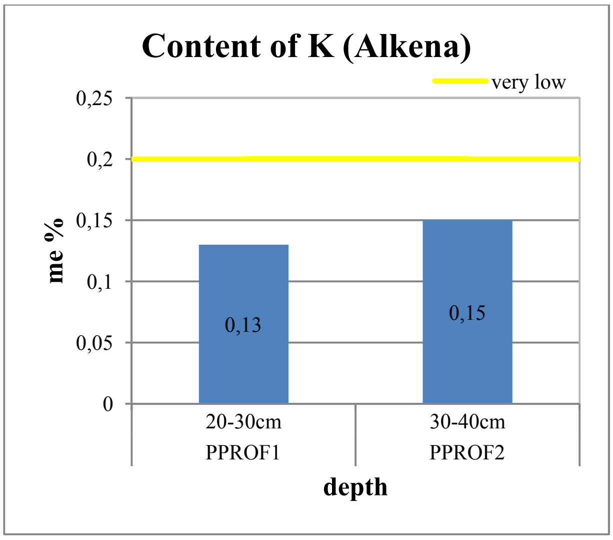


Figure 53: Content of exchangeable calcium (left) and exchangeable magnesium (right) of the soils from Alkena and upper boundaries of ranges according to HAZELTON (2007)



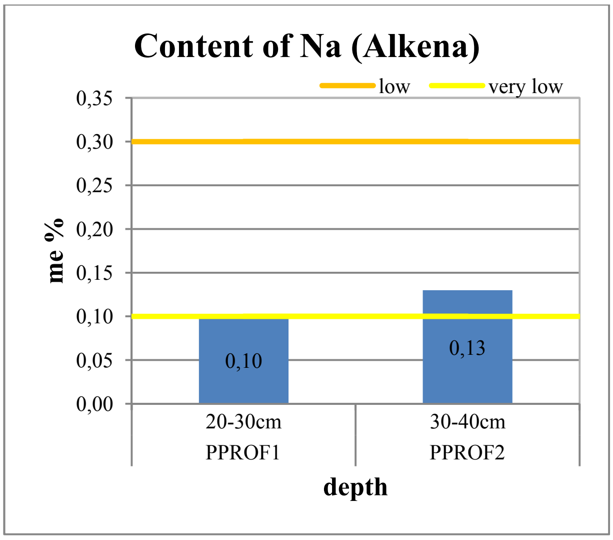


Figure 54: Content of exchangeable potassium (left) and exchangeable sodium (right) of the soils from Alkena and upper boundaries of ranges according to HAZELTON (2007)

Figure 55 shows the content of exchangeable bases in Alkena in context to the total amount of cations that can be exchanged by the soil (CEC). It can be stated, that $P_{PROF}1$ shows similar conditions as $P_{PROF}2$ in Kiripia. Hence the large gap between the CEC and the content of exchangeable bases can also be explained by very strong leaching of the soil as a consequence of the high amount of sand (88%) and heavy rainfall.

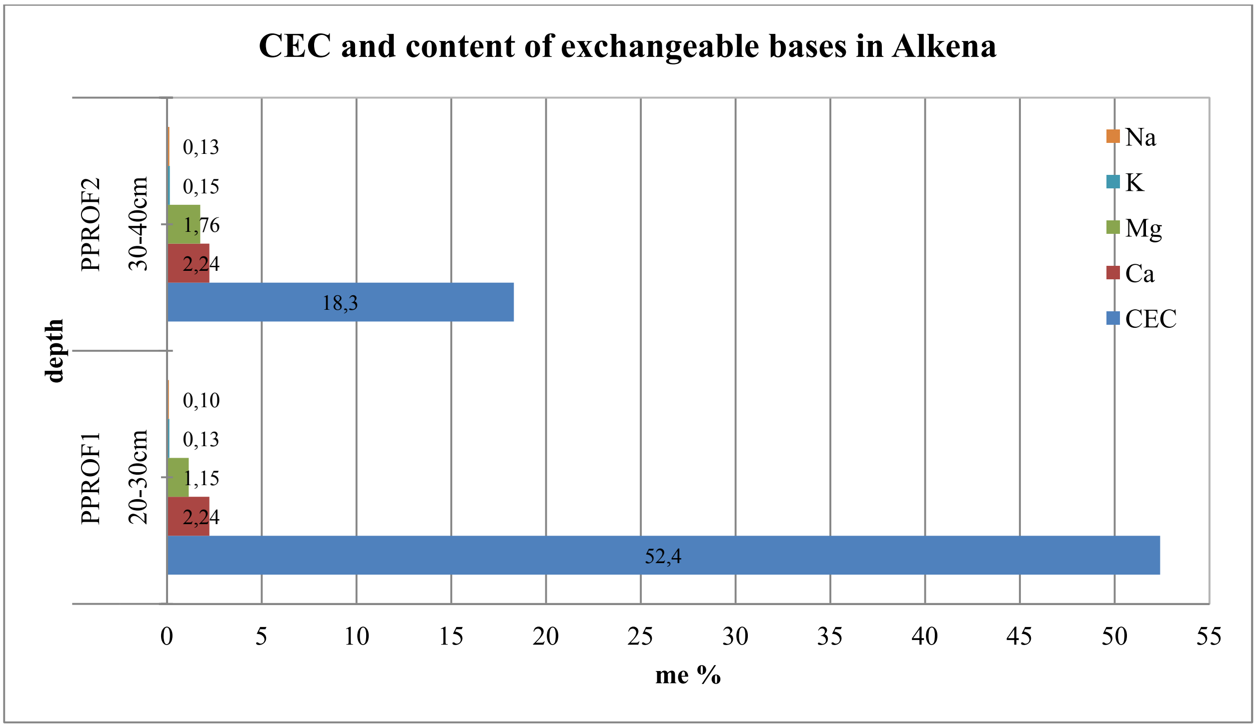


Figure 55: CEC and content of exchangeable bases of $P_{PROF}1$ and $P_{PROF}2$ in Alkena

None of the saturation levels of the bases Ca, Mg and K in Alkena was within the desirable range, but were all rather below the lower threshold level according to HAZELTON (2007) (Figure 56 and Figure 57). It can be concluded that a deficiency of K and Ca is existent in the soils of both profile pits. This is also confirmed by PEVERILL (1999), who expects a deficiency of potassium at levels below 0,2 - 0,5me%. The Mg saturation percentage of $P_{PROF}1$ was below

4% of CEC, which would also denote a deficiency of Mg in this profile according to PEVERILL (1999). The ESP values of the soils were 0,19% at $P_{PROF}1$ and 0,71% at $P_{PROF}2$, which implies that the soils are not under sodic conditions (Figure 56, right).

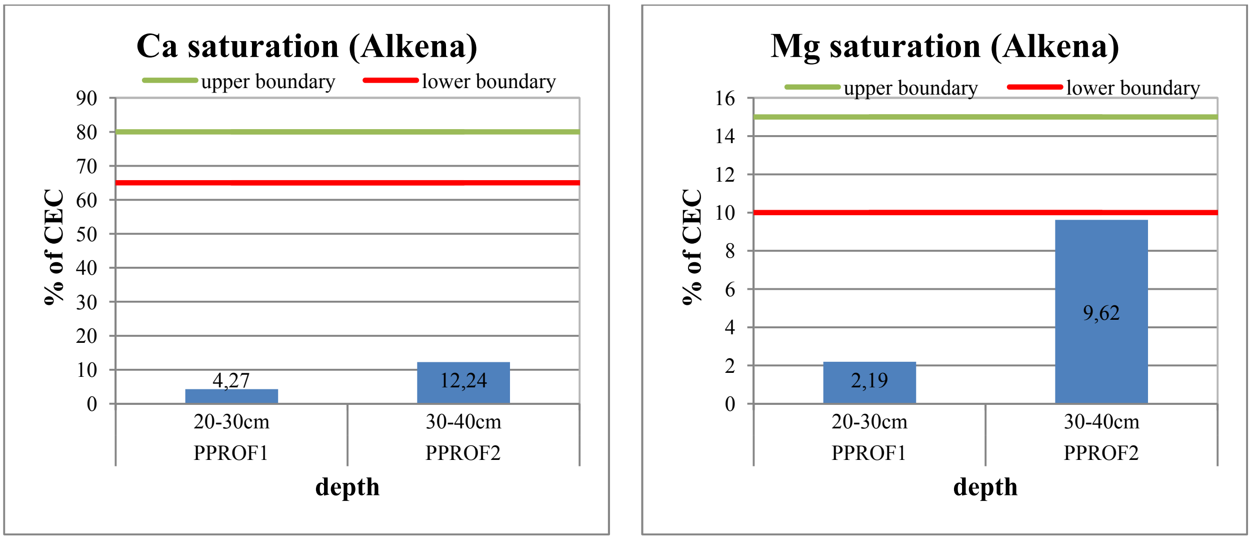


Figure 56: Calcium saturation (left) and magnesium saturation (right) of the soils from Alkena and desirable range for many plants according to HAZELTON (2007)

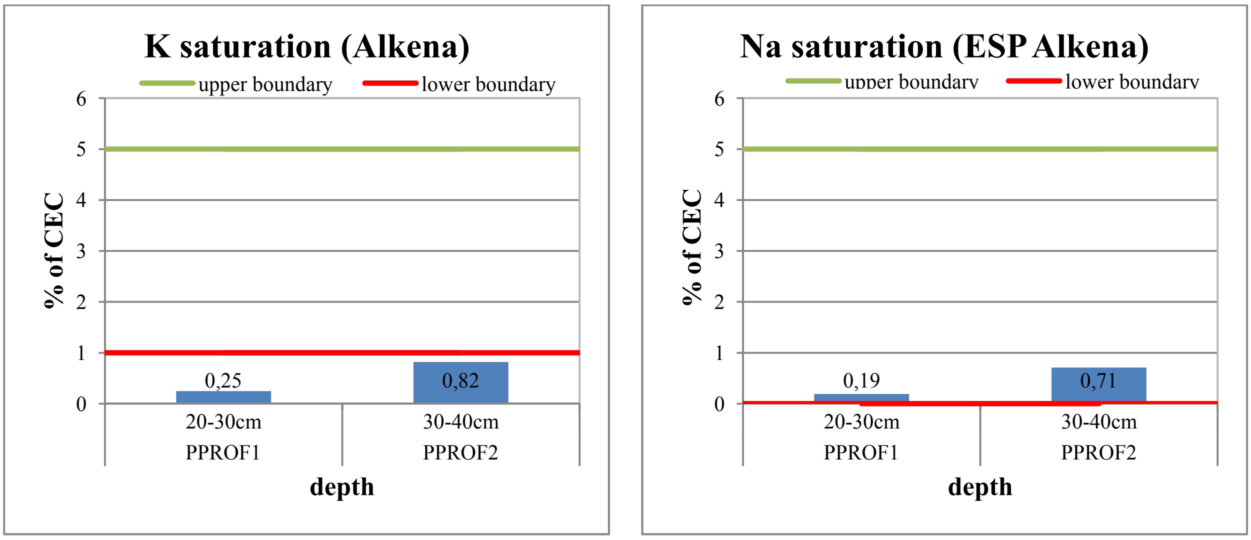


Figure 57: Potassium saturation (left) and sodium saturation (right) of the soils from Alkena and desirable range for many plants according to HAZELTON (2007)

Nutrients

The levels of total nitrogen and organic carbon according to HAZELTON (2007) were very high at $P_{PROF}1$ and medium at $P_{PROF}2$ (Figure 58). The PNGRIS data shows high values (>0,5%) of total Nitrogen for all sites.

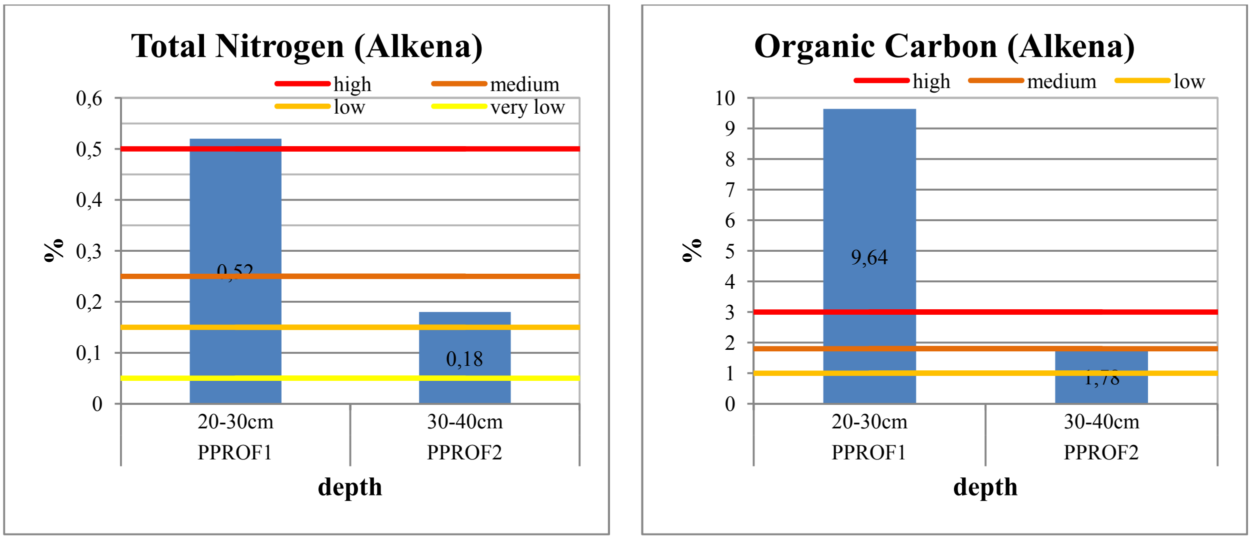


Figure 58: Total nitrogen (left) and organic carbon (right) of the soils from Alkena and upper boundaries of ranges according to HAZELTON (2007)

$P_{PROF}1$ possessed a medium (18,54), and $P_{PROF}2$ a very low (9,89) C/N ratio (Figure 59), which indicates a rather slow decomposition process at $P_{PROF}1$. C/N ratios around ten to twelve are normal for agricultural soils.

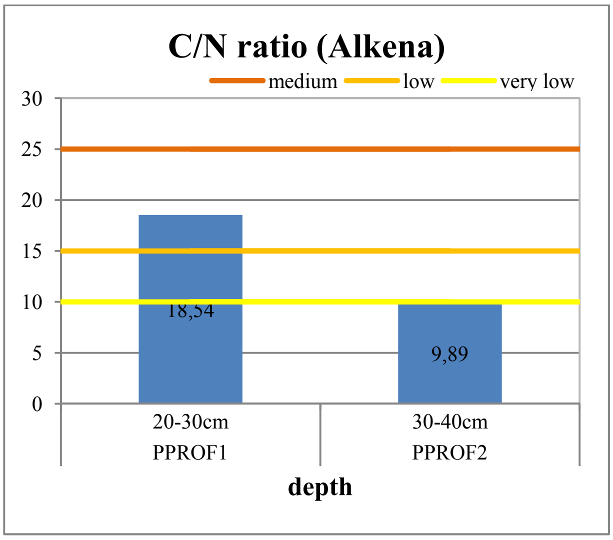


Figure 59: C/N-ratio of the soils from Alkena and upper boundaries of ranges according to HAZELTON (2007)

4.2.2.2.3 Bulk density

The bulk densities of the soils are rated as very low (Figure 60). Hydrandepts normally feature low bulk densities (< 0,85g/cm³), whereas the very low value of $P_{PROF}1$ can be explained by its very high content of organic matter.

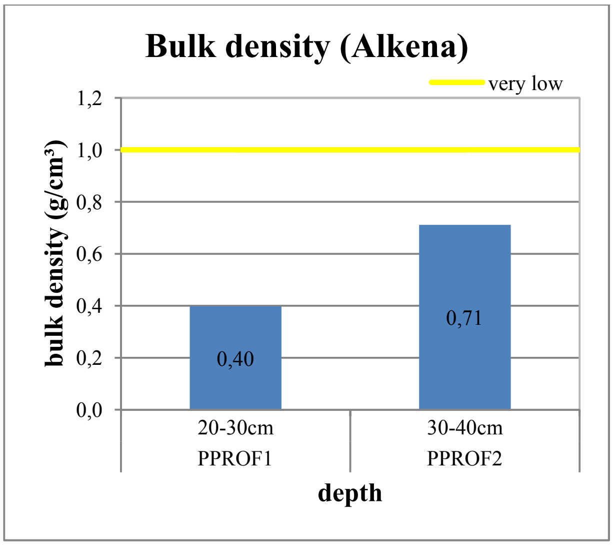


Figure 60: Bulk density of the soils from Alkena and upper boundaries of ranges according to HAZELTON (2007)

4.2.2.2.4 Hydraulic conductivity

The conversion of texture classes from the Australian system to the FAO/USDA system changed the texture classification of $P_{PROF}1$ from loamy sand to sand, whereas the soil of $P_{PROF}2$ was still classified as clay loam (Table 26).

Table 26: Texture of the soils from Tambul according to the FAO/USDA system

		Texture (FAO/USDA)	Texture (Australia)
Tambul (Alkena)	$P_{PROF}1$	Loamy Sand	Sand
	$P_{PROF}2$	Clay Loam	Clay Loam

The hydraulic conductivity of the soils was calculated as very low at $P_{PROF}1$ and extremely low at $P_{PROF}2$ (Figure 62). Soils with extremely low hydraulic conductivities are susceptible for water logging. This is supported by the field investigations of $P_{PROF}2$, which showed an increasing number of mottles in the different soil layers indicating prolonged lack of soil aeration and hence possibly seasonal or prolonged water logging. $P_{PROF}1$ had a higher hydraulic conductivity compared to $P_{PROF}2$, which can be explained by its higher percentage of sand in the soil (Figure 61), but with a value of 0,91mm/h it was still rated as very low.

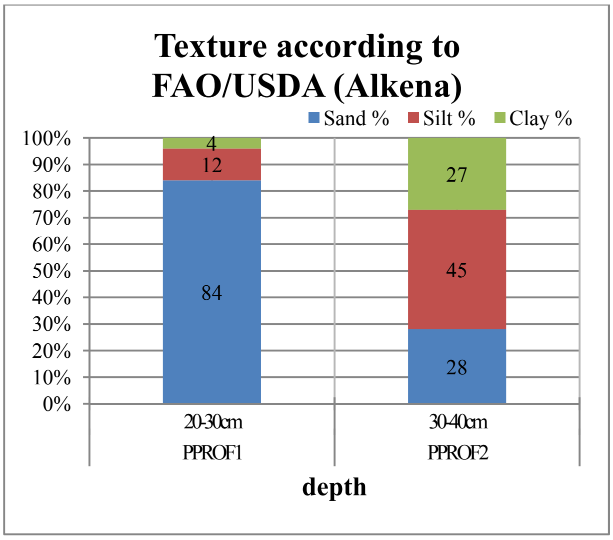


Figure 61 : Texture of the soils from Alkena according to the FAO/USDA system

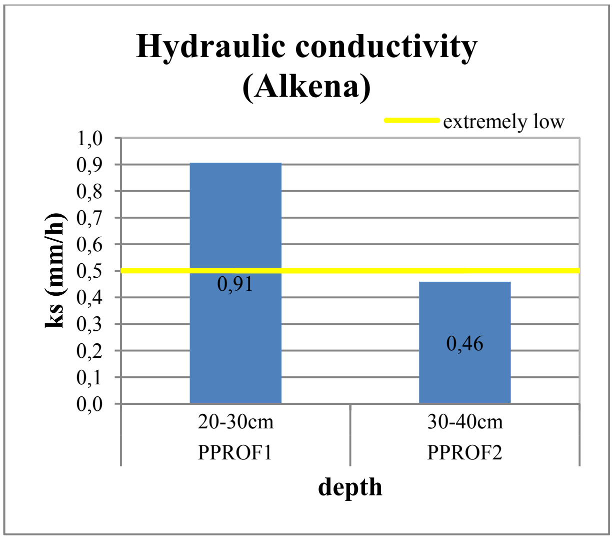


Figure 62: Calculated hydraulic conductivity of the soils from Alkena and upper boundaries of ranges according to HAZELTON (2007)

4.3 KOPAFO

4.3.1 GENERAL INFORMATION

Kopafo is situated in the Bena District of the Eastern Highlands Province, at a distance of about 35km from Goroka, the capital of the Province. It is accessible by highland highway and two kilometres of dirt road passable only by a four wheel drive vehicle. The area of the study site lies at an altitude of 1600m asl and has a population of approximately 2426 people (PNG 2000 census, data source: Mike Bourke, Australia National University). The landscape consists of grass covered small hills mostly without trees, whose vegetation is burned down regularly by the local population. The community of Kopafo lies in a valley which is getting narrower to the north-west and is confined to two hills, one to the north-east and the other to the south-west. Kopafo includes various hamlets and its public institutions comprise a community school, different churches and a community centre called Kakaruk centre (Figure 63).

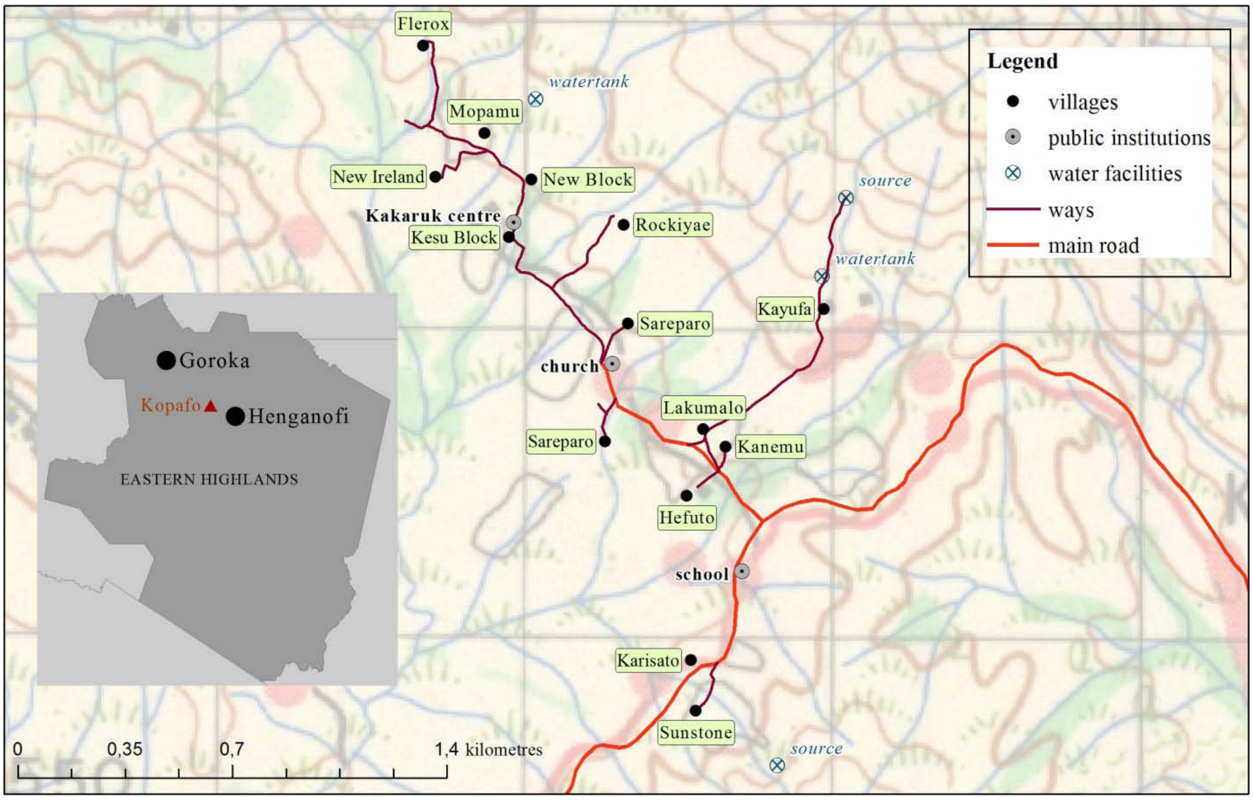


Figure 63: Villages, public institutions and water sources at Kopafo community

4.3.1.1 Climate

To describe the climatic conditions prevalent in Kopafo, weather data from Goroka and Henganofi (situated to the east along the highland highway, see Figure 63) can be consulted. The data refers to the years 1955 - 1960 and was derived from HAANTJENS (1970).The regional climate is mainly governed by the perturbation belt of north-west winds dominating the weather from December to March, and the south-east trade wind belt which dominates the weather from May to October. This leads to a clear differentiation of a dry- and a wet season. The large differences in the topography of this area result in local circulation which dominate the weather during the south-east season and are still important in the north-west season. The mean annual rainfall in Goroka accounts for 1900mm and in Henganofi 1750mm. The area around Kopafo shows a clear seasonality of distribution of rainfall (Figure 64), which decreases to the west of the highlands. Dry spells in which the evaporation exceeds the rainfall consecutively over more than five weeks occur on average once a year (Haantjens H.A. et al., 1970).

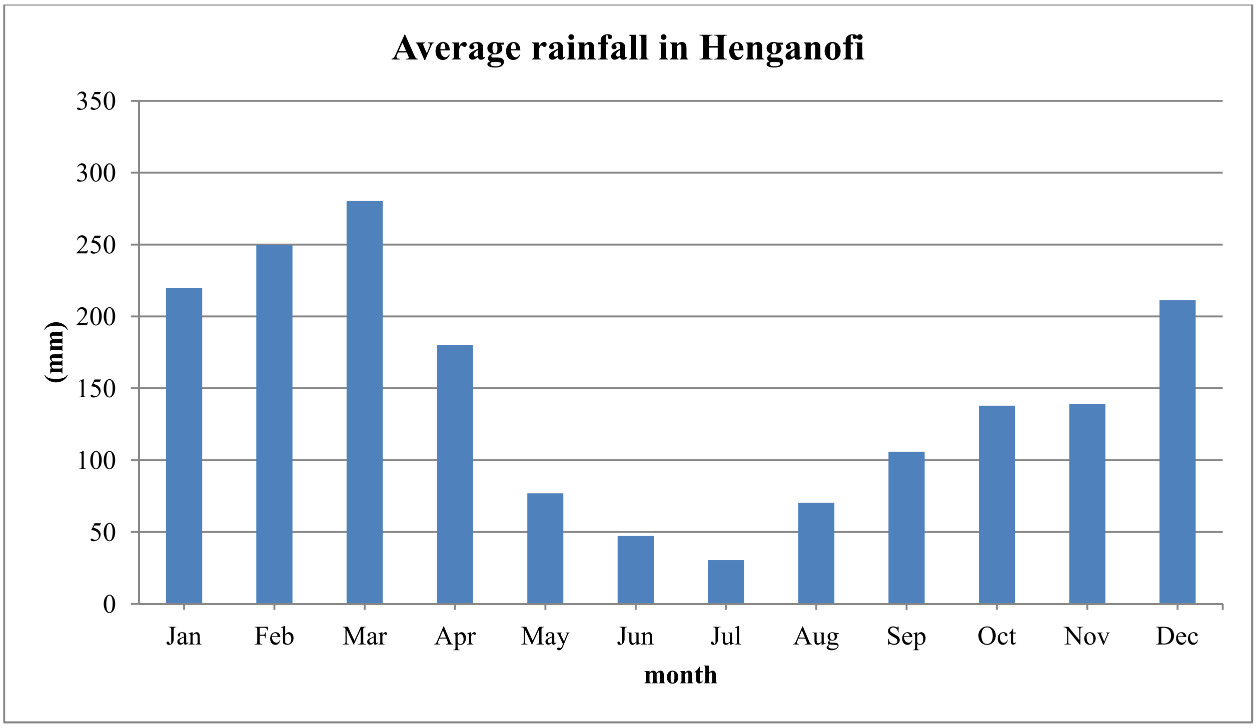


Figure 64: Monthly average rainfall in Henganofi, created with data from Haantjens H.A. et al., 1970

The average maximum and minimum temperatures have a very restricted range, whereas the maximum is around 25°C and the minimum around 15°C over the whole year (see Figure 65). Even extreme temperatures only vary between three and five degrees Celsius. Frosts can occur very occasionally, mostly in depressions where cold air flows through (Haantjens H.A. et al., 1970).

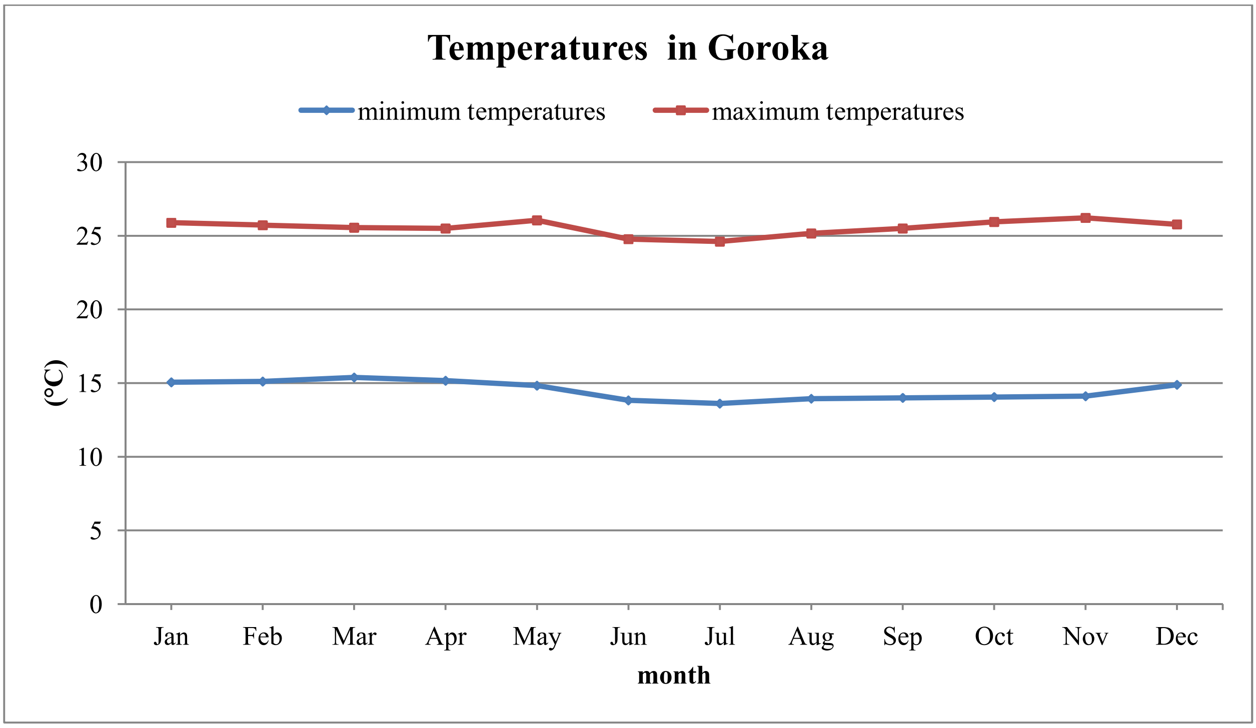


Figure 65: Monthly average minimum and maximum temperatures in Goroka, created with data from Haantjens H.A. et al., 1970

Apart from rainfall the climatic factors of this area show only little variation. HAANTJENS (1970) calculated an annual evaporation about 1100mm to 1300mm at an elevation of 1524 metres.

In Figure 66, the average monthly rainfall in Goroka is confronted with the calculated evaporation data derived from HAANTJENS (1970). It becomes apparent, that the evaporation exceeds the rainfall during several months of an average year. Further, the Bena area is known for its extended dry seasons. The most recent was in 2010 and lasted for five months.

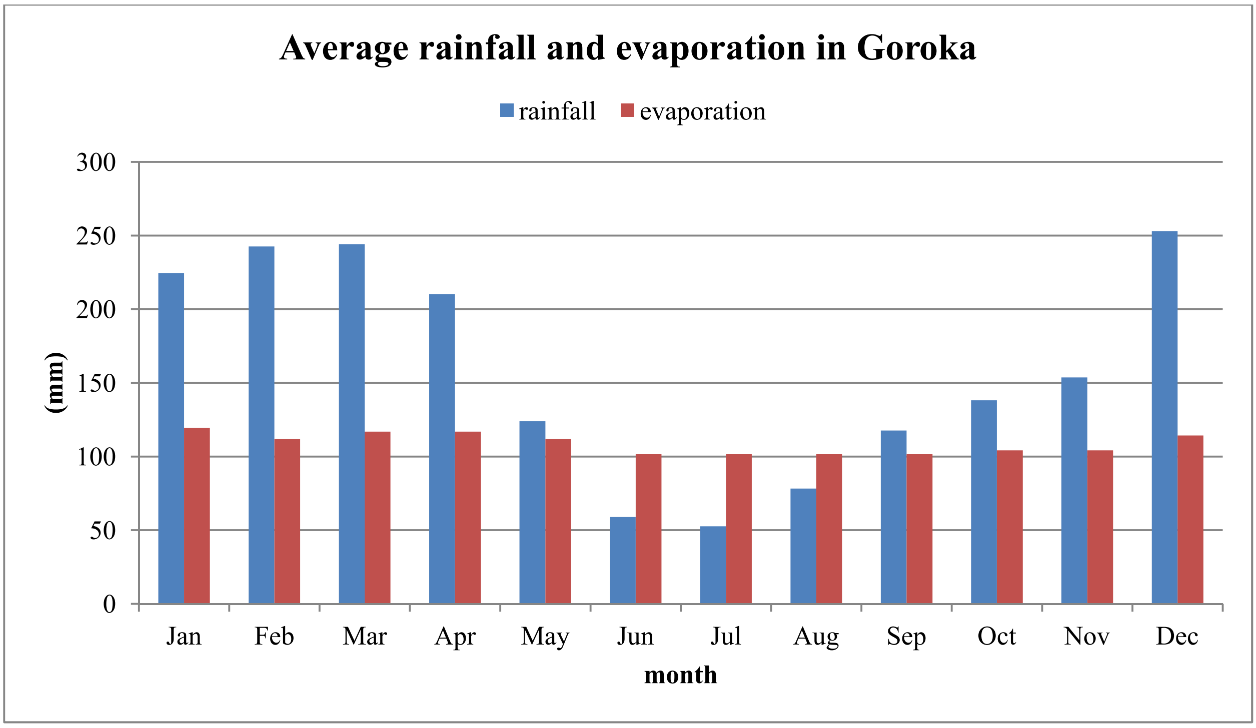


Figure 66: Monthly average rainfall and evaporation in Goroka, created with data from Haantjens H.A. et al., 1970

4.3.1.2 Agriculture

Most of the farmers in Kopafo are subsistence farmers. Many of them generate income by producing food for the markets of cities or selling surplus yields at local markets or in Goroka. Apart from that, the most important source of income is coffee production (every household at least possesses one coffee plot). Some farmers own livestock like cattle, goats, chicken and pigs and there are also a few fish ponds.

The major staple crops are banana, cassava and sweet potato. Other crops planted are: cabbage, tomato, chili, cucumber, corn, peanut, orange, avocado, beans, pumpkin, pineapple, taro, sugarcane, yam, onion and mango. When a new garden is prepared, the clearance of the land is done during the dry season. At the beginning of the wet season the earth is tilled finely, drains are dug and later mounds are build. Mounds in this area are usually small mounds and composting is not practiced. During the dry season the sweet potato is planted on flat beds instead of mounds. Usually the fields are cultivated by mixed cropping, where sweet potato is planted along with other crops. Only fields used for commercial production are cultivated by mono cropping. Coffee fields as well as the food gardens in the valley comprise of a system of drains that remove the excess water during the wet season.

The food gardens as well as the coffee fields of most of the farmers are located close to their homes (uphill and downhill) and some close to the river (downhill). The gardens of the uphill areas are only cultivated in the wet season because during the dry season it is too dry. The lower lying gardens are usually cultivated throughout the year. They are watered during the dry season using simple bucket or water can methods. Only fields used for commercial production (especially tomato) for major markets are watered regularly. However the majority of farmers don't cultivate crops for commercial use, but only sell surplus yield.

Since the downhill area is densely used, farmers cannot extend their food gardens or coffee fields in order to increase their production. This leads to intensification of cultivation and hence to soil fertility depletion. According to local farmers the decrease of soil fertility is especially a problem for uphill farmers (maybe as a result of the combination of dry conditions and erosion). During the dry season the villagers sometimes don't produce enough crops and accordingly have to buy supplementary food from local markets and Goroka.

Erosion is a problem in uphill areas during heavy rains (big gully erosion visible in uphill areas).

In Kopafo farmers are concerned about extended dry seasons as well as pests and diseases of their crops. They would be interested in supplementary irrigation as well as soil moisture conservation practices (especially uphill farmers).

Soil moisture
HAANTJENS (1970) calculated the number of weeks during the dry season in which the soil moisture storage was depleted. The calculation was done for Goroka and Henganofi over the years 1956 - 1966. In Goroka the soil moisture storage was never completely depleted, while Henganofi occasionally showed a complete depletion. Further, for five years soil moisture storage had a depletion of over 50% during half of the dry season. In Goroka, a depletion of over 50% happened only occasionally. On the other side a water balance model showed that soil moisture during the wet season stays at levels above field capacity for a long time if the soil has low drainage conditions (Haantjens H.A. et al., 1970).

4.3.1.3 Water supply
Some of the villages of the Kopafo community are supplied with water through a system which consists of a network of pipes fed by one or more water tanks. Thereby each village is equipped with one or more public taps that are usually located at the central place. The water from these systems is only used for drinking and cooking purposes. For other purposes including washing, laundry and watering animals and crops, water has to be fetched from nearby creeks or springs.

Two water tanks were constructed in 2010 and are located close to the village of Kayufa (Figure 63 and Figure 67). Another water tank was constructed close to the village Mopamu at the northern part of Kopafo. Both were funded by the local member of Parliament (MP). The inlet for the two tanks at Kayufa (Figure 67, right) is at a section of the river Kanemu which is located 44 metres higher than the tanks. It consists of a small dam from which two pipes originate. One pipe leads to the tanks, and a smaller pipe leads to houses situated close to the inlet. The villages Kayufa, Rockiyae, Hefuto, Kanemu, Lakumalo, Sareparo, Kesu Block and Karisato, and the Kopafo community school are supplied by this system. The school also possesses additional rainwater harvesting tanks. The water tank close to Mopamu supplies the villages Mopamu, Flerox, Fumirox, New Block, New Island and Kesu Block.

According to the villagers the water from the tanks is reliable in terms of quality and quantity, although there can be shortages from low water pressure. After heavy rains the water supply is stopped by closure of a central valve because of the high amount of suspended sediment in the water. Only during prolonged dry seasons there can be water shortages because the water source dries out.


Figure 67: Water tanks (left) and inlet (right) of Kayufa in Kopafo community, pictures: Agnes Ulreich, 2012

Sunstone village has its own water supply system which consists of a pipe funded by the church. The pipe leads from a small waterhole to the village. The water is used for domestic purposes as well as irrigation.

People from villages that are not supplied by piped water have to go to small creeks or springs to fetch water. Upstream - downstream conflicts are regularly emerging in those villages because of the pollution of the source. During the dry season it happens that creeks and springs dry out. In that case people have to fetch water at one of the perennial streams. Farmers say, that most of the creeks only dry out during prolonged dry seasons.

4.3.2 SOIL

From a geological point of view the area consists of unconsolidated sedimentary rocks from alluvial deposits, whereas gravel, sand, silt, clay and organic remains from alluvium and swamp deposits prevail. The hillsides to the east and west are of mixed sedimentary and volcanic origin. The eastern hillside consists of tuffaceous shale and siltstone, greywacke, pebbly conglomerate and lithic sandstone, with minor occurrence of lava and pyroclastics. The western hillside is dominated by volcanolithic conglomerate, greywacke and tuff (PNGRIS, 2008).

The landform of the area is conditioned by fluvial erosion and mass movement and consists of mountains and hills with weak or no structural control, showing little dissected or undissected relict alluvial, colluvial mudflow or fans in between. The region is not governed by inundation or flooding events (PNGRIS, 2008).

The main great soil groups of the area are Humitropepts, Tropaqualfs, Argiaquolls and Ustorthents (Figure 68). Interjacent Eutropepts, Plinthaquults, Tropothents and Tropadalfs can be found. The most widespread in the area of the Kopafo community is the Humitropept, which is a young and moderately weathered soil that can be found in the central and eastern part of Kopafo. In the western part there are Argiaquolls and Eutropepts, and at the western end Tropaqualfs. Like the Humitropept, the Eutropept belongs to the soil suborder of Tropepts. It has base saturations of more than 50% (horizons between 25cm and 1m) and does not dry out completely for more than 90 days at a stretch. The Argiaquoll belongs to the suborder of Aquolls and the order of Mollisols, which are soils with thick dark base rich topsoil. The Argiaquoll is poorly drained, exhibits a gleyed or mottled subsoil and is coarser textured in the surface horizon. The Tropaqualf belongs to the soil order of Alfilsols, which are also coarser textured in the surface horizon, and have a base rich subsoil. Their suborder of Aqualfs indicates poor drainage conditions and mottles or iron- manganese concretions, which are characteristics associated with wetness. The Ustorthent belongs to the soil order of Entisols, which are recently formed soils.

The suborder of Orthent indicates a soil without diagnostic horizons on slopes that have a greater inclination than 25%. They normally have loamy or finer textures and show rock at a depth of 25cm. Ustorthents are characterised by their mean annual soil temperature of 8°C or higher and are normally under dry conditions for less than 90 cumulative days (PNGRIS, 2008).

4.3.2.1 Soil survey

The primary data collection in Kopafo was conducted between March 18th and March 29th, 2012. The soil survey included the investigation of twenty soil samples which have been taken with a soil core auger. The survey points formed a regular grid with longitudinal distances of approximately 420m and latitudinal distances of approximately 330m ($P_{KOP}1$ - $P_{KOP}20$). Furthermore three soil profiles have been inspected through profile pits ($P_{PROF}1$ - $P_{PROF}3$). Figure 68 shows the location of the sampling spots with the soil core auger as well as the location of the profile pits in a map of soil groups of Kopafo.

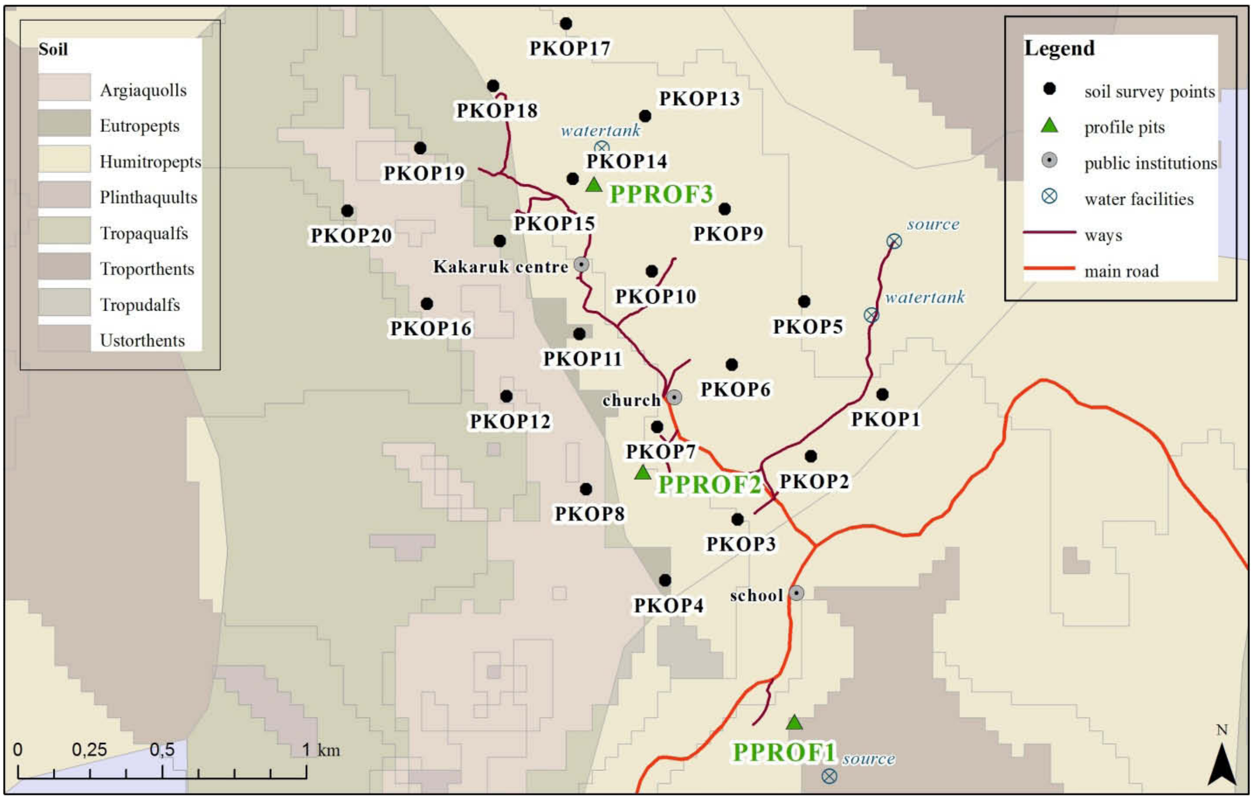


Figure 68: Great soil groups (Source: PNGRIS, 2008) and location of soil sampling spots in Kopafo

4.3.2.1.1 Soil core auger

Table 27 shows the coordinates of the sampling spots from the soil core auger, the elevation and the type of land use at the sampling site.

Table 27: Sampling spots from the soil core auger in Kopafo

Sample	Date	Latitude	Longitude	Elevation (m)	Landscape
$P_{KOP}1$	18.03.2012	-6,221843	145,545399	1618	coffee field
$P_{KOP}2$	18.03.2012	-6,223792	145,543105	1591	grassland
$P_{KOP}3$	18.03.2012	-6,225812	145,540782	1567	peanut field
$P_{KOP}4$	18.03.2012	-6,227775	145,53857	1474	coffee field

$P_{KOP}5$	19.03.2012	-6,218956	145,54293	1614	coffee field
$P_{KOP}6$	19.03.2012	-6,221018	145,540639	1576	coffee field
$P_{KOP}7$	19.03.2012	-6,222663	145,538414	1580	track beside bamboo
$P_{KOP}8$	19.03.2012	-6,22482	145,536169	1558	coffee field
$P_{KOP}9$	20.03.2012	-6,216067	145,540492	1616	grassland
$P_{KOP}10$	21.03.2012	-6,217955	145,538255	1576	coffee field
$P_{KOP}11$	21.03.2012	-6,219599	145,536456	1566	former rice field
$P_{KOP}12$	22.03.2012	-6,221868	145,533663	1556	coffee field
$P_{KOP}13$	20.03.2012	-6,213157	145,538023	1652	grassland
$P_{KOP}14$	21.03.2012	-6,215365	145,535505	1597	grassland beside fish pond
$P_{KOP}15$	21.03.2012	-6,216693	145,533722	1576	field
$P_{KOP}16$	22.03.2012	-6,21906	145,531248	1598	site of burnt house
$P_{KOP}17$	20.03.2012	-6,21031	145,535505	1652	grassland
$P_{KOP}18$	20.03.2012	-6,212182	145,533225	1597	field (banana, tanget)
$P_{KOP}19$	22.03.2012	-6,214277	145,530855	1574	grassland
$P_{KOP}20$	22.03.2012	-6,216135	145,528683	1607	grassland

The soils sampled with the soil core auger were mostly clays and sometimes clay loams or sandy clay loams. Apart from the samples in the grasslands on the hillsides, the topsoil layers of the soils were thick, dark brown and supposedly fertile.

$P_{KOP}16$ and $P_{KOP}20$ (Figure 69 and Figure 70) are located on the slope of the hill to the south-west, which is covered with grassland. $P_{KOP}20$ had a reddish brown soil throughout the whole depth of the profile. At this site big erosion gullies were visible. $P_{KOP}16$ had a similar profile, but showed a light brown topsoil layer. The site of $P_{KOP}16$ was one of the highest lying places in Kopafo that were still cultivated. According to the local farmers both places were governed by very dry conditions.

Figure 69: Soil profile of $P_{KOP}16$ taken by the soil core auger (left) and its location on the hillside (right), pictures: Agnes Ulreich, 2012

Figure 70: Soil profile of $P_{KOP}20$ taken by the soil core auger (left) and its location on the hillside area (right), pictures: Agnes Ulreich, 2012

$P_{KOP}13$ and $P_{KOP}17$ are located at the opposing hillside to the north-east, which is also covered by grassland. The profiles had a topsoil layer of about 15cm to 25cm and were also in very dry conditions. The profiles of $P_{KOP}14$, $P_{KOP}15$, $P_{KOP}18$ and $P_{KOP}19$ had thick, dark brown topsoil layers of 40cm to 50cm and yellow, grey or white clays with ochre or red mottles beneath. The topsoil layers made a fertile impression and partially contained earthworms. Figure 71 shows the profile of $P_{KOP}14$ as an example for a soil profile of a lower lying area.

Figure 71: Soil profile of $P_{KOP}14$ taken by the soil core auger (left) and its location on the valley bottom area (right), pictures: Agnes Ulreich, 2012

The rest of the soil profiles mostly had a thick topsoil layer of fertile dark brown soil and red or yellow colours in deeper layers. Some of the samples taken from coffee fields contained very wet earth and grey colours in the subsoil layers ($P_{KOP}4$ and $P_{KOP}8$). Most of the coffee fields were surrounded by deep drains. A detailed description of the soil profiles taken with the soil core auger according to the soil morphological descriptors (chapter 3.2.2.1) and pictures of all soil profiles are shown in Annex 3.

4.3.2.1.2 Profile pits

The fields chosen for the profile pits were dominated by very dry conditions, but had a water source within a distance reachable by foot. The location details of the profile pits are listed in Table 28.

Table 28: Location of profile pits in Kopafo

Name	Date	Latitude	Longitude	Elevation [m]	Landscape
$P_{PROF}1$ (SUN)	27.03.2012	-6,232061282	145,5426378	1606	fallow grassland
$P_{PROF}2$ (SAR)	28.03.2012	-6,224274432	145,5379096	1559	no vegetation
$P_{PROF}3$ (MOP)	29.03.2012	-6,215321	145,5363886	1592	fallow grassland

Profile pit one ($P_{PROF}1$)

Profile pit one was dug in a field of Sunstone village close to the main track at the south end of Kopafo. The place had been cultivated until three years ago, but then had to be abandoned because pigs broke the fence and destroyed the crops. At the time of the field work it was vegetated by fallow grassland. According to the owner, another reason for the abandonment of the field was its very dry condition during the dry period. About 220 metres uphill there is a spring which is already used for irrigation. Six undisturbed soil samples were taken from this profile pit, two respectively at a depth of 30-40cm, 55-65cm and 90-100cm . Table 29 presents the soil profile description from the field investigations.

Table 29: Soil description of profile pit one ($P_{PROF}1$) in Kopafo

Sample Code	Depth [cm]	Colour	Segregations	Presence of roots	Comments
$P_{PROF}1$ Kopafo	0-80cm	dark brown	ochre colour around stones	few, until 30cm	no clear distinction of horizons
	80-100cm	dark brown	more stones/ochre colour	no	

The soil profile of $P_{PROF}1$ in Kopafo consisted of two soil horizons (Table 29 and Figure 72), which could not clearly be distinguished. The soil had a dark brown colour continuously over the whole depth of the profile. Roots were present until a depth of 30cm. The profile contained small stones that had ochre colours around them and occurred more frequently down from a depth of 80cm.

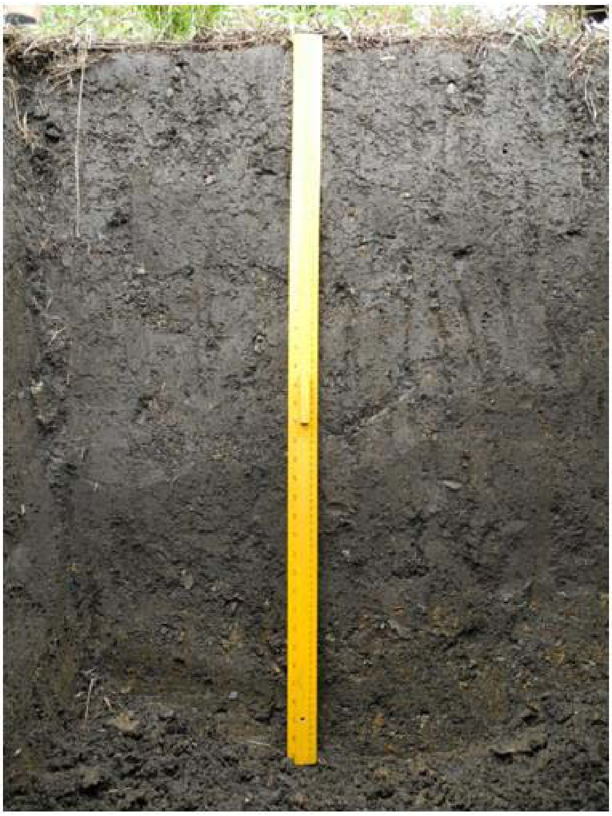


Figure 72: Soil profile of profile pit one ($P_{PROF}1$) in Kopafo, picture: Agnes Ulreich, 2012

Profile pit two ($P_{PROF}2$)

Profile pit two was located in a gardening area at Sareparo village in the middle of Kopafo community close to the main track. The field in which the pit was dug is usually cultivated by crop rotation technique where sweet potato is planted alternating to peanut. At the time of the field work, the field hardly had a vegetation cover. A tap from Kayufa water tank is close to the fields. Six undisturbed soil samples were taken from this profile pit, two respectively at a depth of 30-40cm, 60-70cm and 90-100cm. Table 30 presents the soil profile description from the field investigations.

Table 30: Soil description of profile pit two ($P_{PROF}2$) in Kopafo

Sample Code	Depth [cm]	Colour	Segregations	Presence of roots	Comments
$P_{PROF}2$ Kopafo	0 - 25	dark brown	none	few until 10cm	
	25 - 80	reddish brown	black mottles; grey cords	no	
	80 - 100	greyish white	many black mottles, red cords	no	

The soil profile of $P_{PROF}2$ in Kopafo had three horizons (Table 30 and Figure 73). The topsoil layer had a thickness of 25cm and consisted of loose dark brown earth that was very dry and contained roots until a depth of 10cm. The subsequent soil horizon expanded from 25-80cm of depth and had a reddish brown colour with black mottles and grey chords. The bottom horizon had a greyish white matrix with many black mottles and red cords, probably indicating considerable leaching and low organic matter and fertility status.

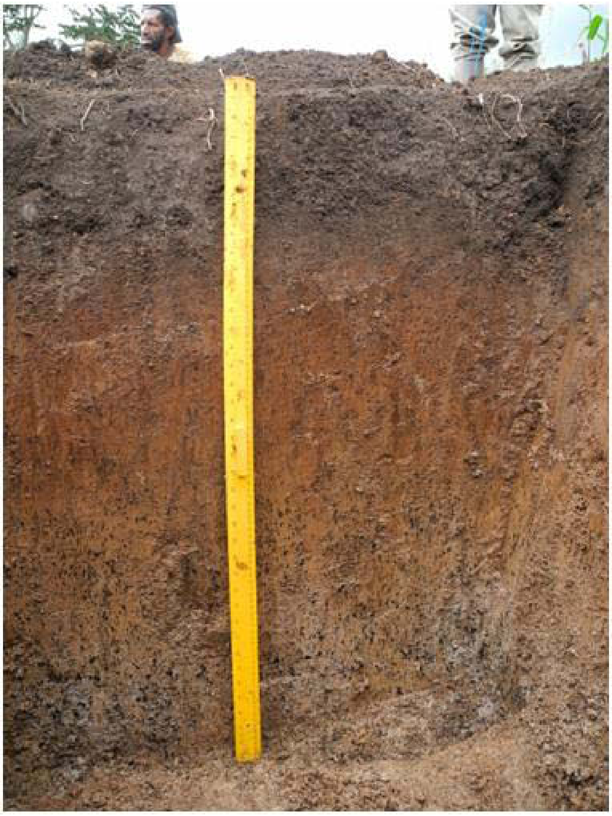


Figure 73: Soil profile of profile pit two ($P_{PROF}2$) in Kopafo, picture: Agnes Ulreich, 2012

Profile pit three ($P_{PROF}3$)

Profile pit three was located close to Mopamu village in the northern part of Kopafo community. The field in which the pit had been dug was not cultivated at the time of the field work, but was dominated by short fallow vegetation. It was partly surrounded by other fields cultivated with sweet potato, cassava and pineapple. On the right hand side there was a fenced grazing land for cattle. The Mopamu water tank was located at a distance of about 130 metres uphill.

Six undisturbed soil samples were taken from this profile pit, two respectively at a depth of 30-40cm, 60-70cm and 90-100cm. Table 31 presents the soil profile description from the field investigations.

Table 31: Soil description of profile pit three ($P_{PROF}3$) in Kopafo

Sample Code	Depth [cm]	Colour	Segregations	Presence of roots	Comments
$P_{PROF}3$ Kopafo	0 - 25	dark brown	none	few	
	25 - 100	red, orange brown	black and few red mottles	no	

The soil profile of $P_{PROF}3$ in Kopafo consisted of two soil horizons (Table 31 and Figure 74). The topsoil layer reached a depth of 25cm and had a dark brown coloured matrix that presented a few roots. The second soil horizon (25-100cm) had a reddish brown colour with black and a few red mottles. The uniform reddish coloured layer suggests good drainage conditions.

Figure 74: Soil profile of profile pit three ($P_{PROF}3$) in Kopafo, picture: Agnes Ulreich, 2012

4.3.2.2 Laboratory analysis

4.3.2.2.1 Texture

The soils of the profile pits in Kopafo are characterized by a higher percentage of clay compared to the soils analysed in the Tambul area. The soil texture at $P_{PROF}1$ had the least content of clay with percentages between 37% and 45% (Figure 75). Its texture was classified as clay in the upper two horizons and as sandy clay at the depth of 80-90cm. $P_{PROF}2$ and $P_{PROF}3$ featured a higher content of clay which increased progressively with the depth of the soil profile. The soils of both profile pits ($P_{PROF}2$ and $P_{PROF}3$) were classified as clays (Table 32) according to the Australian classification system.

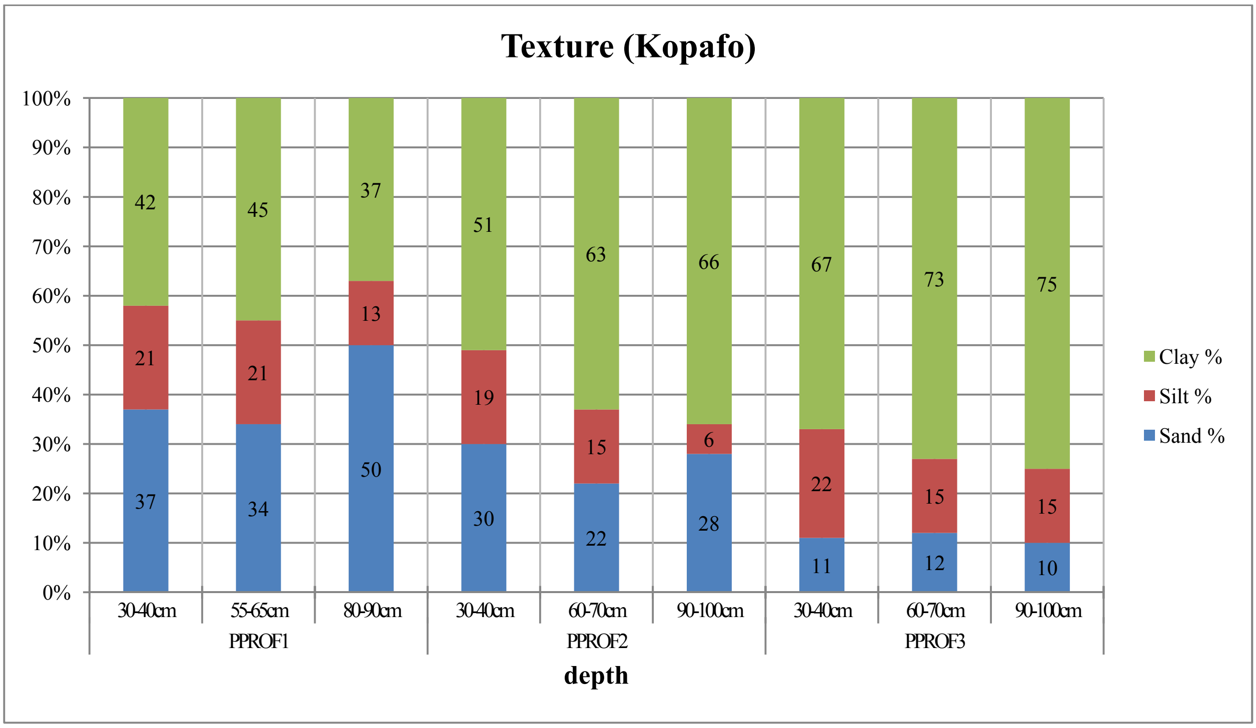


Figure 75: Soil texture of the soils from Kopafo

Table 32 shows a comparison of the soil texture determined in the laboratory and the texture information from the GIS data of PNGRIS for the areas of the profile pits. According to PNGRIS, the soil of the area in which $P_{PROF}1$ is located is classified as Ustorthent, and of the areas of $P_{PROF}2$ and $P_{PROF}3$ as Humitropept. PNGRIS discloses the soil fertility as moderate, the erodibility as low to very low, the soil mineral reserves as high to moderate and the drainage conditions as good.

At the locations of $P_{PROF}1$ and $P_{PROF}3$, the PNGRIS data suggests massive rock down from a depth of 25cm. That could not be verified during the field observations, but increasing numbers of stones in deeper layers of $P_{PROF}1$ lead to the assumption that massive rock lies at greater depths.

Table 32: Comparison of the soil texture specifications from the laboratory analysis and the texture data from PNGRIS at Kopafo

		laboratory analysis		PNGRIS	
		depth	texture	depth	texture
Kopafo	$P_{PROF}1$	30-40cm	clay	0-25cm	sandy loam, loam, clay loam
		55-65cm	clay	25-100cm	massive rock
		80-90cm	clay loam		
	$P_{PROF}2$	30-40cm	clay	0-25cm	sandy loam, loam, clay loam
		60-70cm	clay	25-100cm	clay, silty clay, sandy clay
		90-100cm	clay		
	$P_{PROF}3$	30-40cm	clay	0-25cm	sandy loam, loam, clay loam
		60-70cm	clay	25-100cm	massive rock
		90-100cm	clay		

4.3.2.2.2 Chemical parameters

Soil pH

The soil pH ranged between 5,2 and 5,6 and was therefore rated as strongly acid in the case of $P_{PROF}2$ and $P_{PROF}3$, and moderately acid in the case of $P_{PROF}1$ (Figure 76). The PNGRIS data suggests acid (pH 5,0 - 6,0) soil conditions for the locations of $P_{PROF}2$ and $P_{PROF}3$ and weakly acid to neutral (pH 6,0 - 7,0) conditions for the location of $P_{PROF}1$.

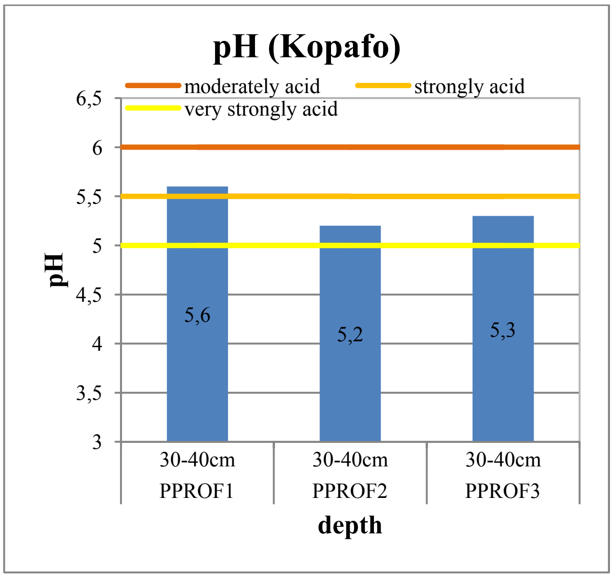


Figure 76: Soil pH values of the soils from Kopafo

The Ustorthent as well as the Humitropept, which are the prevalent soil groups at the locations of the profile pits, are soils of non-volcanic origin (PNGRIS, 2008). BAILEY (2009) found that the average soil pH for non-volcanic soils in the highlands of PNG was 6,2. The results of the own research were all beneath the average value (Bailey J., 2009).

Cation Exchange Capacity and Base Saturation

The cation exchange capacity of the soils was moderate for $P_{PROF}2$ and $P_{PROF}3$, and high at $P_{PROF}1$ (Figure 77, left). Compared to the soils of the Tambul sites, the base saturations of Kopafo were higher. The base saturation at $P_{PROF}2$ and $P_{PROF}3$ were moderate (49%), and of

$P_{PROF}1$ very high (95%) (Figure 77, right). Therefore it can be concluded that the soils of the profile pits $P_{PROF}2$ and $P_{PROF}3$ were weakly to moderately leached and the soil of $P_{PROF}1$ was very weakly leached. That complies with the fact that the Kopafo soils are clay soils which are located in a relatively dry area.

The PNGRIS data shows a high CEC (>25me%) for $P_{PROF}1$ and a moderate CEC (5 - 10me%) for $P_{PROF}2$ and $P_{PROF}3$. Further it indicates a low base saturation (<20%) at the sites of $P_{PROF}2$ and $P_{PROF}3$, and a high base saturation (>60%) at the site of $P_{PROF}1$. Proportionally that complies with the base saturation results from the own research.

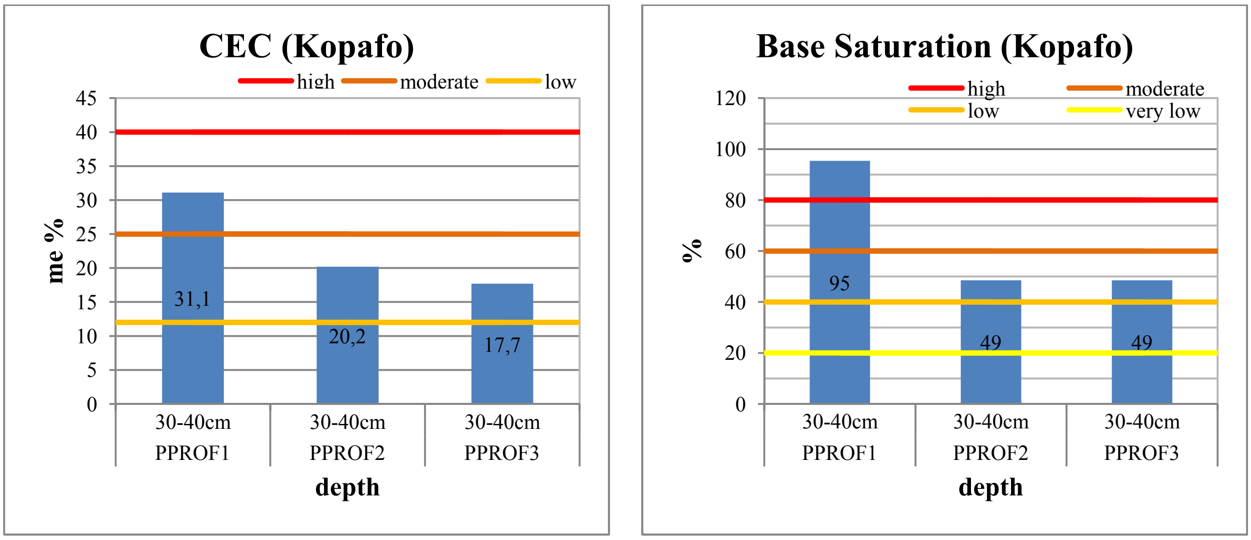


Figure 77: Cation exchange capacity (left) and base saturation (right) of the soils from Kopafo and upper boundaries of ranges according to HAZELTON (2007)

Exchangeable Bases

The content of exchangeable bases in the soils from Kopafo are shown in Figure 78 and Figure 79. The level of exchangeable calcium at the profile pits $P_{PROF}2$ and $P_{PROF}3$ in Kopafo was moderate, and at $P_{PROF}1$ very high (25,52 me%). The content of magnesium ranged from high at $P_{PROF}1$ (3,85me%) to moderate at $P_{PROF}2$ (2,45me%) and $P_{PROF}3$ (1,94me%). According to PEVERILL (1999), Mg deficiency exists in sandy soils from concentrations below 0,2 me%, and in clay soils from concentrations below 0,5 me%. According to that, none of the Kopafo soils was deficient in Mg. The levels of exchangeable potassium in the profile pits $P_{PROF}1$ and $P_{PROF}2$ were low (0,21me%) and in $P_{PROF}3$ very low (0,16me%). According to PEVERILL (1999) a deficiency exists if the level of potassium is below 0,2 - 0,5 me%, which would characterise all soils as K-deficient. All soils had a very low content of sodium (0,08 - 0,1me%).

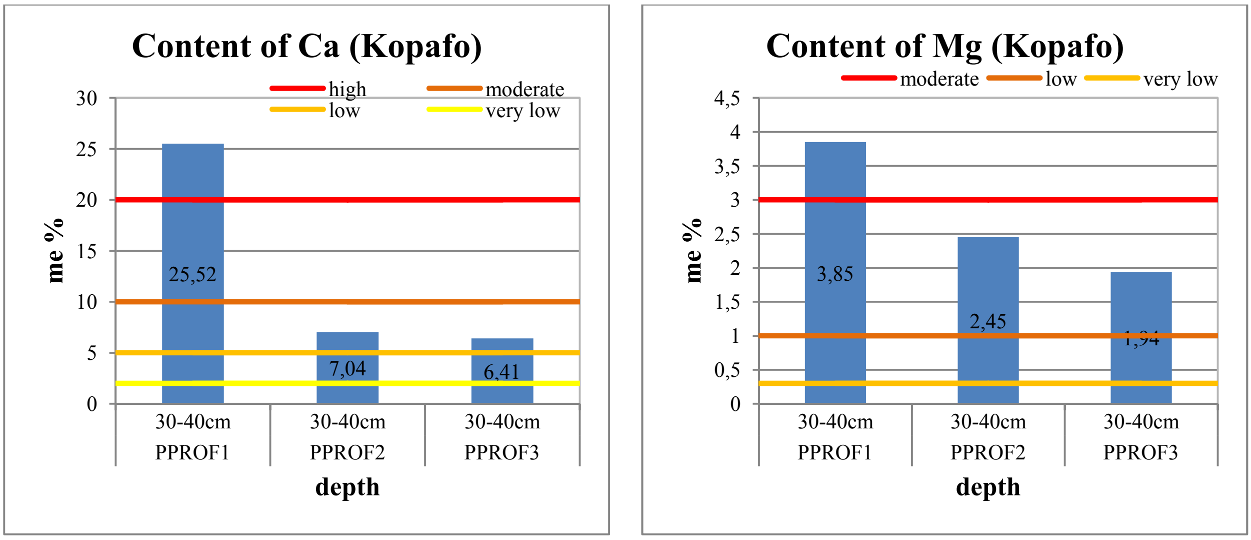


Figure 78: Content o f e xchangeable c alcium (l eft) and exchangeable ma gnesium (r ight) of the so ils from Kopafo and upper boundaries of ranges according to HAZELTON (2007)

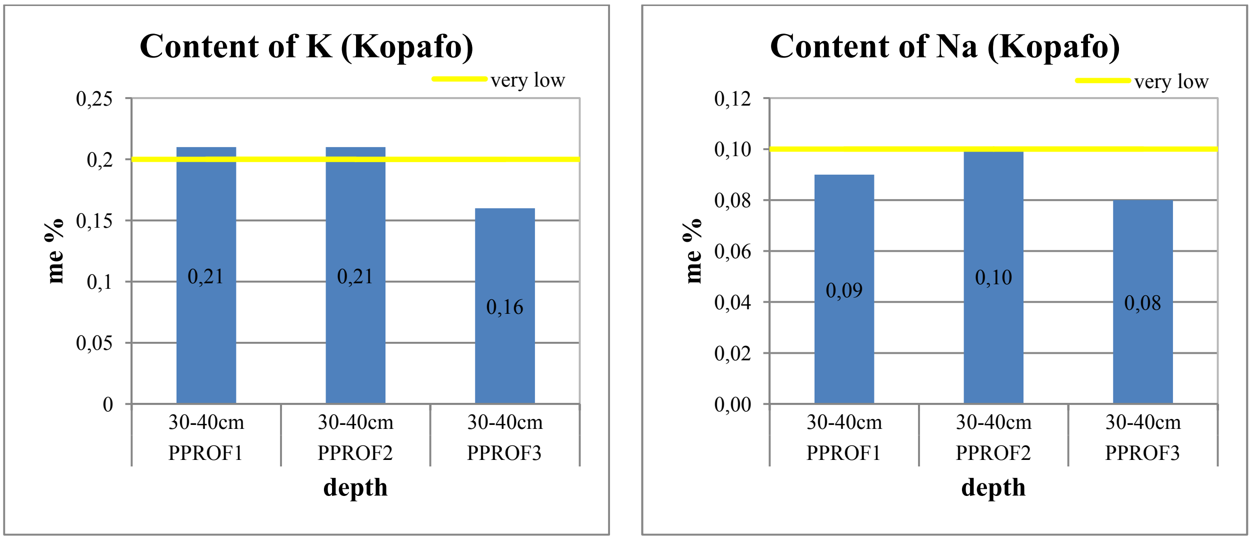


Figure 79 : C ontent o f exchangeable potassium (left) and e xchangeable s odium (righ t) of th e soils fr om Kopafo and upper boundaries of ranges according to HAZELTON (2007)

When observing Figure 80, it can be seen that the high BS of $P_{PROF}1$ was mainly due to the high content of exchangeable calcium in the soil. Compared to the Tambul sites, the gap between the content of exchangeable bases and the CEC was not so large. This is in conjunction with the lower acidity and the higher amount of exchangeable bases of the non-volcanic soils.

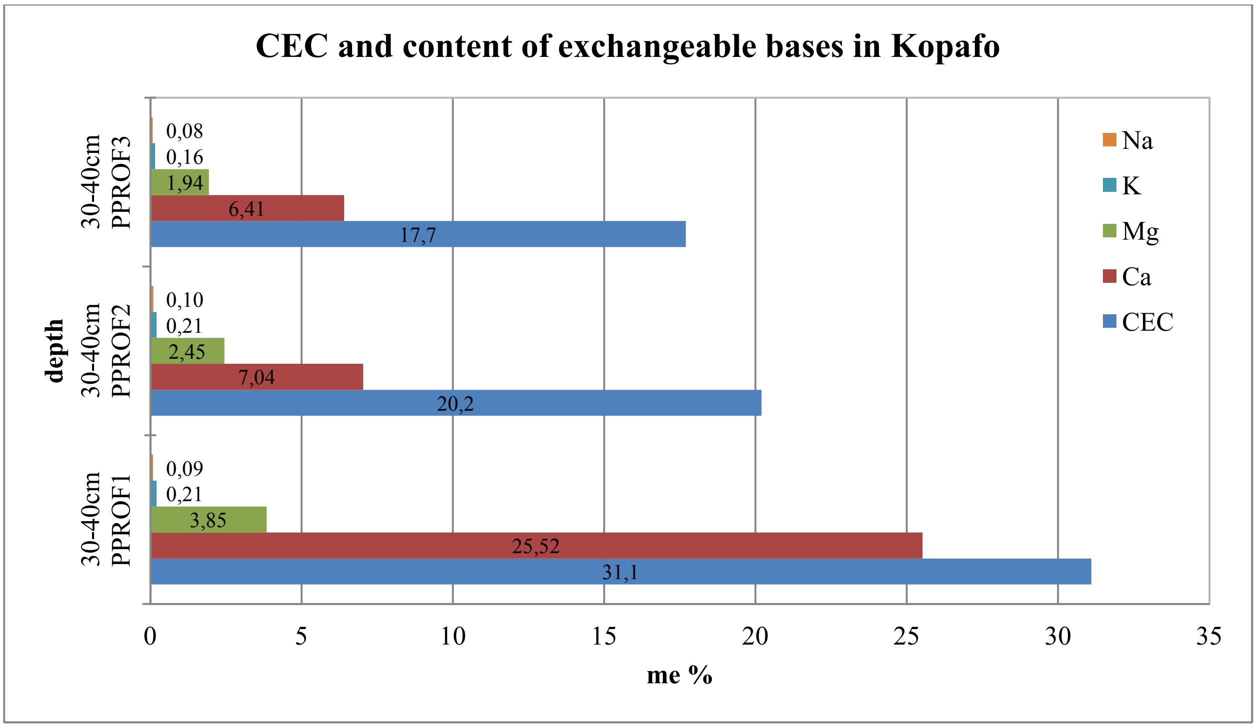


Figure 80: CEC and content of exchangeable bases in Kopafo

Figure 81 and Figure 82 show the saturation percentages of the exchangeable bases. When looking at the Ca saturation percentage, it can be stated that none of the soils from the study sites had saturation levels within the desirable range according to HAZELTON (2007). While the value of $P_{PROF}1$ in Kopafo was slightly too high, the Ca saturation levels of the other profile pits fell much below the lower threshold level of the range. Other sources quote the adequate Ca saturation percentage of soils around 25-30% . This would mean that the soils of $P_{PROF}2$ and $P_{PROF}3$ had Ca saturations of desirable values. From the Mg saturation percentages it can also be concluded that there is no deficiency of Mg. The K saturation percentages of $P_{PROF}1$ and $P_{PROF}3$ were beneath, and of $P_{PROF}1$ slightly above the lower threshold level of the range. The Na saturation levels of the soils show that the soils were not under sodic conditions.

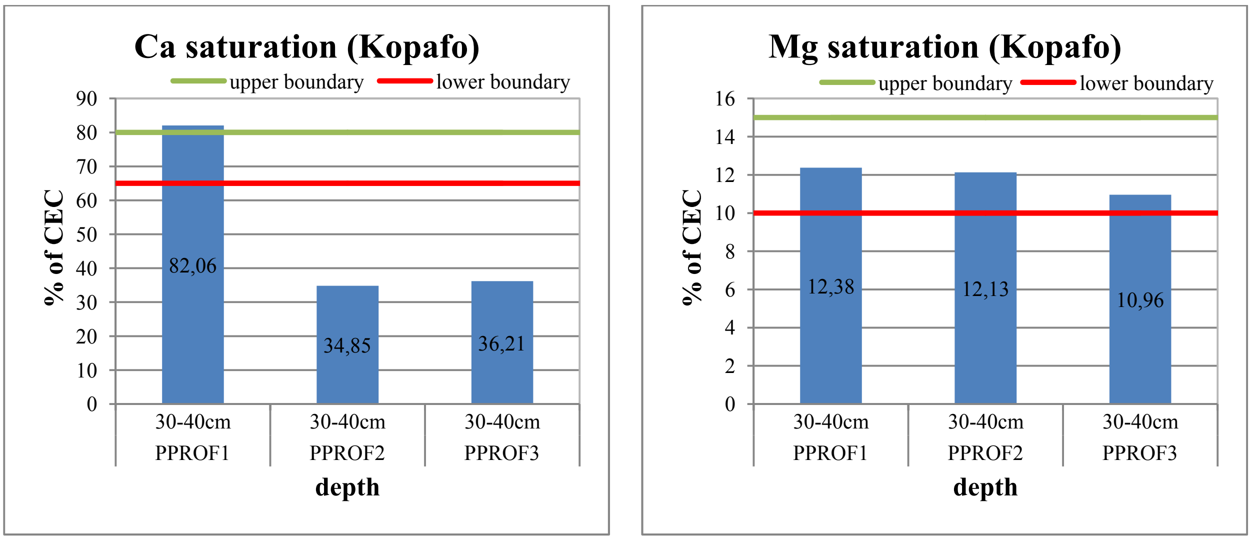


Figure 81: Calcium saturation (left) and magnesium saturation (right) of the soils from Kopafo and desirable range for many plants according to HAZELTON (2007)

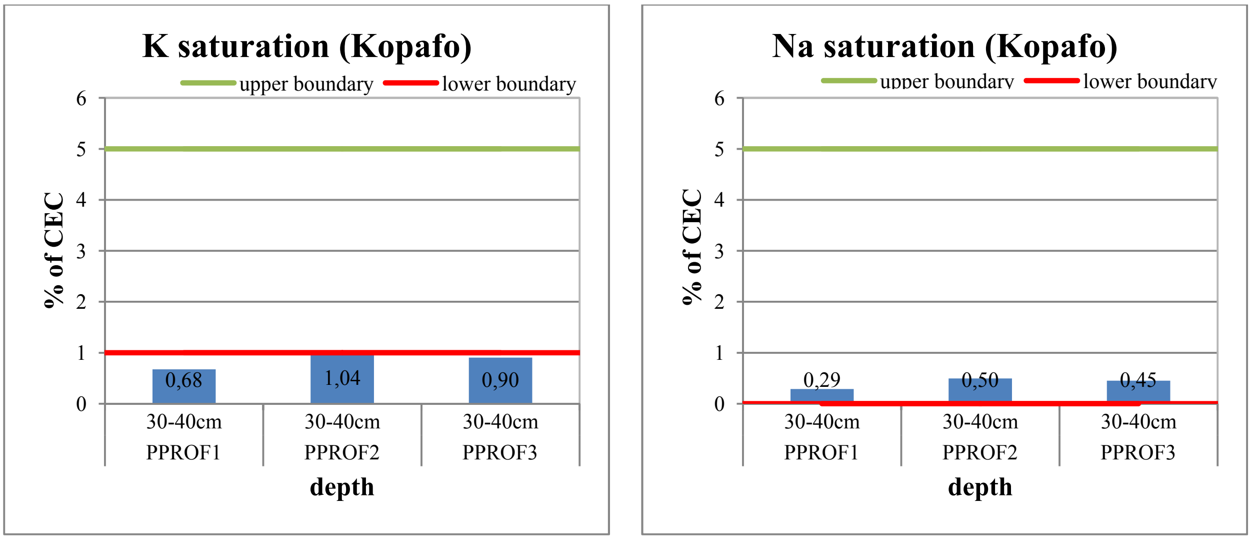


Figure 82: Potassium saturation (left) and sodium saturation (right) of the soils from Kopafo and desirable range for many plants according to HAZELTON (2007)

Nutrients

The levels of total nitrogen were low in $P_{PROF}1$ and medium in $P_{PROF}2$ and $P_{PROF}3$ (Figure 83, left). The content of organic carbon was medium at $P_{PROF}1$ (1,8%) and high at $P_{PROF}2$ (2,68%) and $P_{PROF}3$ (2,56%). The PNGRIS data suggests high values (>0,5%) of total nitrogen for $P_{PROF}2$ and $P_{PROF}3$ and a low (<0,2%) content for $P_{PROF}1$.

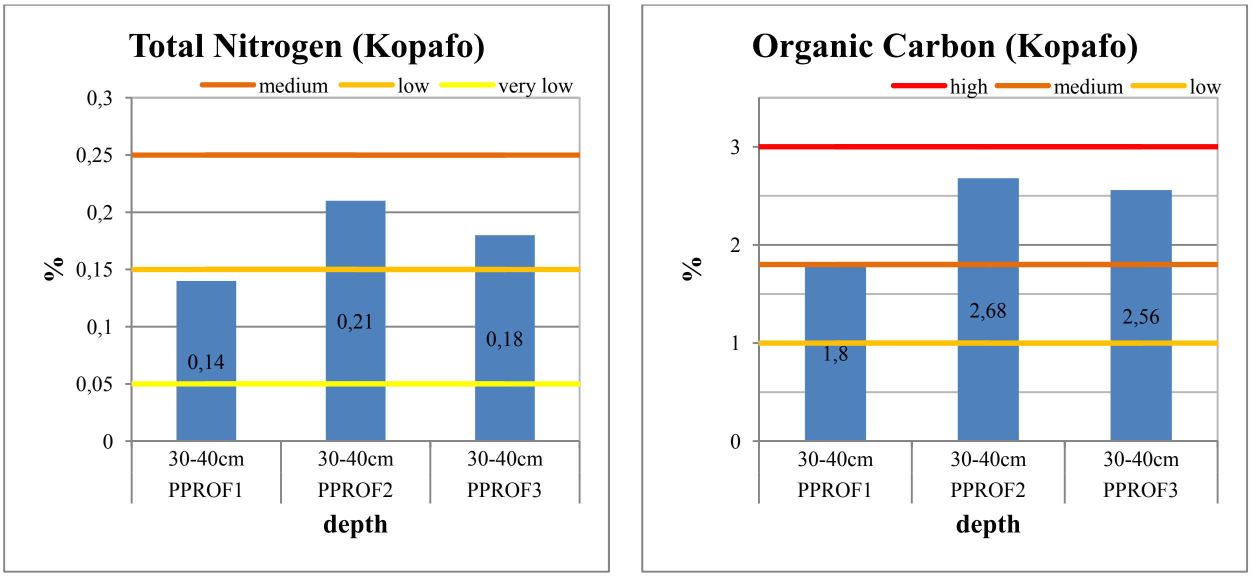


Figure 83: Total nitrogen (left) and organic carbon (right) of the soils from Kopafo and upper boundaries of ranges according to HAZELTON (2007)

The C/N ratios of all profiles were low (Figure 84). The soils had ratios of 12 to 14, which is normal for agricultural soils.

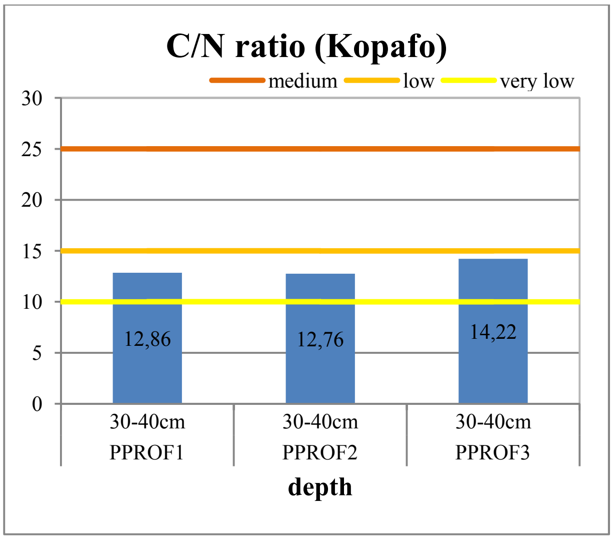


Figure 84: C/N-ratio of the soils from Kopafo and upper boundaries of ranges according to HAZELTON (2007)

4.3.2.2.3 Bulk density

The bulk densities at the Kopafo sites were around 1,2 to 1,3 g/cm³ (Figure 85). In clay soils, bulk densities of this dimension can indicate too compact soil conditions (Hazelton P. et al, 2007, p.20).

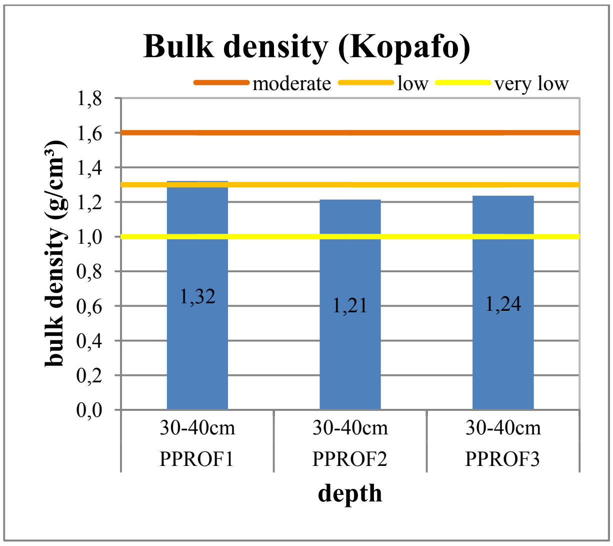


Figure 85: Bulk density of the soils from Kopafo and upper boundaries of ranges according to HAZELTON (2007)

4.3.2.2.4 Hydraulic conductivity

The converted texture classes for the calculation of the hydraulic conductivity did not differ from the texture classes of the Australian system of classification and hence the soils are still classified as clays (Table 33). Only the fractions of sand and silt changed in favour of sand at $P_{PROF}1$ and $P_{PROF}2$ and in favour of silt at $P_{PROF}3$ (Figure 86).

Table 33: Texture of the soils from Kopafo according to the FAO/USDA system

		Texture (FAO/USDA)	Texture (Australia)
Kopafo	$P_{PROF}1$	Clay	Clay
	$P_{PROF}2$	Clay	Clay
	$P_{PROF}3$	Clay	Clay

The calculated saturated hydraulic conductivity in Kopafo was extremely low at $P_{PROF}1$ (0,38mm/h) and $P_{PROF}2$ (0,5mm/h), and low at $P_{PROF}3$ (0,56mm/h) (Figure 87).

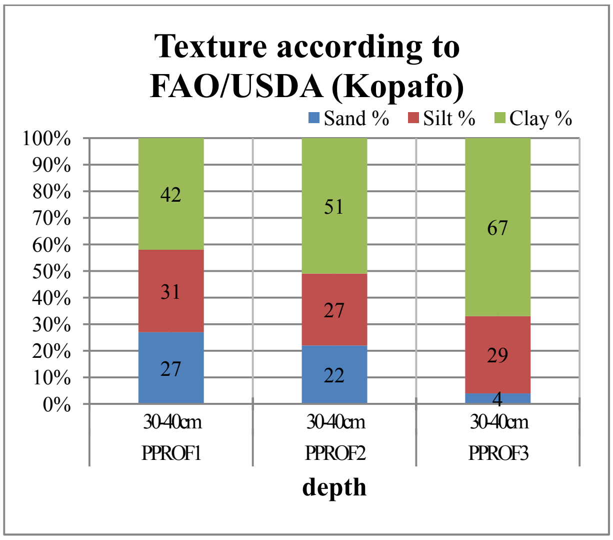


Figure 86: Texture of the soils from Kopafo according to the FAO/USDA system

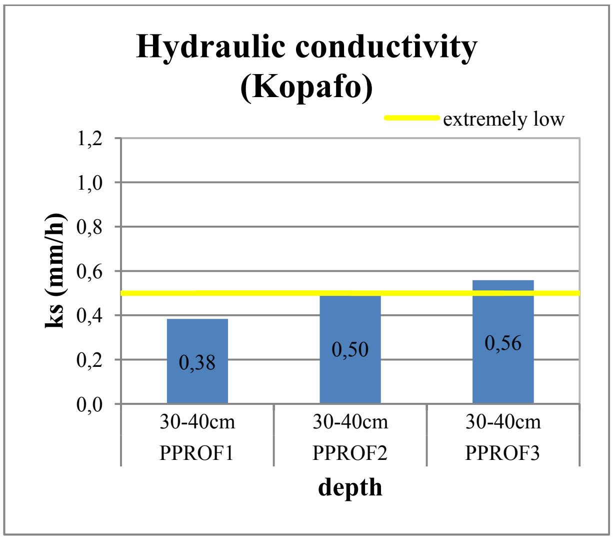


Figure 87: Calculated hydraulic conductivity of the soils from Kopafo and upper boundaries of ranges according to HAZELTON (2007)

5 CONCLUSIONS AND RECOMMENDATIONS

Papua New Guinea is a country suffering from food insecurity. This is accelerated as one factor by the uncertainty of the climate and extreme climatic events. An increase of ENSO events would bring more or longer droughts or periods of heavy rainfall, which affects especially smallholder farmers in remote areas. The most important food crop in PNG is the sweet potato, which is very vulnerable to water logging, but is able to tolerate dry periods to a certain extend. It can be grown up to altitudes of approximately 2700masl on strongly acid to neutral soils and has moderate requirements of Nitrogen and high requirements of potassium.

To improve food security, different farming systems suitable for small scale agriculture have to be developed and adapted. Therefore the knowledge and the application of traditional technology combined with scientific research into the biological processes of agricultural production is required. For this purpose the soil and water conditions of the study sites have been investigated.

Tambul (Kiripia and Alkena)

Tambul is an area of high rainfall. Although the average maximum temperatures stay between 20°C-25°C over the whole year, the monthly evaporation never exceeds the rainfall (Haantjens, 1970). Accordingly the soils suffer from excess soil moisture and the agricultural techniques of the local people reflect the climatic conditions of the area. Deep drains can often be found around the fields to discharge the excess water of the soils. The fields are nearly exclusively cultivated with sweet potato and consist of large mounds, which also fulfil the purpose of discharging the water from the soil.

The soils in Tambul are of volcanic origin, which according to BAILEY (2009) means that they are more acidic than non-volcanic soils, have lower contents of exchangeable bases and higher contents of organic material. Consistently, the results from the laboratory analysis of the Tambul soil samples show that soils are very strong acid (pH values of 4,6 - 4,8) and had low contents of exchangeable bases. Another reason for the low content of exchangeable bases in the soils could be leaching, which especially is a problem in sandy soils as they are found at $P_{PROF}1$ (Alk) and $P_{PROF}2$ (Kir). The soils of those profile pits had lower contents of exchangeable bases. Further it was noticeable, that they had lower base saturations, lower bulk densities and higher hydraulic conductivities than the other soils, and remarkable high contents of organic matter. Both profile pits were situated in swampy areas, where there is a high input of organic material in form of marsh plants combined with a slow rate of decomposition. Furthermore in the western highlands large sweet potato mounds are always constructed in combination with composting, hence the nutrients that are contained in the sweet potato vines and in the fallow vegetation are brought back to the soil.

The low content of exchangeable bases could also be attributed to the intense use of the food gardens. This is due to the shortening of fallow periods, which in turn is a consequence of the high population growth and the resulting increased demand for agricultural land.

Another problem of this area is that the temperature can drop to zero during nights of the dry season, which results in the destruction of crops.

Kopafo

In contrast to the situation in Tambul, the main problems in Kopafo arise from long dry periods. During several months the monthly evaporation exceeds the rainfall and consequently the soil suffers from deficit soil moisture. The food gardens are therefore cultivated by construction of small mounds only during the rainy season and mostly beds during the dry season. Drains can only be found along the valley bottom, whereas the fields of the uphill areas are always dominated by dry conditions. Composting is in general not practiced in Kopafo, which means that the nutrients are removed from the food gardens. The fallowing periods in Kopafo are longer than in Tambul, but are still shortening over time due to the increasing need for more arable land. The agriculture in Kopafo is not only governed by gardens with a high variety of different food crops, but also includes coffee fields for cash cropping. People therefore often possess cash reserves on which they can count during prolonged droughts.

Since the landform consists of hills with weak or no structural control, erosion is a problem in this area. Erosion mainly exists on the slopes of the hillsides, where big erosion gullies are visible. The soils in Kopafo are mostly of non-volcanic origin, whereas the dominating great soil group is the Humitropept which is a young and moderately weathered soil. The results of the laboratory analysis show that the soils are all clay soils with clay contents of about 50% to 70%. Therefore the hydraulic conductivities are extremely low and the soils are not likely to be leached. The bulk densities are notable higher in Kopafo than in Tambul, but the values in Kopafo (1,2 to 1,3g/cm^3) can nevertheless indicate too compact soil conditions in combination with clay soils (Hazelton P. et al, 2007). The results further show high contents of exchangeable bases, a high pH, and low contents of organic matter. This is attributed to the non-volcanic origin of the soils which are normally less acidic (Bailey, 2009), but also due to the absence of leaching. Of the basic exchangeable bases only potassium showed a significant deficit.

Recommendations

It can be stated that a common characteristic throughout the analysed soils in Kopafo and Tambul is a deficiency of potassium. According to BAILEY (2009) there is a potassium deficiency throughout the highlands of PNG. Soils of volcanic origin which are prevalent in Tambul already feature general low contents of potassium, and the common practice of removing old sweet potato vines from the gardens in the area of Kopafo also reduces the K content in soil. In order to improve the potassium budget of the soils, the sweet potato vines, which contain about one third of the total K absorbed by the plant, could be returned to the garden as compost or ash. In Tambul this is already done by constructing large mounds that contain compost in their centre, but in Kopafo a similar practice could improve the situation. In addition fast growing, potassium accumulating plants that are deep rooted could be used as fallow vegetation. As a last option the utilization of K fertilizer could be enhanced.

During prolonged dry seasons in Kopafo a deficit of soil moisture is prevalent. Especially farmers of uphill areas are affected by very dry soil conditions and sometimes cannot cultivate their fields at all during these times. Since the water sources in Kopafo are normally reliable and only fall dry during especially long dry seasons, supplementary irrigation could be an option. Additionally the construction of large mounds in combination with composting as it is practiced in Tambul conserves soil moisture in which the crops are be planted. However the effectiveness of irrigation is not certain, because the soils are compact clay soils with very low hydraulic conductivities.

In Tambul frosts which damage the crops can occur during clear nights in the dry season. The plantation of trees and shrubs around the fields can help to establish a microclimate around the crops which keeps the temperatures above zero.

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7 LIST OF FIGURES

8 LIST OF TABLES

9 ANNEX

9.1 ANNEX 1 - DETAILED SOIL DESCRIPTION KIRIPIA

Sample Code	Depth [cm]	Colour	Texture	Segregations	Presence of roots	Comments
$P_{KIR}1$	0-60	dark brown		small red stones	few	
	60-75	transition zone			no	
	80-100	yellow - brown	heavy clay	ochre and small black mottles	no	
$P_{KIR}2$	0-35	dark brown		none	no	
	40-75	yellow		black mottles	no	
	75-95	yellow, white		small black and red mottles	no	
	95-105	yellow, white		stones	no	
$P_{KIR}3$	0-100	dark brown		none	many	water table at 50 cm
$P_{KIR}4$	0-45	light brown		red mottles	few	deep drain around the field (depth=1m), stones in the nearby creek have a red coating
	50-70	reddish brown		grey mottles	no	
	70-80	dark grey, greenish stains	sandy clay loam	red mottles, small stones	no	
$P_{KIR}5$	0-20	dark brown		none	no	a big drain surrounds the field (depth= 1,30m), water table in the drain at 80cm
	20-40	light brown		none	no	
	40-50	dark brown		none	no	
	50-90	ochre, yellow		small black and red mottles	no	
	90-100	ochre, yellow	heavy clay	black layers (thickness= 2cm)	no	

Sample Code	Depth [cm]	Colour	Texture	Segregations	Presence of roots	Comments
$P_{KIR}6$	0-10	dark brown		none	few	a big drain surrounds the field (depth= 1,30m), water table in the drain at 80cm
	10-20	light brown		none	no	
	20-50	dark brown		none	no	
	50-70	transition zone		none	no	
	70-100	red heavy	clay	none	no	
$P_{KIR}7$	0-40	dark brown		grey spots	few	stagnant moisture?
	40-75	light brown greyish		reddish and ochre mottles	no	
	75-100	dark grey, black	heavy clay	few reddish mottles	no	
$P_{KIR}8$	0-10	dark brown		none	no	
	20-30	light brown		none	no	
	30-85	dark brown		few red mottles	no	
	85-100	yellow ochre	heavy clay	red mottles, grains of sand	no	
$P_{KIR}9$	0-100	dark brown		none	no	from depth of 45cm the earth is more compacted

$P_{KIR}1$ P

$_{KIR}2$

$P_{KIR}3$

$P_{KIR}4$

$P_{KIR}5$:

$P_{KIR}6$:

$P_{KIR}7$:

$P_{KIR}8$:

$P_{KIR}9$:

9.2 Annex 2 - Detailed soil description Alkena

Sample Code	Depth [cm]	Colour	Texture	Segregations	Presence of roots	Comments
$P_{ALK}1$	0-60	dark brown		none	many	small drains (depth= 30-40cm) in the field and deeper drains (depth= 1,20m) around the field
	60-75	light brown	heavy clay	red mottles	few	
	80-100	yellow - brown	heavy clay	ochre mottles	few	
$P_{ALK}2$	0-45	dark brown		none	no	swampy area close to river Kagul;
	45-100	light brown		organic material (grass, reeds)	no	
$P_{ALK}3$	0-45	brown	sandy loam	none	no	alluvial soil; according to inhabitants very fertile soil
	45-70	brown	sandy	black, brown, reddish and silver mottles		
	70-100	brown clay		red mottles	no	
$P_{ALK}4$	0-35	dark brown		none	many	the earth on the mounds is extremely dry and has small fractures
	35-65	light brown		none	many	
	65-80	dark brown	heavy clay	organic material	few	
	80-100	light brown, yellowish grey	heavy clay	organic material	no	
$P_{ALK}5$	0-30	dark brown		none	few	
	30-55	brown		none	few	
	55-100	ochre		organic material, red and white mottles	no	
$P_{ALK}6$	0-100	dark brown		organic material	no	deep drains (depth=1,20m), in this area the soil has widespread fractures on the surface

Sample Code	Depth [cm]	Colour	Texture	Segregations	Presence of roots	Comments
$P_{ALK}7$	0-30	dark brown		none	few	field lies on a plateau; small trees grow between the mounds
	30-40	transition zone		none	no	
	40-65	ochre, reddish		red mottles	no	
	65-80	red	clay	black grains of sand	no	
	80-100	reddish brown	sandy loam	red mottles	no	
$P_{ALK}8$	0-45	dark brown		light brown layers	few	
	45-80	white, light greyish	heavy clay	ochre, white mottles	no	
	80-90	red		none	no	
	90-95	white, light greyish		ochre, white mottles	no	
	95-100	red		none	no	
$P_{ALK}9$	0-40	dark brown		none	no	according to inhabitants fertile soil because rainwater brings the feritle soil from other places
	40-90	dark brown		light brown layers	no	
	90-100	dark brown	heavy clay	organic material (reddish)	no	
$P_{ALK}10$	0-40	dark brown		none	few	no drains in the field, escarpment about 10m away from field
	40-60	reddish brown		ochre and red mottles	no	
	60-100	ochre, red, yellowish	heavy clay	white, black and silver grains of sand	no	
$P_{ALK}11$	0-40	brown greyish		small reddish mottles	no	swampy area
	40-60	grey		red and ochre mottles	no	
	60-90	grey	clay loam	red and ochre mottles	no	
	90-100	grey	sand	black, white and red grains of sand	no	

$P_{ALK}1$ P

$_{ALK}2$

$P_{ALK}3$

$P_{ALK}4$

$P_{ALK}5$

$P_{ALK}6$

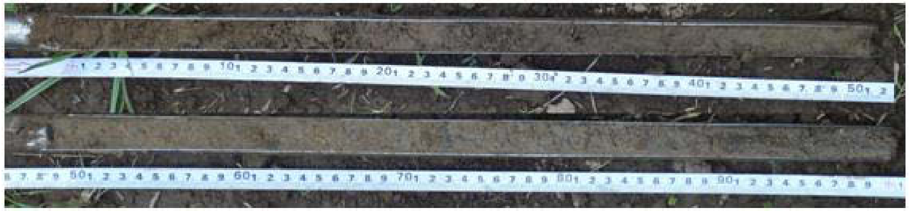
$P_{ALK}7$

$P_{ALK}8$

P_{ALK}9 P

$_{ALK}$10

P_{ALK}11



9.3 Annex 3 - Detailed soil description Kopafo

Sample Code	Depth [cm]	Colour	Texture	Segregations	Presence of roots	Comments
$P_{KOP}1$	0-40	dark brown	light clay	none	few	
	40-100	red light	clay	none	no	
$P_{KOP}2$	0-20	dark brown		none	few	grassland since the 70ies (gras is burned down every one in a while and land used for animals)
	20-100	red		black mottles (charcoal)	no	
$P_{KOP}3$	0-20	dark brown		red mottles	few	field has drains, sampling spot is on the mound
	20-100	red	light clay	black mottles	no	
$P_{KOP}4$	0-50	dark brown	heavy clay	none	few	grey spots indicate stagnant moisture; the drains are always filled with water
	50-100	yellow with grey spots	heavy clay	stones at 90cm depth	no	
$P_{KOP}5$	0-25	dark brown		none	few	deep drains; borderline of horizons is not clear distinguishable
	25-50	dark grey		yellow and black mottles	no	
	50-100	light grey, yellowish	light clay	sandy mottles	no	
$P_{KOP}6$	0-60	dark brown		few red mottles	few	Mojemoje river right beside the field
	60-100	dark brown, grey		big red mottles	no	
$P_{KOP}7$	0-30	dark brown		none	few	firm soil; sampling spot is underneath a bamboo tree, ground is covered with bamboo leaves
	30-100	reddish brown		red and black mottles	no	
$P_{KOP}8$	0-50	dark brown		none	few	drains (depth=50cm); grey mottles indicate stagnant moisture (groundwater influence)
	50-75	grey	heavy clay	red mottles	no	
	75-100	red	heavy clay	grey mottles	no	

Sample Code	Depth [cm]	Colour	Texture	Segregations	Presence of roots	Comments
$P_{KOP}9$	0-50	dark brown		none	many	river at a distance of 5m, land has never been cultivated
	50-100	dark brown		small red mottles	no	
$P_{KOP}10$	0-45	dark brown		small red mottles	few	drains
	45-100	dark brown	sandy clay loam	ochre and orange mottles	no	
$P_{KOP}11$	0-35	dark brown		none	no	rice field used to be planted once a year, now the field is covered with grass
	35-50	dark brown		few ochre mottles	no	
	50-100	grey	heavy clay	ochre and black mottles	no	
$P_{KOP}12$	0-100	brown	sandy clay loam	stones (length=2cm)	no	river at a distance of 3m
$P_{KOP}13$	0-15	brown		few red mottles	few	grassland with big rocks (>1m) in the surrounding
	15-100	red orange yellowish brown	clay loam	black mottles	no	
$P_{KOP}14$	0-50	dark brown		none	few	meadow next to fishponds, soil is very dense in the deeper layers
	50-60	brown		none	no	
	60-100	light brown	heavy clay	ochre mottles	no	
$P_{KOP}15$	0-50	dark brown		none	few	
	50-70	transition zone			no	
	70-100	grey whitish	heavy clay	black and ochre mottles	no	
$P_{KOP}16$	0-25	light brown		red mottles	no	not long ago a house was burned down on this spot
	25-100	light reddish brown	heavy clay	hard, red mottles	no	
$P_{KOP}17$	0-25	dark brown		very big red mottles	no	spot on a hillside
	25-100	orange yellow	clay loam	red mottles	no	

Sample Code	Depth [cm]	Colour	Texture	Segregations	Presence of roots	Comments
$P_{KOP}18$	0-40	brown		none	few	sampling spot in garden right beside the house, soil is very dense in the deeper layers
	40-45	orange brown		red mottles	no	
	45-100	white orange yellow	medium clay	big red and orange mottles	no	
$P_{KOP}19$	0-45	dark brown		none	many	earthworms
	45-100	grey yellowish	heavy clay	ochre mottles	no	
$P_{KOP}20$	0-100	reddish brown	heavy clay	red mottles; greyish spots	no	grassland on hillside, gully erosion visible

$P_{KOP}1$ P

$_{KOP}2$

$P_{KOP}3$

$P_{KOP}4$

$P_{KOP}5$

$P_{KOP}6$

P$_{KOP}$7 P

$_{KOP}$8

P$_{KOP}$9

P$_{KOP}$10

P$_{ALK}$11

P$_{KOP}$12

P$_{KOP}$13

P$_{KOP}$14

$P_{KOP}15$

$P_{KOP}16$

$P_{KOP}17$

$P_{KOP}18$

$P_{KOP}19$

$P_{KOP}20$