Landscapes and soils of South Eastern Tanzania: their suitability for cashew*

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Introduction

The regions of Mtwara and Lindi and the district of Tunduru in Ruvuma region in South Eastern Tanzania cover about 103,000 km^2. This area has a population of more than 2 million people, comprising some of Tanzania's most densely populated parts such as Newala district (100 persons km^{-2}) as well as some of its most sparsely populated parts such as Liwale district (<3 persons km^{-2})†. About 70% of the national cashew nut production is produced in the South East (Topper *et al.*, 1998). The districts of Newala and Tandahimba together take the largest share of the total production, followed by the districts of Masasi and Tunduru (Fig. 1).

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† own calculations based on the 1988 population census (Tanzania, 1991)

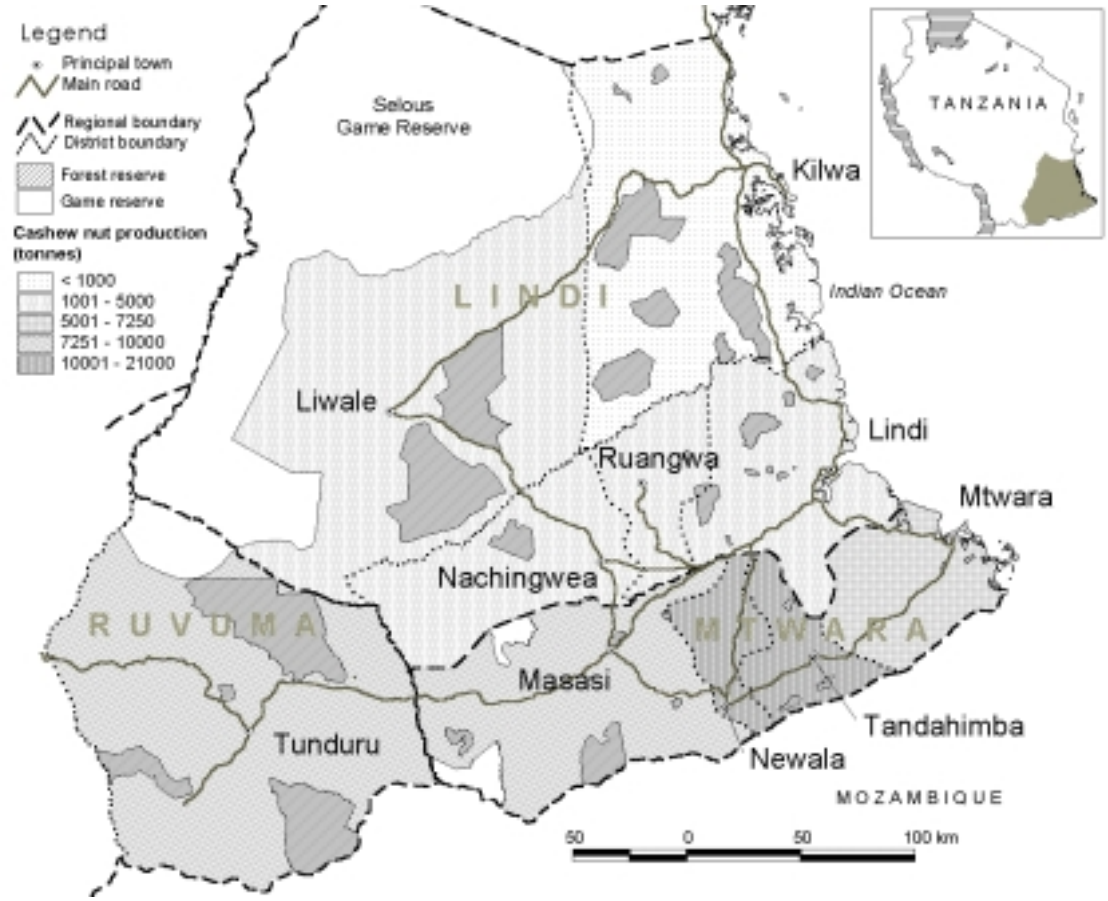


Figure 1 Average annual cashew nut production per district (1995-1997) in South Eastern Tanzania. Production figures for Newala and Tandahimba districts as well as Ruangwa and Lindi districts are taken together. (Source: Topper et al. 1998)

In this chapter, the ecological requirements for cashew are first reviewed. Then, an overview is given of the characteristics of the climate and soil properties of South Eastern Tanzania in relation to the landscape. This leads to an assessment of the land suitability for cashew nut production.

Ecological requirements of cashew

Climatic requirements

For proper vegetative development and regular fruit setting cashew ought to enjoy an average annual rainfall of 800 to 1600 mm, spread over 5-7 months (Ohler, 1979). Higher rainfall leads to excessive vegetative development, accompanied by a scarcity

of flowers and fruits. Insufficient rain leads to irregular flowering and fruit setting. Cashew has a preference for high but above all constant temperatures, such as of the coastal belt of the tropical regions. The most favourable mean annual temperature for cashew lies between the 24° and 28°C.

Soil requirements

Cashew prefers loose, deep, aerated soils that are above all well drained (Ohler, 1979). Heavy clayey, compact soils, or those with hard surface setting or with concretions at shallow depth, even when naturally fertile, retard the plant's growth preventing the roots from penetrating downwards and more generally sideways. Cashew seems to like textural porosity and therefore could be labelled as sand loving plant. Cashew requires soils with little calcium. Too high levels of free lime will result in chlorosis. Optimum pH is between 4.5 and 6.5, and minimum pH is 3.8 (FAO, 1994).

In the vicinity of 30 soil profiles spread over the Makonde plateau and the inland plains, Ngatunga *et al*. (2001a) used a factor analysis to study the dependency between the performance of cashew trees and soil properties. Cashew tree parameters measured were tree dimensions, potential inflorescence, annual growth of branches, number of nuts, yield and tree age. Soil data concerned chemical parameters, depth and texture. As shown in Fig. 2, larger cashew trees giving high yields were found on deep, highly weathered soils, typically on the Makonde plateau. Cashew seems to perform better on this kind of soils, regardless of low chemical fertility. Although on deep and highly weathered soils of the inland plains cashew trees are bigger, and yield more than on shallow, poorly weathered soils, they are not as big as on the Makonde plateau. This is an effect of the drier climate prevailing in the inland plains.

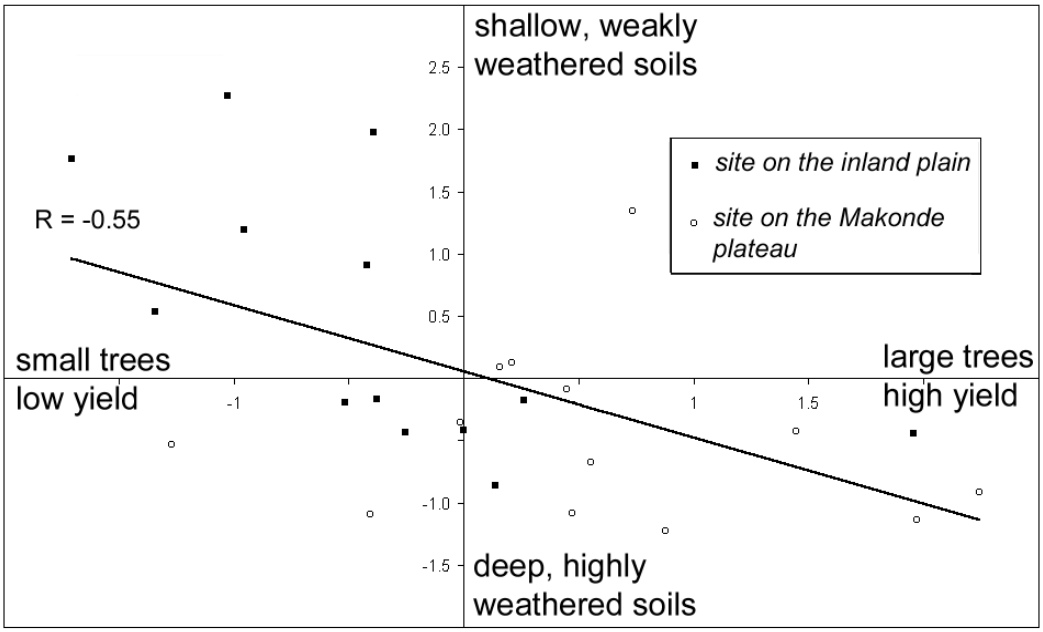


Figure 2 Relationship between cashew tree size and yield, and soil depth and weathering status in South Eastern Tanzania (Source: Ngatunga et al. 2001a)

Climate

The climate of South Eastern Tanzania is influenced by the South Eastern trade wind in mid-year and the north-eastern trade wind during the turn of the year. Temperatures vary little, the mean temperature is 24.3°C in July and 27.5°C in December. The mean annual temperature is 26°C in the coastal area and 24°C in the inland areas (Bennett *et al.*, 1979a).

Mean annual rainfall in South Eastern Tanzania ranges between 820 and 1245 mm (Table 1). Rainfall pattern is uni-modal, but very erratic as can be seen from the ranges of the monthly dependable rainfall (Fig. 3). A dry spell of one to two weeks often occurs at the end of January or at the beginning of February. This is reflected in a decrease in the 20% probability of exceedance on the plateaux and the coastal plain, and in the 80% probability of exceedance in the central plains.

Based on daily rainfall records average monthly rainfall as well as the 20% and 80% dependable rainfall were calculated for three stations on the coastal plains (Kilwa Kivinje, Lindi and Mtwara port), three on the plateaux (Naliendele, Newala, and Tunduru) and three of the central plains (Masasi, Nachingwea and Liwale).

Maertens (1999) calculated the average monthly reference evapotranspiration (ETo) for Naliendele, by using the *FAO Penman-Monteith* equation (Allen *et al*., 1999). The ETo of the other stations can be expected to be similar as temperature does not vary much and as all stations are at almost the same latitude. Therefore, the ETo at Naliendele, with a margin of 20%, is taken as an indicative value and is superimposed on the rainfall graphs in Fig. 3.

Table 1 ***Annual rainfall (mm/year) in South Eastern Tanzania. Rainfall values for a dry and wet year have a 10 year return period***

Landscape unit and Climatic station	Dry year	Average	Wet year	n
Coastal hills				
Kipatimu	820	1082	1342	29
Coastal plains				
Kilwa Kivinje	648	929	1271	52
Lindi	692	935	1216	48
Mtwara port	602	925	1290	33
Plateaux				
Tunduru	656	1016	1379	14
Naliendele	649	1132	1505	17
Mtwara airport	844	1137	1429	45
Newala	688	1245	1912	11
Central plains				
Nachingwea	605	823	1025	14
Liwale	503	868	1220	39
Masasi	538	873	1550	11

n, number of years of observation

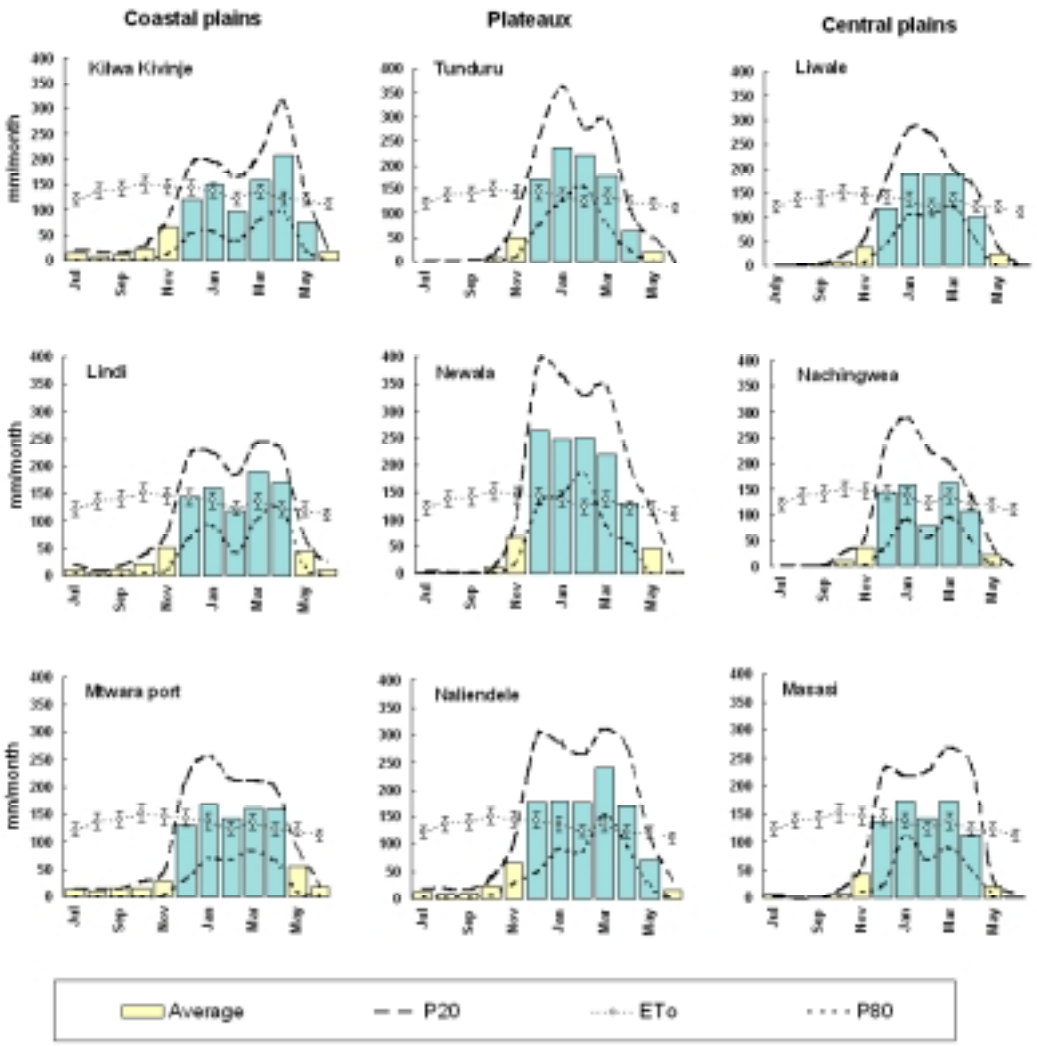


Figure 3 Monthly rainfall and reference evapotranspiration (ETo) of nine climatic stations in South Eastern Tanzania. Dark bars are of wet months (P ≥ ETo/2); P20 monthly rainfall with a probability of exceedance of 20%; P80 of 80%.

Both the annual (Table 1) and the monthly rainfall data (Fig. 3) show that rainfall is higher on the plateaux. In Naliendele rains persist longer due to its proximity to the ocean; the contrary is true for Tunduru which is most land inwards. The central plains, in the rain shadow of the Makonde and Rondo plateaux, have a distinct drier climate. On average, the rainy seasons starts in December, i.e. when rainfall is greater than half the reference evapotranspiration (ETo), and persists till April or May (Fig. 3).

Cashew is well suited to the climate of South Eastern Tanzania, though low rainfall may be a limitation in the driest parts of the central plains. Low temperatures will be unfavourable in the northern part of the Makonde plateau, the western part of the Rondo plateau and the highest parts of the Tunduru plateaux. For example, at 850 m a.s.l. mean annual temperature can be expected to be 19°C in July and 22°C in December.

Landscape units and soils

The landscape units of South Eastern Tanzania vary from undulating plains to large plateaux, as the Makonde and Rondo plateaux. The largest part of the area is below 500 m a.s.l. The highest points are rocky hills reaching 1100 m a.s.l. in Tunduru district, and 918 m close to Masasi town. More hills are found along the coast in the northern part. The area is drained to the Indian Ocean by mostly seasonal streams. The major rivers have a south-west north-east direction. The largest, the Ruvuma, forms the national border with Mozambique.

From east to west the area can be divided into a coastal area, an area of plateaux and floodplains, a central area of plains and a western area of uplands and plateaux. Bennett *et al*. (1979) did a reconnaissance survey on the physical environment of Mtwara and Lindi regions. Most of the following discussion is based on their unpublished report and maps, updated with reports of NSS (1987), Ngailo and Kips (1991), Kips and Kimaro (1993), Verwilghen (1996), Wijffels (1997), Cools (1998) and Dederen (1998). Comparable information was not available for the district of Tunduru. Therefore a land classification was made using a digital terrain model derived from the topographic maps at 1:50 000 scale (Dondeyne *et al*. 2002). Information on the soils of Tunduru district was inferred from an unpublished reconnaissance soil map of the Italo-Tanzanian Cashew Research Programme (1981) and own field observations. Dominant soils of each landscape unit (Fig. 3) are classified according to the *World Reference Base for Soil Resources* (FAO-ISRIC-ISSS, 1998) and their properties are discussed based on information of 137 soil profiles.

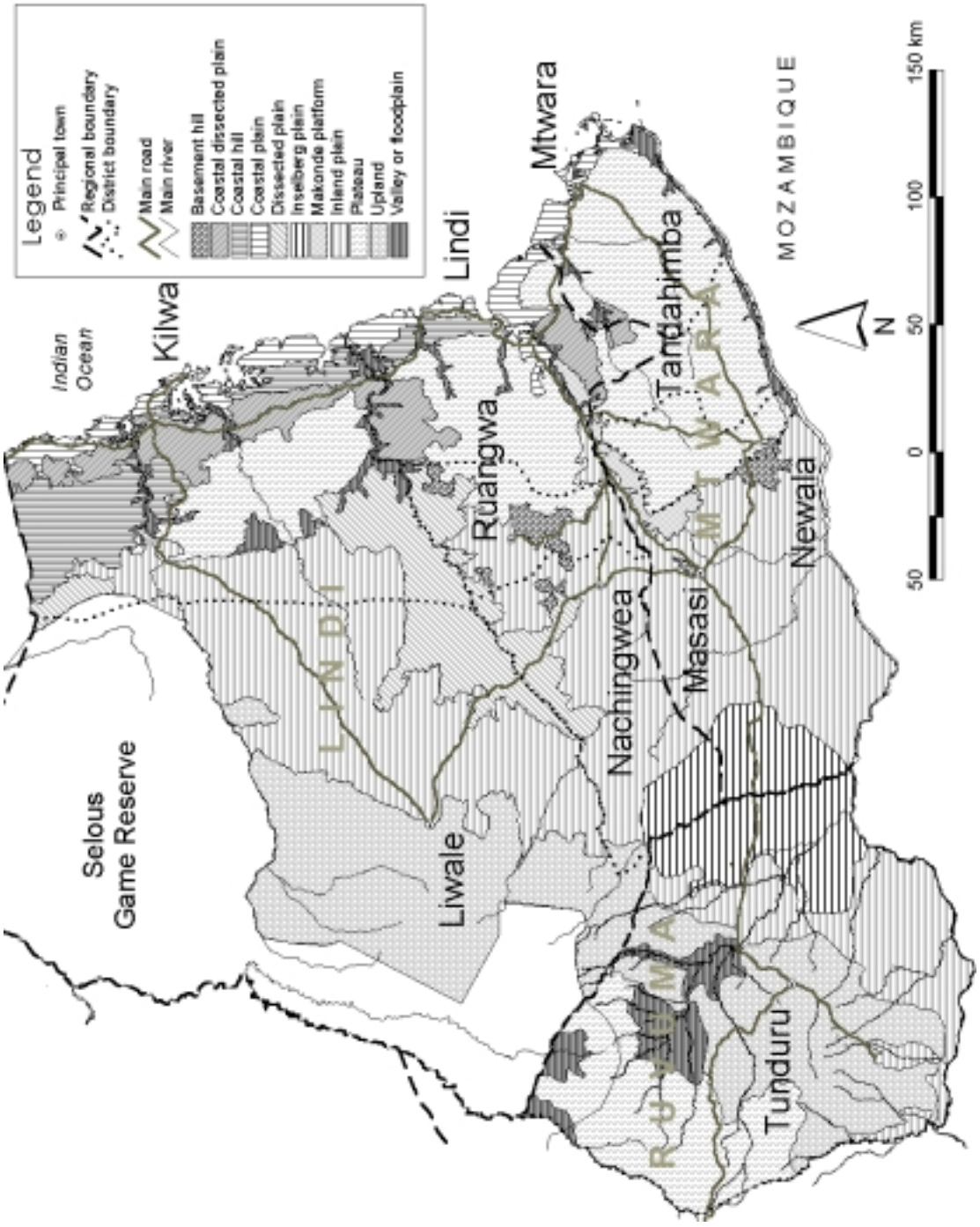
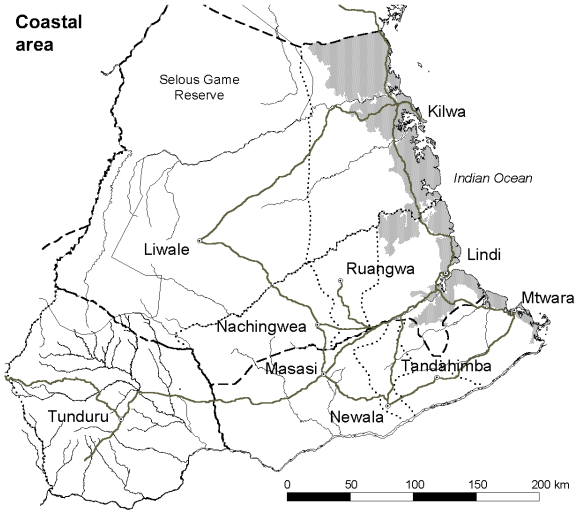


Figure 4 Landscape units of South Eastern Tanzania (adapted from Bennett et al. 1979; Dondeyne et al., 2002)



Coastal area

Coastal plains

The coastal plains form a narrow band, 20 km at its widest, which are mostly below 100 m a.s.l. They consist of marine Quaternary and Neogene deposits of coral limestone and clayey or sandy sediments. Soils derived from the coral lime are red and clayey. Most common soils are poorly weathered, shallow soils as, *Ferralic* and *Dystric Cambisols*. On flat, higher located areas highly weathered soils can be found as *Rhodic Ferralsols* and *Humic Lixisols.* Soil reaction varies from strongly acidic to mildly alkaline (pH-H_2O 4.5 - 7.5). The exchangeable base content of these soils is low to medium (2 - 20 $cmol_c\ kg^{-1}$ soil), as is their cation exchange capacity (2 - 22 $cmol_c\ kg^{-1}$ soil) and organic carbon content (0.6 - 2.6%).

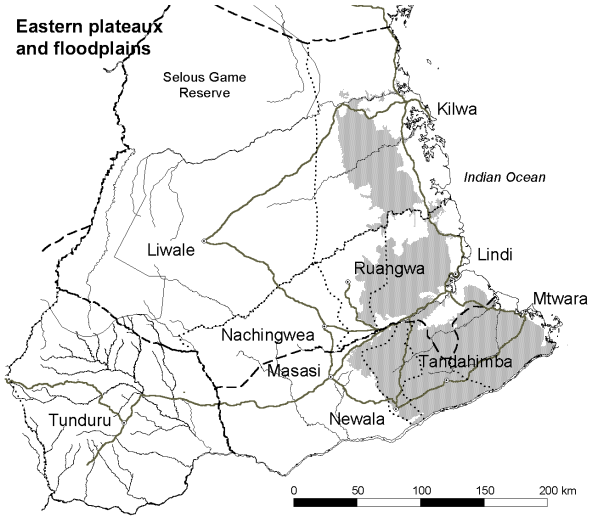
Coastal dissected plains

Land inwards, between 30 and 180 m a.s.l., undulating and incised plains are found at the fringe of plateaux and coastal hills (mostly in Kilwa district). They consist of Cretaceous marine deposits of clays, marls, mudstones and shales. The soils are dark heavy cracking clays, *Calcic Vertisols* in valley bottoms and *Vertic Cambisols* on slopes. Soil reaction is neutral to alkaline (pH-H_2O 7.0 - 9.0). These soils have very high contents of exchangeable bases (> 50 $cmol_c\ kg^{-1}$ soil) and very high cation exchangeable capacity (45 - 70 $cmol_c\ kg^{-1}$ soil). Their organic carbon content is, however, rather low (0.2 - 2.4%).

Coastal hills

In the districts of Lindi and Kilwa, a chain of hills run parallel to the coast. They consist of Paleogene and marine Neogene deposits, mostly limestone and marls. Dark cracking clay soils are also derived from these materials. These are *Calcic Vertisols* to

which *Calcaric* and *Vertic Cambisols* are associated with chemical properties similar to the soils of the coastal dissected plains.



Eastern plateaux and floodplains

Makonde, Rondo and Kilwa plateaux

Vast sandy plateaux separate the coastal area from the inland plains. These are the Makonde plateau in the districts of Mtwara, Tandahimba and Newala, the Rondo plateau in the districts of Lindi and Ruangwa, and the Kilwa plateaux in Kilwa district. They are flat topped, but local deeply dissected and have steep scarps, often 300 to 400 m high. At the northern edge of the Makonde plateau, the escarpment raises 700 m above the alluvial floodplain of the Lukuledi. Reaching 870 m a.s.l., the Makonde and Rondo plateaux are the highest. The Mueda plateau is a similar plateau south of the Ruvuma river in Mozambique. These plateaux have impeded the drainage of the major rivers, giving lead to large alluvial floodplains.

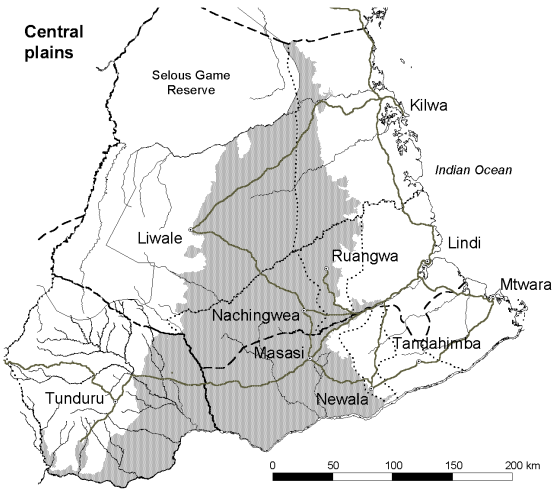
The Makonde plateau is the most populated and its soils have been studied more extensively. It is capped by the Makonde Beds, for the greatest part most probably of Lower Cretaceous origin. These are silty clays, silts, silty sands and soft sandstone, often kaolinitic, and covering a range of colours from brick red through pink to nearly white (Kent *et al*., 1971). The soils of the Makonde plateau, and most likely of the other plateaux, are deep, highly weathered, well drained and with a sandy topsoil and sandy loam or sandy clay loam in the subsurface horizons. The dominant soils of the Makonde plateau are *Veti-Acric Ferralsols* (*Xanthic*). They are acidic (pH-H_2O 4.5 - 6.5) and have very low exchangeable bases contents (0.5 - 1.5 $cmol_c$ kg^{-1} soil), very low cation exchange capacity (2 - 6 $cmol_c$ kg^{-1} soil), as well as very low levels of organic carbon (0.5 - 1%).

Makonde platform

At the northern edge of the Makonde plateau, in the districts of Masasi, Newala and Tandahimba, the escarpment is formed into a step, known as the Makonde platform. Its base is at 150 m a.s.l., while the platform is at around 300 m a.s.l. It consists of lower Cretaceous sandy deposits. Soils are coarse textured, deep and well drained and predominantly red. Soils of this landscape unit have not been studied in detail, but are expected to have similar properties as those of the Makonde plateau.

Floodplains

These are flat to gently undulating floodplains with meandering riverbeds. Altitude ranges from sea level to 200 m. The floodplains consist of Quaternary alluvial deposits or, locally, of lacrustine and marine deposits as the Kitere and Mambi plains. Being associated to the sandy plateaux, they are most extensive in the districs of Kilwa, Lindi and Mtwara. Soils are poorly drained and, depending on the origin of the deposits, are dark heavy cracking clays (*Calcic Vertisols*) or lighter textured and clearly stratified *Gleyic*, *Humic* and *Mollic Fluvisols*. In backswamps very poorly drained soils (*Mollic Gleysols*) as well as organic soils (*Fibric Histosols*) are found. Soil reaction of these soils is slightly acidic to alkaline (pH-H_2O 5.5 - 8.5). These soils have low to high exchangeable base contents (16 - 77 $cmol_c$ kg^{-1} soil) with equally low to high cation exchange capacity (20 - 60 $cmol_c$ kg^{-1} soil) and organic carbon contents (0.2 - 2.5%). The organic carbon content of *Fibric Histosols* can be as high as 23%.



Central plains

Inland plains

The inland plains are gently undulating with broad flat topped interfluves and wide shallow valleys. They dominate the landscape of the districts of Liwale, Nachingwea, Ruangwa, Masasi and extend to Tunduru. Altitude varies from 75 to 400 m a.s.l. These plains are

derived from Precambrian Basement rocks, mostly gneiss. Soil changes reflect variations in lithology, drainage and erosional history. On the interfluvial crest, least affected by erosion, deep, highly weathered, red sandy clay loam or sandy clay soils occur (*Veti-Acric Ferralsols — Rhodic*). On the slopes, less weathered or shallow, coarse textured soils occur. They may be less than a metre deep and comprises *Chromic, Rhodic* and *Arenic Luvisols, Mollic, Leptic Cambisols* and *Petric Plinthosols*. Soil reaction is mostly acidic, but can be alkaline on poorly drained sites (pH-H_2O 4.5 - 8.2). The exchangeable base content is usually very low (<5 $cmol_c$ kg^{-1} soil), as is the cation exchange capacity (0.2 - 15 $cmol_c$ kg^{-1} soil) and the organic carbon content (0.5 - 1%). Towards Liwale town, more sandy and deep soils are found. These soils are derived from Continental Neogene sandstone deposits and have similar properties to the soils of the Makonde plateau. They are mostly *Hypoluvic Arenosols*, *Profondic* and *Arenic Luvisols*.

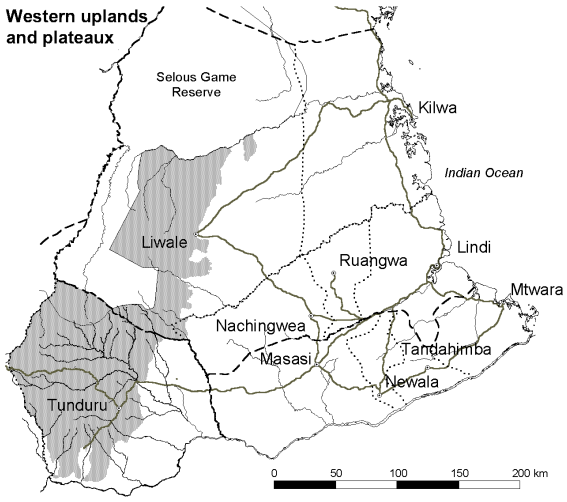
Dissected plains

Due to uplifting of the western sedimentary area, erosion processes dissected part of the plains. This is e.g. clearly noticeable on aerial photographs along the Mbwemkuru river, along the boundaries of the districts of Nachingwea, Liwale, Ruangwa and Kilwa. Soils derived from the Precambrium Basement rocks are shallow, stony and weakly weathered, mostly *Leptic Cambisols* and occasionally *Petric Plinthosols*. On hill crests, deeper and more weathered soils can be found as *Profondic Lixisol* and *Chromic Phaeozem*. Soils of this landscape unit have sandy topsoil with increasing clay content in the subsoil and their soil reaction is moderately acidic to neutral (pH-H_2O 5.6 - 7.1). Their exchangeable bases content is very low (0.2 - 15 $cmol_c$ kg^{-1} soil) as is their cation exchange capacity (5 - 15 $cmol_c$ kg^{-1} soil). Organic carbon content is equally low (0.3 - 1.5%).

Inselberg plain and basement hills

In the south-west of Masasi district and extending into Tunduru district, inselbergs dominate the landscape. The plain lies mostly between 200 and 400 m a.s.l. while the highest inselbergs reaches 800 m a.s.l. Soils of these landscape units have not been studied in detail but are presumably similar to the soils of the inland plains.

Rocky hills, the Basement Hills, are also found in the eastern part of the plains adjacent to the Rondo and Makonde plateau. They are mostly gneisses, although west of Newala quartzite seems to dominate. Soils are usually stony and shallow, but where deeper soils have formed they may be fertile.



Western uplands and plateaux

The western area, spread over the districts of Liwale and Tunduru, is a complex landscape of uplands and plateaux. It consists of sandstone of Karroo age, overlying basement rocks which are exposed on the sides and in incised valleys. Just as with the eastern plateaux poorly drained alluvial floodplains are associated to these plateaux.

Uplands

Bennett *et al*. (1979) described the Liwale uplands as a complex of flat plateaux, sloping, slumped and dissected plateaux, and highly dissected terrain of ridges and valleys. Similar dissected uplands extend into Tunduru district. Soils are well drained and coarse textured. The two soil profiles Bennett *et al*. (1979) described for this landscape unit are *Veti-Acric Ferralsols*. They are acidic (pH-H_2O 4.7 - 6.5), with very low levels of exchangeable bases (<5 $cmol_c$ kg^{-1} soil) and cation exchange capacity (<5 $cmol_c$ kg^{-1} soil). The organic carbon content is equally very low (0.4 - 0.9%).

Plateaux

Flat topped plateaux and dissected plateaux are found in the north western part of Tunduru district, the highest parts reaching up to 900 m a.s.l. A residual hill piercing the plateaux, reaches 1100 m a.s.l. and is the highest point of South Eastern Tanzania. The soil map of the Italo-Tanzanian Cashew Research Programme (1981) indicates

that soils have a sandy topsoil with a clayey subsurface soil. It can therefore be expected that these soils are similar as those of the uplands and of the eastern plateaux.

Suitability for cashew

Considering the ecological requirements of cashew and the characteristics of the landscape units of South Eastern Tanzania, enables to draw the land suitability map for cashew presented in Fig. 5.

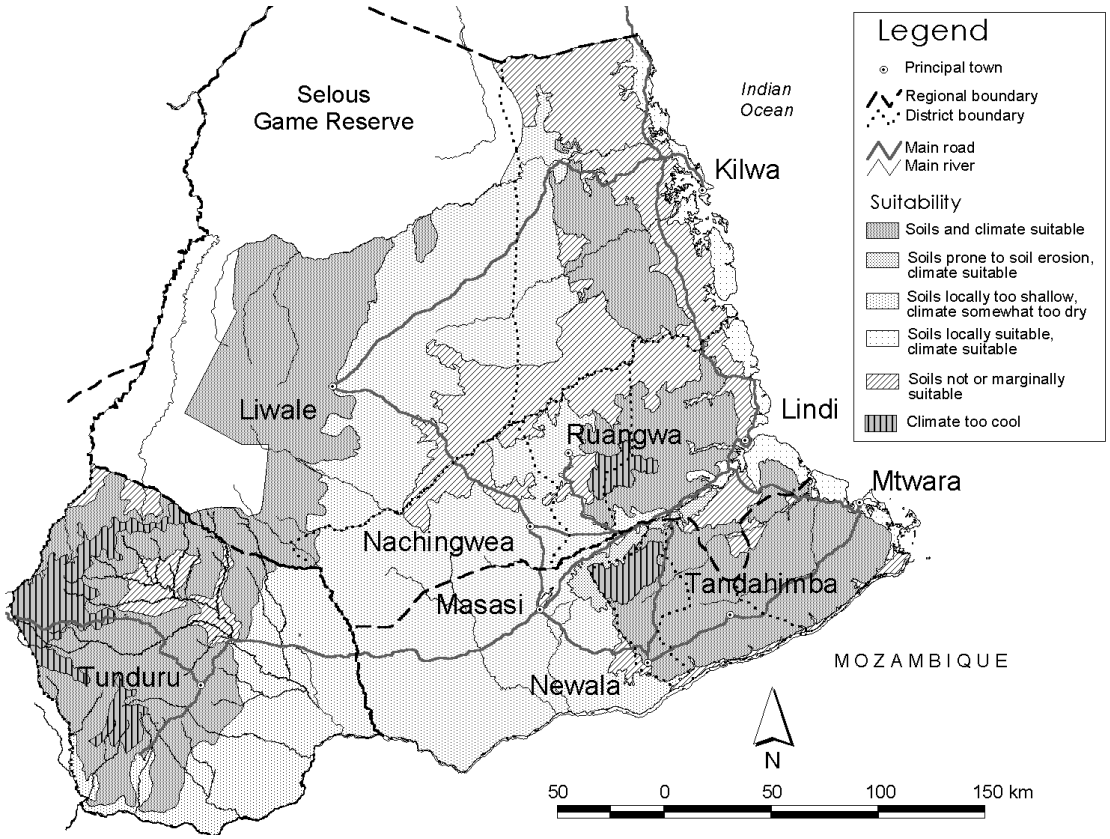


Figure 5 Land suitability for cashew nut production in South Eastern Tanzania

Coastal area

In the coastal plains, only sandy sediments or deep, highly weathered, acidic soils developed on coral lime, are very suitable for cashew. Major parts of the coastal plains are, however, marginally suitable due to shallowness or too high soil pH. The

soils of the coastal dissected plains and coastal hills are predominantly dark cracking clay soils not suitable for cashew.

Eastern plateaux and floodplains

The highly weathered sandy soils of the plateaux are very suitable for cashew. The Makonde plateau indeed is the major cashew producing area within South Eastern Tanzania. Cashew production could possibly be expanded on the Rondo and Kilwa plateaux. Soils of the plateaux are however more sensitive to acidification when sulphur is applied for controlling powdery mildew (Ngatunga *et al*. 2003; Ngatunga *et al*. 2001b;). Soils of the Makonde platform are most likely equally suitable but due to erosion risk, cultivation in this part should be discouraged. The alluvial floodplains are not suitable due to their poorly drained and heavy clayey soils.

Central plains

As the soil pattern of this area is complex, so is its suitability. The deep and highly weathered soils on interfluve crest are very suitable. Moreover, soils in this area have the advantage to be less sensitive for soil acidification (Ngatunga *et al*. 2003; Ngatunga *et al*. 2001b). Marginally suitable are the soils on slopes which tend to be shallow or the poorly drained soils in the valley bottoms. In this area, however, low rainfall can be a major limitation to cashew production.

Western uplands and plateaux

Most of the western uplands and plateaux are very suitable for cashew nut production. Only the highest parts, above 800 m a.s.l., are not or marginally suitable as lower temperatures are unfavourable for cashew production. The lower lying sandy dissected uplands are very suitable.

Summary

Cashew requires high temperatures, a pronounced dry season and produces highest yields on deep, highly weathered soils. Rainfall in South Eastern Tanzania is distributed over five to six months, though can be very erratic; once in ten years annual rainfall may be as low as 600 mm or as high as 1900 mm. Mean annual temperature is between 24 and 26°C. This climate, combined with the widespread occurrence of deep, highly weathered soils, makes that vast areas of South Eastern Tanzania are very suitable for cashew nut production.

From east to west the landscape can be grouped into:

- A coastal area of plains, dissected plains and hills. In the coastal plains, suitable soils are found only where there are deep sandy sediments or on elevated areas where deep, highly weathered soils developed from coral lime. More common are shallow, weakly weathered clay soils, marginally suitable for cashew. The coastal dissected plains and coastal hills have dark cracking clay soils not suitable for cashew.
- An eastern area of plateaux to which floodplains are associated. The plateaux have deep, highly weathered, sandy soils, very suitable for cashew. Only small parts of the plateaux — above 800 m a.s.l. — are too cool for cashew nut production. The soils of the plateaux are, however, prone to acidification when sulphur is applied for controlling powdery mildew. The poorly drained, often clayey soils of the floodplains are not suitable for cashew.
- A central area of inland plains, dissected plains and inselberg plains. On interfluve crests deep, highly weathered soils are found, very suitable for cashew. Less suitable are soils on the slopes which tend to be shallow, or poorly drained soils in the valley bottoms. Low rainfall is another factor limiting cashew nut production in this area.
- A western area of dissected uplands and plateaux with deep, sandy soils very suitable for cashew. Here, only a restricted area is too cool as it reaches above 800 m a.s.l.

Particularly the sandy plateaux, as the Makonde plateau and the plateaux of Tunduru are very suitable as they have, besides a favourable rainfall regime, deep and highly weathered soils (*Veti-Acric Ferralsols*). The suitability of the central plains is restricted due to its drier climate and the prevalence of shallow, weakly weathered soils (mostly *Cambisols*, *Luvisols* and *Petric Plinthosols*).

The wide occurrence of dark cracking clay soils (*Vertisols* and *Vertic Cambisols*) over vast areas of Kilwa district, sheds light on the low contribution to the total cashew nut production of this district. The Kilwa plateaux would be suitable for cashew but are thinly populated. The Rondo plateau, in the districts of Lindi and Ruangwa, as well as the plateaux and dissected upland of Tunduru and Liwale districts present the highest potential for expanding cashew nut production.

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