NGWAZI ESTATE, MUFINDI, TANZANIA

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NGWAZI ESTATE, MUFINDI, TANZANIA

REPORT ON LAND AND WATER RESOURCES, WITH SPECIAL REFERENCE TO THE DEVELOPMENT OF IRRIGATED TEA

PART 1: SOILS AND LAND SUITABILITY

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Contract No. 81/3101
NOVEMBER 1993

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ACKNOWLEDGEMENTS

The team received excellent clarification of the ToR, logistic facilities, provision of field assistance and general co-operation and hospitality from many members of the staff of BBT, especially Mr T. C. E. Congdon, Acting Chairman; Mr D. Dawson, Estate Manager, Ngwazi; Mrs C. Dawson; Mr J. J. Ng'umbi, Development Manager, Ngwazi Estate; and Mr S. Patel, Office Manager, Dar es Salaam.

Particular thanks go to Mr Badan Sanga, Research Officer, Ngwazi, who accompanied the soils team continuously throughout their fieldwork, organised their day-by-day labour and field equipment needs and enthusiastically participated in their work.

The soils team received useful information about the current status of soil classification in the Southern Highlands from Mr J. P. Magoggo of the National Soils Service, Mlingano, and about the general environment of the survey area, courtesy of Mr R. Makame, Reference Librarian, Water Master Plan Co-ordination Unit, Ministry of Water, Energy and Minerals, Dar es Salaam.

We are grateful to the laboratories of Brooke Bond (Kenya) Ltd and the Tea Research Foundation of Kenya for the processing of our soil samples.

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REPORT ON LAND AND WATER RESOURCES, WITH SPECIAL REFERENCE TO THE DEVELOPMENT OF IRRIGATED TEA

PART 1: SOILS AND LAND SUITABILITY

EXECUTIVE SUMMARY

1. The land and water resources of the Ngwazi Estate, Mufindi, Tanzania were surveyed and assessed in 1993.

2. The fieldwork for soil survey and land suitability assessment took 38 man-days at Ngwazi in January-February 1993. The soils of the 2534 ha of dry land on the Estate were examined by augering at 315 sites, and in more detail in 12 profile pits. The pH of the topsoil and upper subsoil was measured at each auger site and 73 disturbed and 64 undisturbed samples were collected from the profile pits for laboratory analysis.

3. The most extensive soils belong to the Ferralsols grouping in the FAO Classification. They are deep, well drained, brightly coloured, medium textured and moderately acid. They have good physical properties such as a stable micro-structure but are chemically poor, have a limited available water holding capacity and low cation exchange and effective cation exchange capacities (CEC and ECEC). They cover almost all of the gently sloping land of the Ngwazi and Nzivi blocks to the east and west of the lake.

4. The soils on the low hills in the north of the Estate are more varied. They include soils in which rooting depth is restricted by dense ferruginous gravel, massive ironstone, or compact weathered rock.

5. There are small areas with impeded drainage along the shores of the lakes, stream lines and in the swamp in the northern apex of the estate.

6. The median field pH value of 5 for topsoils and upper subsoils, with the majority of sites sampled falling in the pH range 4.5 to 5.5, is suitable for tea cultivation.

7. The soils of the Estate were assessed for their suitability for intensively managed irrigated tea. The areas of the suitability classes are:
   1530 ha of class S1 (highly suitable),
   726 ha of class S2 (moderately suitable),
   42 ha of class S3 (marginally suitable),
   152 ha of class N1 (currently unsuitable but reclaimable at considerable cost),
   84 ha of class N2 (permanently unsuitable).

   There are large continuous tracts of suitable land in the Nzivi and Ngwazi blocks. The suitable land in the northern block is less extensive and more fragmented.

8. Most of the land not needed for plantations of irrigated tea is suitable for plantations of rainfed gums for fuelwood.

9. The proposed location of the factory on the most westerly of the hills in the north of the Estate does not encroach on land with high potential for irrigated tea.

1. INTRODUCTION AND TERMS OF REFERENCE

1.1 Introduction

Silsoe College and SSLRC surveyed the land and water resources of a number of the Lonrho estates in the Mufindi district in the Southern Highlands of Tanzania during 1990 (Weatherhead *et al.* 1992). They mapped the soils, assessed their suitability for intensively managed irrigated tea, assessed the water resources, and indicated how these might be managed to increase the area under irrigated tea and raise tea production.

In 1992 Silsoe College and the Soil Survey and Land Research Centre (SSLRC) were invited by Brooke Bond (Tanzania) Ltd (BBT) and Unilever Plc (UK) to submit a proposal for a similar study of the Ngwazi Estate, and agreement was reached in January 1993. The fieldwork for the soil survey and land suitability component was completed by a two-man team, I. C. Baillie and R. G. O. Burton, in a 19-day stay at Ngwazi in January to February 1993. The fieldwork for the assessment of the water resources and their development potential was carried out by E. K. Weatherhead in July 1993, and the results form Part 2 of the report.

An early draft of the land resources part of the report has been made available to the clients in June/July 1993.

1.2 Terms of Reference

The full text of the technical parts of the Terms of Reference (ToR) are reproduced as Appendix 1. The main requirements are:

- to map the soils of the Estate
- to analyse the characteristics of the main soils found
- to assess their suitability for plantations of irrigated tea and fuelwood gums.
- identify suitable areas for those crops, and for housing and a tea factory
- assess the water resources available for the development of the Estate
- advise on the management of these water resources
- report on all of these issues within six months of the completion of fieldwork

The ToR are specific on some aspects of the study, but left sufficient flexibility on others to allow for adjustment to meet the real management needs of the client, as apparent in the field. Some of these points relating to the soil survey and land resources assessment were discussed at Ngwazi on 3 February 1993 by T. C. E. Congdon and D. Dawson (both of BBT) and I.C. Baillie and R. G. O. Burton (both of SSLRC). It was agreed that:

- the published soil and land suitability maps should be at 1:25,000 scale, but that more detailed site data would be provided in the forms of a site-by-site database, and copies of the survey field data and draft mapping material.

- land suitability should be reported using the FAO terminology.

- the land suitability assessments for irrigated tea and rainfed fuelwood gums should be combined on the same map, giving priority and prominence to the tea.

2. GENERAL ENVIRONMENT

2.1 Location, extent and access

The Ngwazi Estate is located in the Mufindi district of Iringa province in the Southern Highlands of Tanzania (Fig 2.1). The Estate stretches from 8° 29'30" to 8° 32'30" S, and from 35° 07' to 35° 11'30" E, about 6 km north of the village of Igowole and about 15 km northwest of Lugoda, the Mufindi headquarters and nearest tea factory of BBT.

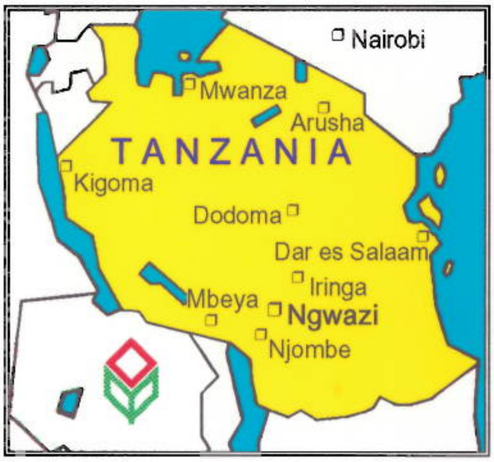


Figure 2.1

Location of Ngwazi in the Southern Highlands of Tanzania.

The boundaries and extent of the Estate have varied in recent years as Brooke Bond Tanzania ceded the northern and western parts of their original holding to the Forestry Department of the Government of Tanzania in the 1970s. Part of the ceded area is currently being returned to the company to enable the projected development of irrigated tea on the estate. The exact boundaries of the returned areas were still being adjusted and marked on the ground in January-February, 1993. The survey area boundaries shown in Figure 2.2 and Maps 1 to 4 are those indicated by BBT and marked with Forestry Department pegs.

The soil survey area covers 2534 ha. This includes only the land areas of the Estate, and excludes Lake Ngwazi, and the area of swamp to the south of it that is likely to be flooded if and when the lake level is raised.

The northern boundary of the estate is less than one kilometre from the tarred Tanzam highway, connecting to Iringa, Dar es Salaam, Njombe and Mbeya.

The Estate therefore has better external access than others in the Mufindi tea area. This benefit is partly offset by the probably higher risks of theft and vandalism.

Access to Lugoda and the other BBT estates in Mufindi is by public, murram-capped road through Mninga. This is of variable quality according to the season and state of repair.

In order to facilitate orientation, we refer to a number of place names within the survey area, which are shown in Figure 2.2. We also gave the one kilometre squares of the map grid a simple letter-digit notation, along the lines of a conventional chess board. The origin is at the intersection 3354 and the squares are coded A-J eastwards and 1-8 northwards, as shown in Figure 2.2.

2.2 Geology and Soil Parent Materials

The area is underlain at depth by acid and intermediate crystalline rocks of great age. The Iringa Water Master Plan indicates that the bedrock for the survey area is an undifferentiated complex of granites, granodiorites, gneisses and migmatites. A body of Karagwe-Ankolean undifferentiated metamorphics - quartzites, schists, phyllites and metavolcanics - is mapped at some distance to the northeast of the estate (CCKK 1982). The absence of outcrops in the survey area and the very deep and intense weathering makes it difficult to characterise bedrock except in general terms. Very little hard rock was seen throughout the survey; only rare residual boulders on Longstaff and Makabila hills, or at White Rock on the western shore of Lake Ngwazi. These appear to be leucocratic granites or possibly granodiorites.

Like most of the rest of the Southern Highlands plateau, the Estate is mantled by a very deep and intensely weathered regolith. Borrow pits, deep soil pits and deep augerings show that the weathering reaches to at least 6 m. Deep excavations and bores elsewhere in the Southern Highlands indicate weathering of depths of 10-70 m (CCKK 1982).

The weathered material is varicoloured but reddish hues predominate. Most of the primary minerals have disappeared except for quartz and a few feldspars which are still being kaolinised.

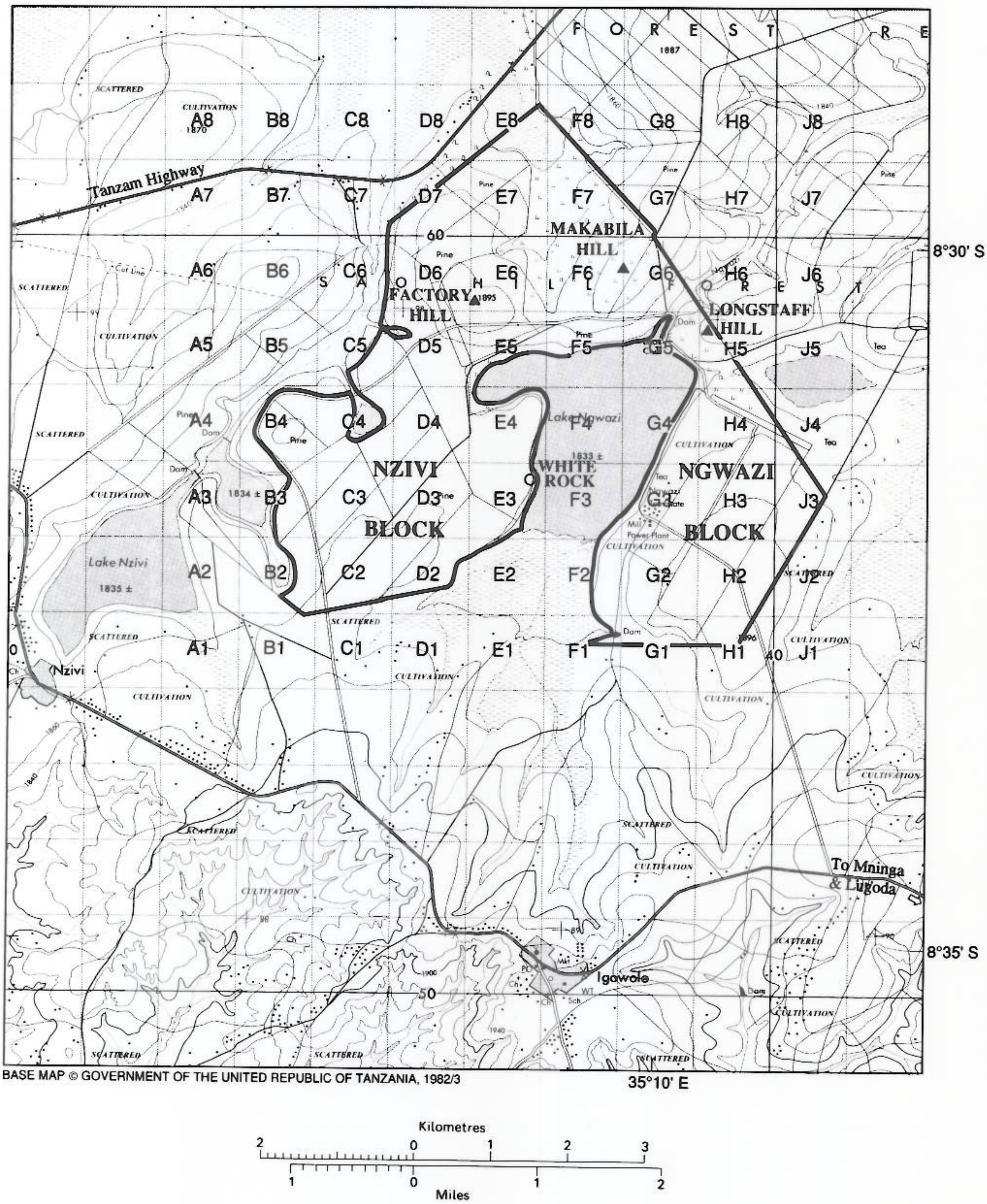


Figure 2.2 Location of the Estate with place names

The upper metres of the material are generally soft enough to auger or dig by hand and there are few signs of the original rock structure. However, some of the colour patterns suggest that much of the material is a colluvial mixture, including some large boulders that were of initially different composition from the matrix. These have weathered to produce redder patches with higher clay contents. This microvariability is apparent at scales of about a metre. At larger scales the weathered material is quite uniform over most of the estate. The main exception is the redder and finer grained material that mantles the lower southern and southeastern slopes of Makabila Hill. This contains a few highly weathered greenish-grey floaters, possibly pieces of metargillite. The red clay may be derived from the Karagwe-Ankolean metamorphic, rather than the granitic and gneissic material elsewhere. All of the deeply weathered regolith is called 'laterite' by some engineers (*e.g.* CCKK 1982), but modern pedologists tend to avoid the term because of its ambiguity. In this report it is referred to as 'strongly weathered rock' or 'saprolite'.

There are ferruginous accumulations and gravels in many of the soils of the Estate. Some of those in soils in low-lying areas are thought to be current, and still in the process of formation. However, those high up on the flank slopes of Makabila and Factory Hills, in the northern part of the Estate, and much less commonly on the slopes of the Ngwazi and Nzivi blocks, are much thicker and harder. They are though to be relict, dating from entirely different soil moisture regimes, back in early Quaternary or Tertiary times. These ancient ferricretes supply the 'murram' that is now used for roads. As far as soil formation is concerned, the ancient ferricretes are best regarded as parent materials rather than the result of current or recent pedogenic process.

Virtually the whole area is covered by slope deposits that are either residual or colluvial, i.e. having been moved short distances downhill by a combination of creep and wash processes. There are very thin strips of material along the lake shore and in the valley of the Ngwazi downstream of the dam that may be alluvial, having been moved considerable distances and deposited by running water. The material beneath the swamp at the northern apex of the survey area is probably also alluvial.

2.3 Topography

The Estate is situated on the undulating/rolling plateau of the Southern Highlands. The 1:50,000 map shows it as ranging in altitude from 1830 m to just under 1900 m above sea level. The plateau is thought to be part of the African surface. This was formed by prolonged pediplanation during the late Cretaceous-early Tertiary, and may therefore be over 30 million years old. The landscape is thought to have been formed by normal slope and channel erosion processes, operating at low altitudes. The plains, low hills, and swamps so produced were then elevated by tectonic uplift, possibly in association with the formation of the Rift Valley to the west, or the faulting of the Uzungwa scarp to the southeast. Since uplift, fairly gentle erosion has continued and the relatively undissected landscape has been preserved. Eventually younger, post-African, surfaces will encroach by scarp retreat and the whole area will become deeply dissected. The very deep and intense weathering is thought to be mainly due to the great age of the landscape.

In the original landscapes, the swampy areas were probably characterised by ferruginous accumulations. Since uplift these have desiccated and hardened, to form ferricrete and have served partially to protect the areas they cover. As a result these original swamps now form the higher areas of Makabila and Factory Hills, as examples of landscape inversion. On the Nzivi and Ngwazi blocks, the less common bodies of ancient ferricrete are associated with flat hill tops or gentle convexities on flanking slopes. The occurrence of subrounded quartz pebbles with some of the ancient ferricretes on Makabila and Factory Hills tends to confirm their hypothetical origins in low-lying, poorly drained areas.

Topographically the survey area falls into three distinct blocks. The **Ngwazi block** to the east of the lake consists of a broad flat interfluve at about 1890 m altitude, with very gently graded (usually less than 2°), straight upper and middle slopes. The lower slope profiles are distinctly convex, tending to steepen down towards the lake shore or stream lines. The **Nzivi block** to the west of the lake has a similar shape, with a broad flat interfluve and distinctly convex lower slopes. However it is lower, with a maximum altitude of about 1870 m. The topographic form of these two blocks means that the main pumping lift is expended in reaching a fairly small proportion of the area -- the convex lower and middle slopes. Once pumped to the upper mid-slope level, water can be spread to the extensive upper slopes and tops with relatively little additional lift.

The **Northern block** is the topographically complex northern third of the estate. It consists of the crest and upper slopes of a flat-topped hill ('**Factory Hill**') in the west, the nose and flanking slopes of a broad flat-topped spur (**Makabila Hill**) in the centre, and a small area on the lower slopes of a third hill (**Longstaff Hill**) in the east. It also includes the slopes, valleys and a saddle between them, and an arm of an extensive swamp in the north. Both of the main hills have considerable outcrops of ancient ferricrete on their upper and middle slopes. These are often, but not always, associated with a perceptible step in the slope profile (Fig. 3.1), as though the ferricrete has been slightly more resistant to erosion than the rest of the colluvium. The main convexity thus formed is usually found on the mid-slope but it appears that there is more than one ferricrete ('murram') band on the northwestern slope of Makabila Hill and in several places on Factory Hill. Both Factory and Makabila Hills have approximately convex shapes with broad flat crests, and slopes that steepen towards the base. This has the same implications for water supply as the convex form of the two southern blocks. However the hills are higher and the lower slopes are steeper, approaching 10° in places, and the interfluve areas above the convexities are less extensive than in the other two blocks.

The rolling/undulating topography of the Estate is quite different from that of the other Mufindi tea estates. These are located close to the Uzungwa escarpment, where the pediplaned African surface is being encroached upon by younger erosion cycles. This results in deeply dissected landscapes with local relief over 100 m in places, and high proportions of steep slopes.

2.4 Climate

An account of the climate as it affects water resources is given in Part 2 of the Report.

Weather data have been recorded at the Ngwazi Tea Research Unit for the periods 1967 to 1970 and 1986 to the present. Recent figures are reproduced in Table 2.1. The climate is characterised by a **warm wet** period from November to April, a **cool dry** season from May to August, followed by a **warm dry** period from September through to the start of the rains. The weather is sufficiently variable, particularly rainfall and the start, end and duration of the dry season, to affect tea yields. The annual rainfall ranges from 800 to 1100 mm. This is a distinctly drier climate than any of the other Mufindi tea estates which lie nearer to the Uzungwa Escarpment where an additional 600 mm of rain falls annually. Irrigation is thus essential for anything better than mediocre tea yields, even with high yielding clones and heavy applications of fertilisers.

Table 2.1 **Summary of meteorological observations at Ngwazi Tea Research Unit, (8°32'S, 35°10'E, altitude 1840 m) 1989-91.** (Source: *Annual Report 1992*)

	Monthly totals		Monthly	Monthly means of daily values		
			Max	**Air temperature**		
	Rain	E_{pan}	**SWD**	Max.	Min.	Mean
Month	(mm)	(mm)	(mm)	(°C)	(°C)	(°C)
January	226	92		22.5	13.6	18.1
February	196	96		23.2	13.6	18.4
March	185	98		23.1	13.7	18.4
April	104	87		21.7	13.7	17.7
May	21	75	79	19.9	12.8	16.3
June	2	85	162	19.7	9.8	14.8
July	1	86	246	18.4	8.9	13.6
August	0	95	341	19.2	9.7	14.5
September	1	119	465	21.6	10.8	16.2
October	1	141	600	23.4	11.8	17.6
November	55	127	696	23.9	12.8	18.4
December	157	116	697	23.3	13.7	18.5
Year	**951**	**1217**				
Mean				**21.7**	**12.1**	**16.9**

2.5 Land Use and Vegetation

There is little natural or semi-natural vegetation left on the estate. There is a small area of miombo savannah woodland on the slopes of Longstaff Hill and in the valley of the Ngwazi downstream of the dam. Elsewhere the natural vegetation may have been a fire-climax mosaic of grassland and thicket, but this has all been removed and the plant cover is now entirely artificial, consisting of plantations of perennial crops, artificial grasslands, and early successional grass/herb communities following the cultivation of annual crops.

The Ngwazi block to the east of the lake is currently the only area growing tea. From a nucleus of about 16 ha, the area is currently being expanded, with about a further 130 ha planted by January 1993, and an active nursery for further expansion. Currently planting is on the lower and middle slopes next to the lake but may soon expand onto the flat top of the block. The tea is intensively managed, with irrigation and high inputs of fertilisers. A variety of clones are grown, and there are field-scale trials of different planting patterns, including double hedgerows.

In addition there are a series of field experiments by the Ngwazi Tea Research Unit, a joint effort sponsored by BBT, other Tanzanian tea producers (Mufindi Tea Company Ltd, Tanganyika Wattle Company Ltd, George Williamson Tanzania Ltd), the Tanzania Tea Authority, Silsoe College International Centre for Plantation Studies and the UK Overseas Development Administration. There are trials on drought resistance and irrigation requirements, levels of nitrogen fertilisation, and plant spacing, each combined with interclonal comparisons. These trials and general field experience have shown that high yields (5000 kg made tea ha^{-1} a^{-1}) are possible at Ngwazi as long as the plants are not moisture- or nitrogen-stressed (Carr *et al.* 1992, Stephens 1991, Stephens and Carr 1991, Burgess 1992).

The plant cover of most of the rest of the Ngwazi blocks still reflects its former use for ranching and maize production. There are shelter belts of tall gums (mostly *Eucalyptus, salinga/grandis*, although some *E. globulus* has been reported (D. Dawson pers. comm 1993)). These are often widened by dense tangles of volunteer black wattle trees and shrubs along their fringes. The large fields so separated have been recently used for maize, and now have volunteer grasses, herbs and low shrubs covering old stovers, or have been planted to improved pasture species, especially Rhodes grass (*Chloris gayana*). Scattered or clustered volunteer wattle shrubs and low trees are found throughout these fields.

The Nzivi block to the west of the lake is used entirely for timber plantations of fast-growing exotic species. Comparison of present cover with the 1979 aerial photograph shows that most of the area is well into its second rotation.

Pinus elliottii was the main species used in the early plantings but Mexican pine *Pinus patula* is apparently now preferred. Growth generally appears to be good, but there are some areas of persistent stunting, poor form, and high levels of blanking. The soils of the most conspicuous of these areas of poor tree growth were specifically examined in our survey (see Appendix 2). Some of the firebreaks, particularly in wetter areas along drainage lines are maintained as low grass. Others have been planted or allowed to grow as dense belts of black wattle.

The land-use pattern in the northern, Factory and Makabila Hills, block is more varied. Most of Factory Hill is under pine plantations, managed similarly to those on the Nzivi block. There is a large borrow pit for murram road metal on the northeastern boundary. An area of patchy pine growth on the crest of the hill has been used recently as a maize shamba by Forestry Department workers. Makabila Hill has been used for maize production, pasture and coffee (under the shade of *Grevillea sp.*). The lower southern and southeastern slopes have belts of black wattle, the alignment of which look as though they were planted mainly for soil conservation purposes. In contrast to the vigour and fecundity of wattle elsewhere on the estate, these belts appear to be languishing. The reason for this is not clear – see Appendix 2.

The natural savannah vegetation of Ngwazi is quite different from that of the other Mufindi tea estates, which lie in the lower montane forest zone of the wetter climates close to the Uzungwa scarp.

2.6 Previous Soil Surveys

The only detailed soil survey in Mufindi that we know of is that of Weatherhead *et al.* (1992), which is concerned with soils in the moist forest zone close to the Uzungwa scarp. The generalised soil map of south western Tanzania (scale *ca* 1:3 million) in Hathout (1983) shows the survey area to be in a zone of well drained clay oxisols on hilly landforms. General observations on the soils of the Southern Highlands appear to be relevant to the survey area (*e.g.* Trapnell *et al.* 1986).

3. SOILS

3.1 INTRODUCTION

The soil survey and the soils found are reported here in sufficient detail to clarify the discussions on land suitability that follow (Chapter 4). Some technical aspects of the soils are discussed in more detail in Appendix 2.

3.2 SOIL SURVEY MATERIAL AND METHODS

3.2.1 Maps

The topographic base maps for the survey area are the Mufindi West and Sao Hill 1:50,000 sheets (Nos. 248/1 and 232/3) in the Series Y742, Edition 1-TSD. These were published in 1982-3 and are based on aerial photographs from 1977-8. They have been enlarged to 1:25,000 scale for the final soil and land suitability maps (Annex 4, Maps 1 & 2), and to 1:10,000 scale for the working field maps (Annex 5, Maps 3 & 4). Although convenient to use, it is important to note that these are not true 1:25,000 and 1:10,000 maps, and can be no more accurate than their 1:50,000-scale base. As contour intervals on the 1:50,000 maps are at 20 m, it is clear that they are not adequate for the detailed planning of irrigation layouts, and more detailed topographic surveys are required.

The maps were supplemented by a 1:25,000 panchromatic vertical aerial photograph, taken in 1979, that covers most of the estate. As it is solitary, there is no stereoscopic coverage. Although over 13 years old, the photograph was useful for location. However the rigidly geometric pattern of the pine plantations on much of the western part of the estate masked many of the subtler changes in tone and texture that would have been apparent in natural and semi-natural vegetation. The photograph was, therefore, of only limited help in delineating soil boundaries.

3.2.2 Field Methods

The morphological features of the soils, such as colour, texture (see Appendix 2), stoniness and depth, were examined in auger bores 2 to 3 m deep at 315 sites. Field pHs (in a 1:1 soil:water suspension) were measured in samples from depths of 0-10 and 55-65 cm at each site. The sites were mostly located along traverses that could be easily located on the map and photograph. The usual interval was 200 m but this was varied in places.

The soils were examined in more detail and sampled in 12 profile pits, taken to exemplify the characteristics of the more important soils. Two of the profiles were in cut back borrow pit sections, one was in an existing root-examination pit, and the remaining nine were in purpose-dug profile pits of 2-3 m depth. Augering reaching to as deep as 6 m below ground level was done in the bottom of some pits. All sites were described along the lines of the FAO Guidelines to Soil Description (FAO 1990(b)) and the Soil Survey Field Handbook (Hodgson 1976).

Disturbed samples for chemical and granulometric analysis were taken from the main soil layers or **horizons** of all profiles. Triplicate undisturbed core samples for the analysis of soil moisture release characteristics were taken from the 4 or 5 main horizons of 6 of the profiles. Most of the samples are to be analysed at the laboratories of Brooke Bond (Kenya) Ltd and the Tea Research Foundation of Kenya, both at Kericho, Kenya. A limited number of samples and duplicates are to be analysed in the laboratory of SSLRC in the UK. Details of the laboratory methods are given in Annex 2.

3.3 DESCRIPTION OF SOILS

The soils are summarised in Table 3.1. In that table, in the following descriptions, and in the field descriptions (Annexes 1 and 3), the textures given are those apparent to the hand in the field. Because of the strong bonding of clay and fine silt particles by the free iron and aluminium oxides, the finer fractions in these soils are difficult to separate in the field, and hand texturing tends to give higher estimates of the sand contents and lower estimates of the clay contents than laboratory analyses, in which the fine particles are separated chemically. This is a perennial problem in highly weathered tropical soils (Akamigbo 1984). It can be argued that hand texturing gives a truer impression of the physical condition of these soils in the field and is more realistic. However, the higher, laboratory-determined clay contents give a truer impression of the chemical characteristics of the soils.

The classes in Table 3.1. are those to which soils could be assigned at each observation site. As noted below (3.4) they cannot all be mapped separately.

Nzivi (Nz)

These are the most extensive soils on the estate, and are likely to be the main soils for extensive tea developments. They occupy most of the middle and upper slopes and the crests of the broad flat interfluves of the Ngwazi and Nzivi blocks.

The profile is characterised by a dark greyish brown to brown topsoil of sandy loam or sandy clay loam texture, grading through intermediate brown and slightly heavier textured horizons to a very deep, uniform, brightly coloured subsoil of fine sandy clay loam, fine sandy clay, or clay loam texture. Subsoil colours are mostly reddish yellow or strong brown, with occasional yellowish reds. There may be some slightly redder nodules of soil, but there are no clear mottles or ferruginous gravels within the upper 2 m. The topsoils and subsoils are both friable, but there is usually a firmer, compact horizon in the upper subsoil, between about 20 and 60 cm depth. This has probably been caused by cultivation operations, either for agriculture or forestry. The subsoil has a distinct granular secondary structure with common rounded soil nodules. These fine structures are often organised into weak or very weak larger subangular primary structures (Trapnell *et al.* 1986). Deep augering shows that the subsoil grades into very strongly weathered rock, still predominantly reddish yellow or yellowish red but with many white, pink and orange flecks. This is very soft and appears to be penetrable by roots as well as augers.

This appears to be a good soil for intensively managed irrigated tea and is rated as Class S1. It is potentially very deeply rooting, has a high to moderate capacity for storing available moisture, and is well drained. It is moderately to strongly acid, and aluminium is an important labile cation. As it is naturally a savannah soil, its organic matter and nitrogen contents are only moderate, but it is assumed that the crop's nutrient requirements will be met by sufficient and balanced applications of fertiliser.

Table 3.1 Summary of Soil Types, Ngwazi Estate

Soil Type (Phase)	Symbol	Brief Description	Representative Profiles (Annex 3)
Nzivi	Nz	Brown sandy loam and sand clay loam, grading to deep, uniform, brightly coloured reddish yellow to strong brown sandy clay loam and sandy clay subsoil. No ferruginous accumulations or mottles within top 2 m. Well drained and good to moderate moisture retention. Acid and base deficient. Low to moderate organic matter and N.	PR3, PC1, PC2
Nzivi (mottled)	Nz(m)	*Similar to Nzivi* but with weak red or yellow mottling below 1 m depth. Few mottles, slightly indurated but mostly soft. Well drained.	PR4
Nzivi (gravelly)	Nz(g)	*Similar to Nzivi* but with few or common ferruginous gravel and nodules below 2 m depth. Gravel in penetrable matrix.	PC4
Makabila (deep)	Mk(d)	Brown sandy loam and sandy clay loam, grading to brightly coloured reddish yellow to strong brown sandy clay loam and sandy clay, over penetrable reddish yellow ferruginous gravelly loam or gravelly clay at 1-2 m depth, over varicoloured strongly weathered rock. Well drained, moderate moisture retention. Acid and base deficient. Low to moderate organic matter and N.	PC3
Makabila (shallow)	Mk(s)	*As Makabila (deep)* but penetrable ferruginous gravel occurs at <1 m depth.	
Ngongwa (deep)	No(d)	Brown sandy loam and sandy clay loam over bright reddish yellow to strong brown sandy clay loam and sandy clay over impenetrable ferricrete or ferruginous gravel at >1 m depth.	
Ngongwa (shallow)	No(s)	*Similar to Ngongwa (deep)* but with impenetrable ferricrete or gravel at <1 m depth.	PC7
Longstaff (deep)	Lg(d)	Brown sandy loam and sandy clay loam over bright reddish yellow to strong brown sandy clay loam and sandy clay over fairly soft varicoloured strongly weathered rock at 1-2 m depth. Well drained, moderate moisture retention. Acid and base deficient. Moderate to low organic matter and N.	PC5
Longstaff (shallow)	Lg(s)	*As Longstaff (deep)* but with weathered rock at <1 m depth. Moisture retention moderate to low.	PC6

Table 3.1 Summary of Soil Types, Ngwazi Estate ..... continued

Hehe (deep)	He(d)	Brown sandy clay loam, grading to reddish brown clay loam, grading to deep, uniform bright red clay loam and clay. Well drained. Moderate to high water retention. Acid and base deficient. Moderate to low organic matter and N. Possibly high P fixation.	PR1
Hehe (gravelly)	He(g)	*Similar to Hehe (deep)* but with penetrable ferruginous gravel in red clay matrix within top 2 m.	
Kihanga (deep)	Kg(d)	Brown sandy loam and sandy clay loam over yellowish or pale brown sandy clay loam to sandy clay with moderate to strong, reddish-brown mottling below 1 m depth; some mottles indurated. Imperfectly drained, moderate to high moisture retention. Acid and base deficient. Moderate- to low organic matter and N.	PR2
Kihanga (shallow)	Kg(s)	*Similar to Kihanga (deep)* but with mottling at <1 m depth.	
Ngwazi	Ng	Brown sandy loam and sandy clay loam grading to pale brown, grey and white sandy clay loam and sandy clay, moist not wet, over drier varicoloured red, yellow and orange strongly weathered rock – sandy clay loam and sandy clay. Imperfectly to well drained. Moderate to high moisture retention. Acid and moderately base deficient. Moderate to low organic matter and N.	PC8 [also R W Payton 1990 profile]
Bottomland Complex	Bc	Brown, yellow, grey and white wet soils, often mottled. Textures range from loamy sand to silty clay. May have surface or buried peat layers. Watertable at <2 m depth. Drainage poor to imperfect. Moisture retention variable. Slightly to moderately acid and base deficient. Variable organic matter and N, sometimes quite high.	

Nzivi (mottled) (Nz(m))

These soils are similar to the modal Nzivi in most respects. They differ in having distinct reddish and yellowish mottles coming in the second metre of the profile. Some of these are slightly hard and have a slightly crisp feel on the auger and in the hand. They appear to be a development from the soil nodules noted in the subsoils of the modal Nzivi, and they may originate from slightly less weathered remnants in the original colluvium (Trapnell *et al.* 1986). They are not thought to indicate significant impedance of the drainage.

These also appear to be good soils for intensively managed irrigated tea (Class S1) subject to the same proviso of adequate fertilisation as in the modal Nzivi soils.

Nzivi (gravelly) (Nz(g))

These soils cap Makabila Hill and part of Factory Hill, and are also found on their middle and lower slopes. The top two metres are similar to the modal Nzivi, and are indistinguishable in augering to that depth. They differ in the third metre, in having significant contents of rounded ferruginous gravel. Much of this is not particularly hard and can be cracked open by hand to reveal brown or red amorphously structured soil cores, encased in a ferruginously enriched coating. The gravel is set in a friable, bright coloured reddish yellow or strong brown clay loam or fine sandy clay matrix, and the horizon is penetrable by auger and roots.

The gravel dilutes the fine earth in the lower subsoil, and slightly reduces the capacity for storing available moisture. However, the depth and penetrability of the gravel horizon is thought to make this a minor limitation. The gravel is thought to be derived from the ancient ferricretes that crop out on the same slopes, and not to indicate any significant current impedance to drainage. Subject to the same provisos about nutrients as the other Nzivi soils, these are assessed as good soils (Class S1) for intensively managed irrigated tea.

Makabila (Mk)

These are well drained, brightly coloured soils with thick gravel layers in the upper two metres. Their upper horizons are similar to those of the Nzivi soils. They have dark greyish brown sandy loam to sandy clay loam friable topsoils, grading through slightly firmer and slightly finer intermediate brown horizons in the upper subsoil, to friable, bright reddish yellow or strong brown sandy clay loam to sandy clay subsoils. However, the subsoils become gravelly to very gravelly at less than two metres depth. In the **deep phase (Mk(d))**, the gravel commences at 1 to 2 m depth, but it is shallower than one metre in the **shallow phase (Mk(s))**. The gravels are mostly ferruginous-coated amorphous soil nodules. The coatings make the gravels moderately hard, but many can be cracked by hand. The coatings tend to be reddish in the upper part of the layer and grade to more varicoloured yellow, orange, dark brown and black with depth. There are also some harder, larger and more angular fragments of old ferricrete, often dark brown to purplish in colour. Angular quartz grit and fine gravel is a subordinate component in the upper part of the gravel layer but increases with depth. The various gravels are set in a matrix of the same bright coloured sandy clay loam or sandy clay as the overlying subsoil.

The gravelly horizon gradually merges into predominantly reddish yellow to yellowish red very strongly weathered rock. This is varicoloured, with orange, yellow, red, white and pink specks and patches. It is soft and penetrable by auger and roots.

The gravel dilutes the fine earth and reduces the soil's capacity for storing available water. Generally it does not appear to be a mechanical barrier, and tea roots should be able to penetrate through it and utilise the underlying soft weathered rock. Nonetheless, these are likely to be slightly more droughty soils than the Nzivi types. The gravel is derived from ancient ferricrete and is not thought to indicate any impedance to drainage in the modern soil. In fact the coarse fragments may improve subsoils drainage. These soils are moderately acid and have aluminium as an important labile cation. Organic matter and nitrogen contents are thought to be variable according to the considerable range of previous land uses, but are generally moderate to low. The deep phase is rated as moderately suitable (Class S2m) for intensively managed irrigated tea, but the shallow phase is only marginally suitable (Class S3m), on account of its greater tendency to droughtiness.

Ngongwa (No)

These soils are characterised by having massive ferricrete or densely packed and impenetrable ferruginous gravel within the upper two metres. The upper horizons are similar to those of other soils in the area, with friable, dark greyish brown sandy loam or sandy clay loam topsoil, grading through brown intermediate horizons, often of firmer consistence than those above or below, to a friable, bright coloured strong brown or reddish yellow sandy clay loam subsoil. These upper horizons may contain some ferruginous gravel. In the **deep phase** the bright subsoil overlies, usually fairly abruptly, a dense mass of ferruginous nodules and concretions at between 1 or 2 metres. These may be cemented in a reddish or yellowish hard matrix to form massive ferricrete, or may still be discrete gravels but so densely packed as to be impenetrable by auger and all but a few fine roots. In the **shallow phase** the brightly coloured subsoil is thin or absent, and the brown sandy clay loam upper horizons lie directly on the impenetrable ferricrete or gravel at less than one metre depth. Where exposed in borrow pit sections, the ferricrete appears to be moderately (1-2 m) thick. In general the proportion of rounded, moderately hard, red-coated ferruginous nodules decreases, and those of angular, very hard fragments of ferricrete, and of quartz stones, both angular and subrounded, increase with depth. The lower ferricrete merges gradually with predominantly reddish yellow strongly weathered rock with varicoloured red, yellow, white and pink spots and patches.

The ferricrete or gravel severely limits rooting and gives these soils low capacities for storing available moisture. This is most acute in the shallow phase soils. Above the ferricrete/gravel the soils appear to be well drained. The soils are moderately acid and have significant contents of labile aluminium. Organic matter and nitrogen levels are moderate to low.

Because of the restricted rooting depth and droughtiness, these soils are rated as unsuitable for intensively managed irrigated tea. The shallow phase soils are rated as permanently unsuitable, N2r. The deeper soils could be used if necessary but at the cost of increased irrigation frequency and with increased risk of moisture stress and its attendant problems, and are rated N1r.

These soils tend to occur as fairly narrow belts parallel to the contours on the upper and middle slopes of Makabila and Factory Hills. However, they do not appear to form continuous girdles, and may occur at several places down the same slope. A few small areas were found in a mid- and lower-slope positions in the Ngwazi and Nzivi blocks.

Longstaff (Lg)

These are relatively non-gravelly shallow soils over strongly weathered rock at less than two metres depth. The profile consists of the ubiquitous dark greyish brown sandy loam friable topsoil, grading through brown, slightly firmer, intermediate sandy loam and sandy clay loam, to friable, brightly coloured reddish yellow or strong brown sandy clay loam or sandy clay subsoil. In the **shallow phase**, this grades into varicoloured red, brown yellow, orange and white strongly weathered rock within a metre of the surface. In the **deep phase**, the weathered rock comes in at between one and two metres. The junction between the solum and the weathered rock is often marked by a stone layer, which is mainly quartz, but may include some ferruginous gravel. The weathered rock is fairly soft and augerable at the top but becomes compact and impenetrable with depth. These soils appear to be well drained. However the root penetration and storage capacity of available moisture in the weathered rock are limited, so that these soils, especially the shallow phase, are prone to be droughty. The soils are moderately acid and have significant contents of labile aluminium. Organic matter and nitrogen contents are only low to moderate.

Because of limited depth and moisture capacities, the soils of the deep phase are rated at moderately suitable, (Class S2r), and those of the shallow phase as marginally suitable (Class S3r) for intensively managed irrigated tea.

These soils occur on the lower slopes of Longstaff Hill and on the western and southern slopes of Factory Hill. On Factory Hill, ferruginous gravels form a significant component of the stone layer, and these soils are intricately mixed with ferruginous gravelly soils of the Makabila type.

Hehe (deep) (He(d))

These soils are characterised by redder colours and finer textures than other soils on the estate. The profile consists of brown to dark brown sandy clay loam grading through reddish brown clay loam to a deep, uniform bright red clay or clay loam subsoil. In the profile examined (see PR1 in Annex 3), there are a few soft fragments of strongly weathered rock in the subsoil, but these remain insignificant to more than four metres. This soil appears to be friable throughout and has a strongly developed microgranular structure, with fewer soil nodules than in the browner and coarser textured soils of the Nzivi type. The microgranules are only weakly aggregated into medium and fine subangular blocky units.

This soil is moderately acid, and aluminium is an important labile cation. The organic matter content of the topsoil of Profile PR1 appears to be quite low.

The soil is well drained, and appears to have a moderate to high capacity for storing plant-available moisture. It looks like a good prospect for intensively managed irrigated tea. However the black wattle presently growing on these soils is very patchy and does not appear vigorous. This may be due to phosphate fixation and deficiency or there may be some micronutrient imbalance. Whatever the reason, these soils have been downgraded, and are rated as moderately suitable (S2en) for tea.

They are not extensive, occurring only on the southern and southeastern lower slopes of Makabila Hill.

Hehe (gravelly) (He(g))

These are red clays similar to Hehe (deep) but have ferruginous gravel in the subsoil, usually below one metre depth. The gravel is set in a fairly friable red clay to clay loam matrix, and appears to be readily penetrable by auger and roots. It is not thought to detract significantly from the suitability of the soil for irrigated tea, and these soils are also rated as S2en.

This soil is intimately intermixed with the deeper Hehe soils, and the two are not separated for mapping.

Kihanga (Kg)

These soils are characterised by indications of intermittently impeded drainage, such as yellowish or pale matrix colours, moderately strong mottling, often rusty brown in colour, and fresh-looking ferruginous accumulations. However these soils are by no means really wet, and no water table or serious water accumulations were encountered during fieldwork in any of the bores or in the pit (Profile PR2).

The upper horizons are somewhat similar to those of the soils of the Nzivi type, with dark grey or dark greyish brown, sandy loam and sandy clay loam friable topsoils, over grey or brown slightly compact intermediate horizons of slightly finer texture, over the main mottled yellow or pale brown subsoil horizon, which has sandy clay loam to sand clay textures. The mottles and/or ferruginous accumulations tend to occur in bands, of which there may be several, and within which they have a moderately apparent vertical alignment.

In the shallow phase, there is moderate to strong mottling within the top metre. In the deep phase the mottling starts at between 1 and 2 metres depth.

These soils appear to have moderate to high capacities for storage of available moisture. However the occasionally impeded drainage may inhibit deep root penetration and render tea plants slightly susceptible to moisture stress in dry spells. These soils are moderately acid and have significant contents of labile aluminium. Organic matter and nitrogen contents are moderate to low, but may be slightly higher than those in the better drained Nzivi soils upslope.

Because of their suspect drainage these soils are rated as moderately suitable (Class S2d) for intensively managed irrigated tea. Some of the shallow phase may be only marginally suitable (Class S3d).

Ngwazi (Ng)

These are a relatively inextensive soils, occurring only on some lower slopes, often intricately mixed with soils of the Kihanga type. The most striking feature of the profile is a deep, white or light grey subsoil horizon that appears to result from previous waterlogging, but which is now fairly freely drained. It is underlain by brightly coloured red and yellow strongly weathered rock, although often at considerable depth.

The topsoils are similar to others in the area, consisting of friable, dark greyish brown sandy loam and sand clay loam. This grades through slightly firmer brown intermediate horizons of slightly finer texture, to a deep white or light grey sandy clay loam or sandy clay. This has brownish patches at the top where the white material is mixed with the intermediate horizon, and has pale yellow and very pale brown patches at depth, but is generally free of strongly contrasting bright reddish or brownish mottling. At depths usually greater than 2 m, and sometimes more than 3 m, the grey horizon overlies brightly coloured red and yellow strongly weathered rock. The boundary is fairly sharp and is sometimes marked with a weak or moderate stone layer of quartz and/or rounded ferruginous gravel.

The origin of the deep white/grey subsoil horizon is not clear. In the face of the deep, long-dug root examination pit at experiment N9, this horizon was seeping slightly after heavy rain, but there was not enough water to indicate that this horizon is actively gleyed by current throughflow. The patchy distribution of this soil on the lower slopes towards the lake in the area currently under tea at Ngwazi suggests that it may have formed by locally concentrated subsoil seepage (percoline drainage) at a time when rainfall and watertables were higher than now. A feature of some of the white horizons in the presence of cores or stones of whitish, amorphous to weakly laminated, soft to slightly hard, non-quartzose material. It is uncertain whether these are residuals of weathered gneiss or high grade metamorphics, or were formed during soil formation by some kind of secondary cementation, such as by silica or alumina.

These soils have a moderate to high capacity for storing available moisture. There may be occasional impedance to drainage but the subsoils are well rooted, with roots of mature tea penetrating to more than 5m depth. These soils are moderately acid and contain substantial quantities of labile aluminium. Organic matter contents and natural nitrogen levels are low to moderate.

Because of their distribution it is not always possible to map these soils separately from those of Kihanga type. They have been given the same moderately suitable (S2d) rating as the Kihanga soils, however, they appear to have grown tea satisfactorily for more than 20 years at the Research Station, so that there are only minor doubts about their drainage.

Bottomland Complex (Bc)

This complex includes all of the wet soils with watertables within the top 2 m. They are not extensive, occurring along the lake shore, stream lines and in the swamp in the northern apex of the survey area. They are morphologically heterogeneous with textures ranging from loamy sand to silty clay. The textures are sometimes layered but this is probably due to alluvial deposition rather than clay movement within initially homogeneous parent materials. Some of these soils have peaty surfaces, up to 30 cm thick in places. In one augering in a stream line, a buried peat layer was found. Matrix colours are mostly dull and pale – grey, light grey, pale brown, pale yellow and occasionally white – often with venose reddish brown mottling along root and faunal channels. One subsoil was seen with a combination of waterlogging and bright reddish yellow colours. This may be due to lack of the organic matter that is necessary for gleying.

These soils are of variable acidity and aluminium status, due to the inflow of bases from upslope. They are well supplied with water but the impeded drainage restricts root growth. Because of their drainage limitations these soils are rated as unsuitable (N1d) for intensively managed irrigated tea. They are rated N1 (currently unsuitable) rather than N2 (permanently unsuitable) because their drainage could be improved. However the areas involved are not large, and the expense would be fairly high, so it is unlikely to be a significant management option.

3.3.1 Soil Reaction

The tea plant thrives best in moderately acid soils within the pH range of 4.5 to 5.5 (Bonheure 1990). The topsoil and upper subsoil pH values obtained from each auger bore are given in full in Annex 1 and the distribution is shown on Map 4 in Annex 5. The pH ranges and frequency are illustrated in Figure 3.1 for all sites (a) and for sites with suitability rating S1 for tea (b).

The pH of all sites examined ranged from 3.36 to 6.63 in the topsoil and from 3.61 to 6.41 in the upper subsoil, with mean values of 5.10 and 4.94 respectively. Only 11% of topsoil and 9% of upper subsoil samples had a pH of 4.4 or below, but 22% and 9% respectively had a pH of 5.6 and above.

Sites considered most suitable for tea had pH values with very similar ranges with 3.36 to 6.48 for the topsoil and 3.61 to 6.11 for the upper subsoil, and similar mean values of 5.02 and 4.93 respectively. 13% of topsoil and 11% of upper subsoil samples had a pH value of 4.4 or below, and 20% and 7% respectively had a pH of 5.6 or above.

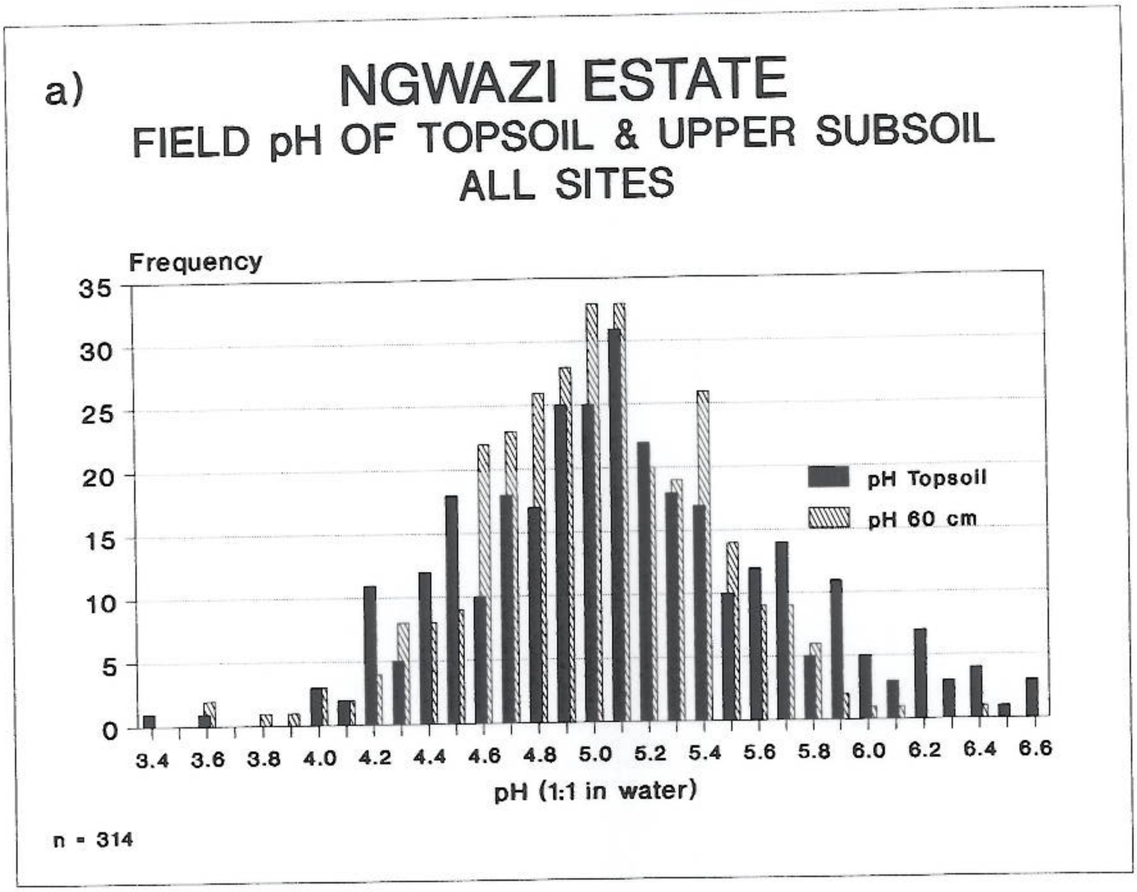
The dominant portion of the most suitable sites for tea – 63% – have both topsoil and upper subsoil pH values within the range recommended by Bonheure (1990).

Two aspects of a pattern to pH distribution were noted during the survey –

a.) pH values tended to be higher in low-lying, receiving sites, in Kihanga and Bottomland Complex soil types in particular (Table 3.2).

b.) pH tends to be variable on a very localised scale. The effect of termites and burning were shown to raise the pH locally. At auger bore site no. R170 (square E5) material from a termite mound had a neutral reaction with a pH of 6.74, while the nearby topsoil was moderately acid with a pH of 4.63. Similarly, at site R173 (square E7) the topsoil sample had a pH of 4.80 but a sample of ash from burnt timber had a pH of 6.46.

Figure 3.1 (a) and (b) Range and frequency of pH values at auger bore sites.



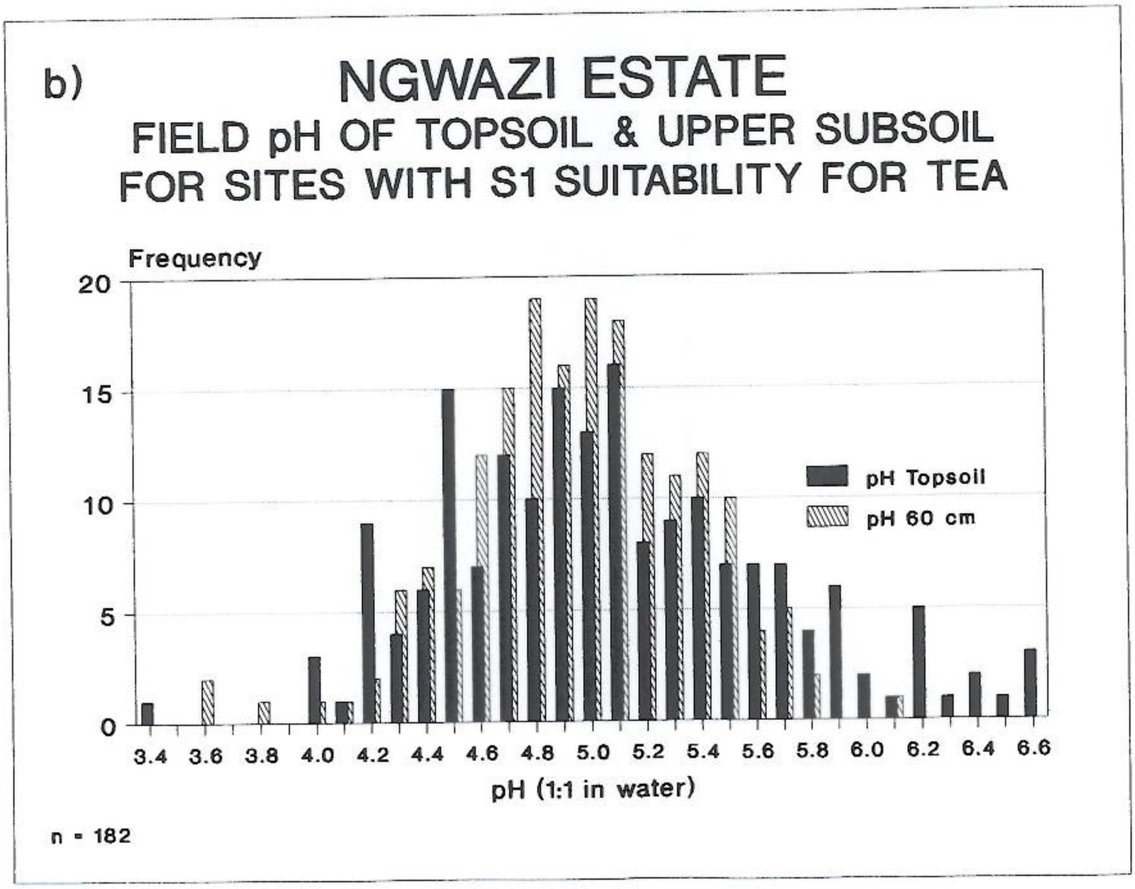


Table 3.2 **Mean pH values by soil type**

Soil Type (all phases)	– Mean pH – Topsoil	Upper Subsoil	No. of Sites
Kihanga	5.56	5.12	(21)
Bottomland Complex	5.29	5.30	(15)
Makabila	5.18	5.15	(37)
Ngongwa	5.14	4.84	(20,17)
Longstaff	5.07	5.03	(14)
Nzivi	5.02	4.93	(182)
Ngwazi	5.01	4.88	(14)
Hehe	5.00	4.94	(10)

There was a large proportion of soil samples with pH values in the upper end of the range around the new nursery site on the flanks of Makabila Hill (square F6). The values were reported to the Estate Manager during the survey, and additional samples from the nursery site were analysed. Comparisons were made with the established nursery at Ngwazi for three samples each of locally-obtained brown topsoil and red subsoil derived from the borrow pit (Profile PR1) near the dam (Table 3.3). The results also show the level of reproducibility of the field method of pH measurement.

Table 3.3 **pH of soil used for cuttings at Ngwazi Nursery**

	Brown Topsoil pH		Red Subsoil pH	
Sample No.	1st analysis	2nd analysis	1st analysis	2nd analysis
1	5.23	5.51	5.93	5.82
2	5.58	5.44	5.94	5.79
3	5.72	5.43	5.85	5.94
Mean	5.49	5.46	5.88	5.94

3.4 SOIL DISTRIBUTION AND MAPPING

There are fairly clear topographic patterns in the distribution of the soils, but they vary in different parts of the Estate, as depicted in a generalised and simplified way in Figure 3.2.

The broad flat interfluves in the Ngwazi and Nzivi blocks have modal Nzivi soils, which become increasingly mottled, downslope, grading through Nzivi (mottled), and Kihanga and Ngwazi to the wetter soils of the Bottomland Complex in the drainage lines. This pattern is illustrated in Figure 3.2(a). On some slopes there is a narrow band of ferricrete soils (Ngongwa) giving a noticeable convexity.

On the western slopes of Makabila Hill and the eastern slopes of Factory Hill, the interfluve soil is relatively deep, with a ferruginous gravelly subsoil (Nzivi (gravelly) or Makabila (deep)), running down to a band of ferricrete soils (Ngongwa), below which are deeper gravelly soils (Nz(g) or Mk(d)), running down to mottled and pale soils on the lower slopes (Kihanga and Ngwazi), with wet soils (Bottomland Complex) in the stream lines and swamp. This pattern is shown in Figure 3.2(b).

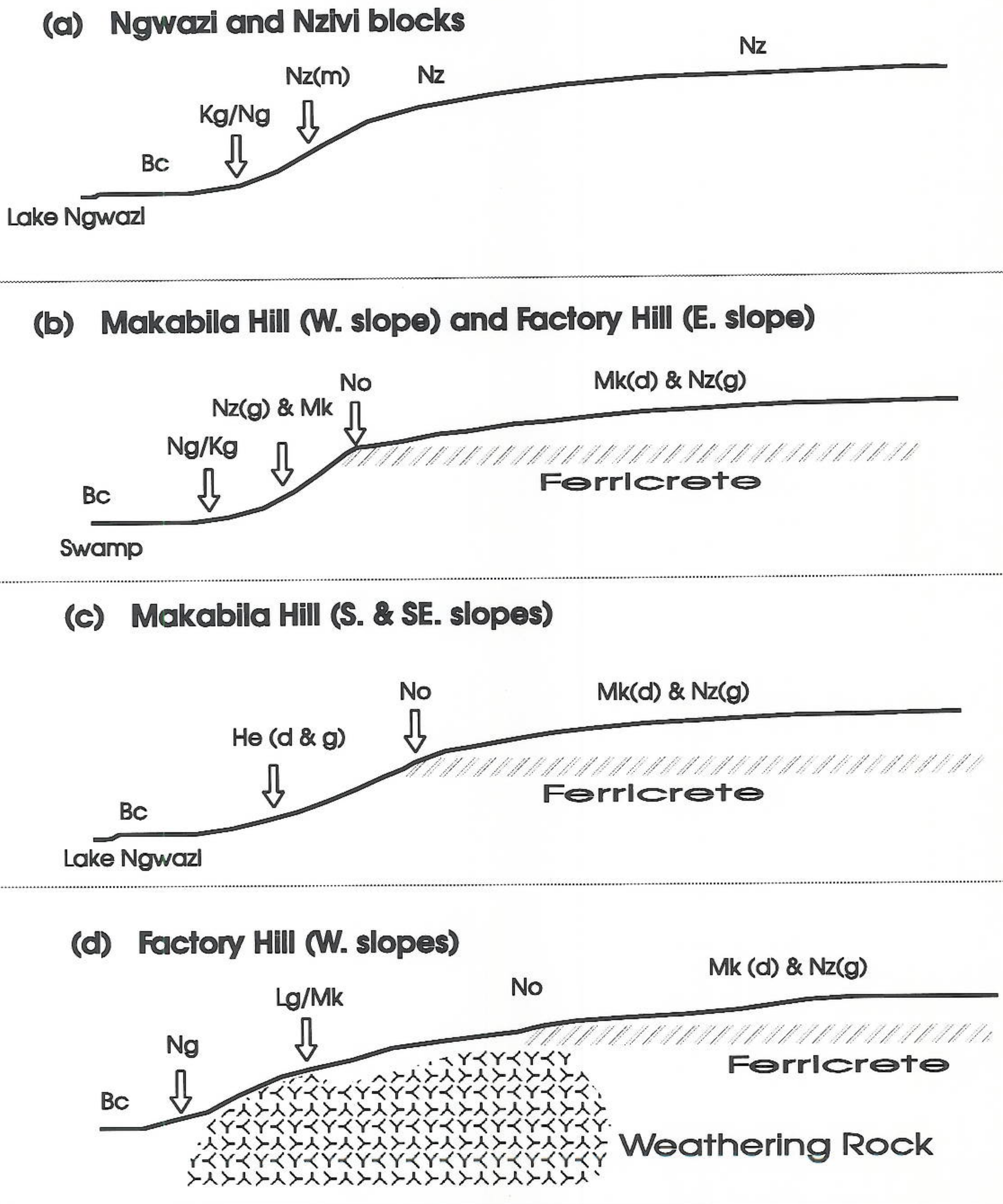
The pattern is similar on the southern and southeastern slopes of Makabila, except that the soils below the main ferricrete are deep and gravelly red clays (Hehe), as shown in Figure 3.2(c).

On the western slopes of Factory Hill the weathering rock occurs relatively close to the surface in the soils below the main ferricrete band, so that a mixture of Longstaff and Makabila are the main mid- to lower slope soils, as shown in Figure 3.2(d).

The soil types listed in Table 3.1 have been mapped separately as far as possible. However it has been necessary to map composite units in some areas, where the pattern appears to be very intricate. The complexes involving different soil types, rather than just phases of the same type, are:

Figure 3.2

Generalised Soil Toposequences Ngwazi Estate



- the area on the top and western slopes of Factory Hill where there are variable thickness of ferruginous gravel over fairly shallow weathering rock, and the soils are a mixture of Makabila and Longstaff.

- the lower western, lakeside slopes of the Ngwazi block, where there is an intricate pattern of Ngwazi and Kihanga soils, the distribution of which has no obvious surface indicators.

- the mixture of wet soils in the Bottomland Complex.

Table 3.4 Extent of Soil Mapping Units, Ngwazi Estate

Soil Mapping Unit	Map Symbol	Extent	
		ha	% of survey area
Nzivi	Nz	*1281	50.5
Nzivi (mottled)	Nz(m)	108	4.3
Nzivi (gravelly)	Nz(g)	141	5.5
Makabila	Mk	32	1.3
Makabila (deep)	Mk(d)	125	4.9
Ngongwa (deep and shallow)	No	84	3.3
Longstaff (deep and shallow)	Lg	42	1.7
Makabila and Longstaff Complex	Mk/Lg	184	7.3
Hehe (deep and gravelly)	He	117	4.6
Kihanga (deep and shallow)	Kg	83	3.3
Ngwazi	Ng	60	2.4
Ngwazi and Kihanga Complex	Ng/Kg	125	4.9
Bottomland Complex	Bc	152	6.0
Total		2534 ha	

* includes 9 ha used as airstrip

3.5 FERRALSOLS SUMMARY

The dominant soils on the Estate as classed as Ferralsols in the FAO classification scheme.

Summary of characteristics

As summarised in Driessen and Dudal (1991) these are red and yellow tropical soils with a high content of sesquioxides, typically on level to undulating stable land of great age. Deep and intensive weathering has resulted in a residual concentration of resistant primary minerals and the formation of kaolinitic clays and iron and aluminium oxides and hydroxides. This mineralogy and the low pH account for a stable micro-structure (pseudo-sand) and yellowish (xanthic) or reddish (rhodic) colours. Ferralsols have good physical properties but are chemically poor. Their low natural fertility, virtual absence of weatherable minerals and very low cation retention capacity are normally serious limitations to agricultural use.

Characteristic features are:

morphological

1. a deep solum, usually several metres thick, over weathering rock;
2. diffuse or gradual horizon boundaries;
3. a high iron content, with good internal drainage forming distinct red (haematite) or yellow (goethite) matrix colours, usually without mottles;
4. a well developed microstructure, with strong micro-aggregates – soils with a clay content of 60% or more feel loamy in the field and have the same mechanical properties as medium or light-textured soils;
5. a weak macro-structure with absence of well developed blocky or prismatic structures.

hydrological

1. most soils have high water retention at permanent wilting point;
2. the formation of micro-aggregates reduces moisture storage at field capacity and results in a rather limited available water holding capacity (e.g. 10 mm of moisture available for each 10 cm of soil depth);
3. most ferralsols are sensitive to drought, particularly those in elevated positions.

physical

1. stable micro-structures and many biopores account for excellent porosity, good permeability and high infiltration rates;
2. strong aggregate cohesion and rapid reflocculation of suspended particles complicate the determination of the particle-size distribution;
3. low susceptibility to erosion.

chemical

1. absence of weatherable minerals;
2. low cation exchange capacity (CEC), less than 16 cmol(+) kg^{-1} (= me/100g) of clay;
3. effective CEC (ECEC), the sum of the bases plus the exchangeable acidity representing the cation exchange capacity at field conditions, lower than the CEC;
4. strong inactivation of phosphorus;
5. complication of fertiliser selection and mode/timing of application.

4. LAND SUITABILITY

4.1 INTRODUCTION

In accordance with the ToR and the meeting at Ngwazi on 3 Feb 1993, the assessment of the Estate's land resources focused primarily on the suitability for intensively managed irrigated tea, with rainfed fuelwood gums, and housing, factory and other infrastructure as second choice alternatives.

4.2 LAND SUITABILITY FOR IRRIGATED TEA

The assessment of land for irrigation is usually considered under two main headings – topographic and soil. For the Estate there are few topographic constraints except height of lift, which is considered separately under water resources in Part 2. Otherwise slopes are rarely steeper than 6° and never more than 10°. Tea is grown on far steeper slopes in other parts of the world, and tea is irrigated on steeper slopes elsewhere in Mufindi. Erosion risks are therefore not considered to be severe or limiting constraints. However, casual observations in heavy rainfalls during our fieldwork, and discussions with the Estate management, indicate that the sandy loam topsoils that are characteristic of most of the soil types do tend to seal under drop impact. Runoff and sheet erosion can therefore be significant in young tea. However the problem disappears once the dense low canopy of tea closes. Of more lasting importance is the erosion off the roads and other bare ground associated with housing, yards and infrastructure.

As the area's topography is seen as non-limiting, the suitability assessment for irrigated tea is based on the soil characteristics. It was assumed that the management would be highly intensive and that the crop's nutritional requirements would be met by adequate and balanced applications of fertilisers. Current soil contents of organic matter, nitrogen and other nutrients need therefore not be given undue weight. The only chemical characteristics that might not be remediable at reasonable cost are high pH and high capacities to fix phosphate. As the routine determinations showed that virtually all of the soil pH values were less than 6, and that most were below 5.5, this was discounted as a major constraint. The only soils in which phosphate fixation might be a serious constraint are the relatively inextensive red clays of the Hehe type.

The soils were therefore assessed mainly on the basis of their physical characteristics, especially their ability to take in large volumes of irrigation water and store it in forms available for uptake by the crop. This requires a soil to have a friable, porous topsoil and a deep, well drained and well structured, medium or fine textured subsoil. The main limitations are impermeable topsoils, excessively sandy subsoils, or any restriction to deep rooting such as a physical barrier or poor subsoil drainage. All of the main soils of the estate have satisfactory topsoil porosities and subsoil textures, and they differ mainly in their rooting depths.

The soils are rated using the notation of the FAO Framework for Land Evaluation (FAO 1976). Land is divided into 5 classes, 3 of them suitable and 2 unsuitable, i.e.

Class S1	Highly suitable, with no or minor limitations.
Class S2	Moderately suitable, with only moderate limitations.
Class S3	Marginally suitable, with severe limitations, but usable at some cost and with lower returns.
Class N1	Currently unsuitable, with very severe limitations but could be brought into use at considerable cost.
Class N2	Permanently unsuitable, with very severe limitations that are not amenable to amelioration.

For all classes except S1, the main limitation or limitations (up to two) are indicated with a subscript, using the abbreviations of the FAO Guidelines to land evaluation for irrigated crops (FAO 1985). For the soils of the Estate the main limitations are:

r	restricted rooting depth
d	poor drainage and aeration
m	restricted capacity for storing available moisture
e	erosion risk
n	nutrient deficiency or imbalance

The ratings applied to the soil mapping units are summarised in Table 4.1. These ratings apply to dominant soil types within the unit. An individual site may differ from that of the mapping delineation in which it falls, although not by more than one class. The ratings for individual sites are given in the summary database in Annex 1.

The areas of the suitability classes for irrigated tea are summarised in Table 4.2 (a). A large proportion of the 1530 ha of highly suitable Class S1 land occurs in large continuous tracts on the Ngwazi and Nzivi blocks of the Estate. The airstrip occupies about 9 ha. There are also areas of land of moderate or better suitability in the north of the estate, but the pattern there is more broken and intricate.

4.3 LAND SUITABILITY FOR RAINFED FUELWOOD GUMS

The proposed new tea factory will have a considerable demand for energy, and plantations of purpose-grown fuelwood gums is the currently favoured option for its supply. The gum plantations are to be located on areas not required for tea development, and are of lower priority.

The gum species most likely to be planted is *Eucalyptus saligna/grandis*. This is a productive and robust species, and appears to be able to yield satisfactorily in Mufindi and elsewhere on soils that have moderate limitations of rooting depth or drainage (Allen 1986). The gum ratings assigned to the soil mapping units in Table 4.1 are therefore generally less stringent than those for irrigated tea. It is assumed that most of the land rated as Class S1 for tea will go under that crop and will not be available for gum plantations. The gum ratings for such land are given in brackets on the land suitability map (Annex 4, Map 2) and in Tables 4.1 and 4.2.

Table 4.1 Land Suitability Ratings of Soil Mapping Units Ngwazi Estate

Map Unit	Intensively managed irrigated tea	Rainfed fuelwood gums
Nz	S1	(S1)*
Nz(m)	S1	(S1)*
Nz(g)	S1	(S1)*
Mk(d)	S2m	S1
Mk	S2m	S1
No	N2r	S3r
Lg	S3r	S2r
Mk/Lg	S2r	S2r
He	S2en	S2en
Kg	S2d	S1
Ng	S2d	S1
Ng/Kg	S2d	S1
Bc	N1d	N1d

* These are rated as Class S1 for irrigated tea, the priority crop.

Table 4.2 Extent of Land Suitability Classes, Ngwazi Estate

Crop Suitability Class			Extent ha	Extent % of total survey area
(a) Irrigated tea				
	Class	S1	1530	60.4
		S2m	157	6.2
		S2r	184	7.3
		S2en	117	4.6
		S2d	268	10.5
		Class 2 subtotal	726	28.6
		S3r	42	1.7
		Total suitable	**2298**	**90.7**
		Nld	152	6.0
		N2r	84	3.3
		Total unsuitable	**236**	**9.3**
		TOTAL	2534	
(b) Rainfed gums				
	Class	(S1)*	(1530)*	(60.4)*
	other	S1	425	16.8
		S2r	226	8.9
		S2en	117	4.6
		S3r	84	3.3
		Total suitable land available	**852**	**33.6**
		Nld	152	6.0
		TOTAL	2534	

* These areas are rated class S1 for irrigated tea, the priority crop, and are assumed not to be available for gums.

The map and Table 4.2 show that most of the estate is assessed as capable of growing gums satisfactorily. Exclusion of the larger blocks of the best tea land means that gum plantations are likely to be concentrated in the north of the estate.

4.4 LAND SUITABILITY FOR OTHER USES

The ToR require that land suitability for the factory and housing should also be indicated. In discussions in the field, it was indicated that these uses have lower priority.

These installations will be located so as to minimise encroachment on to land suitable for irrigated tea. On this basis, the proposed factory site on Factory Hill seems satisfactory, as this is a complex area of gravelly soils with only moderate potential for irrigated tea.

The location of housing is a complex issue involving water supply, access to transport, access to services, security, distance from work, and provision of plots for food shambas, amongst other things. It will clearly be preferable to concentrate housing as far as possible on the less favourable tea soils in the northern part of the estate. However it is likely that at least some housing will have to be located on good tea soils in the Ngwazi and Nzivi blocks. The existing New Camps housing area on Ngwazi block (square H3) is already located on soils of the modal Nzivi type, rated as Class S1 for irrigated tea.

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APPENDICES

APPENDIX 1

TECHNICAL PROPOSAL

SOIL SURVEY, LAND AND WATER RESOURCES AND IRRIGATION ASSESSMENT OF NGWAZI TEA ESTATE, TANZANIA

A1.1 BACKGROUND

The Estate has a total area of approximately 2500 hectares of which a proportion has recently been degazetted from forest reserves. A detailed soil survey of the whole of Ngwazi is requested together with an assessment of the water resources available to the Estate and so the feasibility and value of irrigating the tea crop.

A1.2 TERMS OF REFERENCE

Although no specific terms of reference have been given to the consultants, the following are proposed for the project.

In order to satisfy the general objectives of the project a sequence of stages is required. These are listed briefly below as terms of reference.

1. To evaluate and map the soil types.

2. To analyse, quantify and interpret the soil physical and chemical characteristics of the major soil types.

3. To identify the areas of land most suitable for tea production, planting of gums, and location of housing and a factory.

4. To assess the water resources available to the Estate in relation to irrigation requirements and to advise on the storage and utilisation of this water.

A1.3 METHODOLOGY

The work required to fulfil the terms of reference is described below:

1. The initial stage of the project will involve a field study of the physical and chemical properties of the major soils on Ngwazi Estate, subdividing them into soil types of similar properties and management characteristics. Once identified, the extent of these soil types will be assessed by regular observations and delineated on a soil map. Other environmental information necessary to predict the suitability of each soil type for the growth of tea and alternative crops, and to predict irrigation needs will also be collected.

   The soil map will provide the spatial basis for extrapolating the analytical data from soil samples, for predicting land suitability for tea and its irrigation need, and for identifying soil nutrient requirements. It will provide a fundamental scientific base for the management strategy recommended for the estates.

2. A comprehensive range of soil analyses will be undertaken using both disturbed and undisturbed samples taken from exposed soil profiles representing the kinds of soil identified on the map. It is likely that most analyses will be undertaken in Kenya but a number of check analyses will be carried out in the United Kingdom in the quality assured laboratories of the Soil Survey and Land Research Centre. A detailed characterisation of the major soil types will be made with laboratory analysis of particle-size distribution; water retention capacity and available water content; bulk density and porosity; pH; cation exchange capacity; exchangeable aluminium; major nutrients and selected trace elements; organic carbon; and available phosphorus.

3. The suitability of the land for tea, with irrigation, will be assessed. This will involve interpretation of the data collected from 1 - 2 above, will also incorporate the conclusions and extensive information accumulated in experimental trials in Tanzania by Silsoe College as well as other relevant research in East Africa.

4. Evaluation of the land for growing gums and suitable locations for a factory and housing will be identified.

5. The water resources of the Estate will be estimated by developing a spreadsheet based model for the Estate catchments, the lake and the irrigated areas. Rainfall data will be obtained from records at the research station and by statistical correlation to longer-term stations nearby. Estimates of run-off factors and reservoir capacity curves will be made during the site visit. The model will be used to examine the effects of varying the dam crest level, tea area and pumping from downstream on the reliability of supply.

6. The final stage of the work will draw together all the results of the field evaluation, research and interpretative work. At this stage, the soil map will be of prime importance for stratifying land areas for tea and irrigation suitability.

A1.4 PRODUCTS

Arising from the work described above will be the following products:

1. A set of detailed records describing the soils of Ngwazi at each point where the observations were made; the location of these observations will be georeferenced and recorded on the map of the Estate.

2. A soil map on transparent film showing the distribution of soil types at Ngwazi and a brief explanatory legend.

3. A comprehensive set of analyses describing the properties of each soil type identified based on samples taken from typical soil profiles selected as a consequence of the soil survey and will be described in detail.

4. Five copies of a report summarising: the project methodology; the kind of soils identified and their properties as revealed by profile description and analysis; other relevant environmental information including climate; assessment of the suitability of the land for tea; the water resources available to the Estate and their use for irrigation; recommendations for water resource development and longer-term data collection and analysis.

5. Further maps displaying the spatial distribution of the suitability of land for tea, suitability for gums and potential sites for the location of a factory and housing.

Delivery of draft maps and reports will be made within six months of the completion of the fieldwork.

APPENDIX 2

SOME TECHNICAL ASPECTS OF THE SOIL SURVEY

A2.1 INTRODUCTION

The methods and main findings of the soil survey are reported in Chapter 3 of the main report. This appendix discusses some of more detailed technical aspects.

A2.2 SOIL TERMINOLOGY

Texture refers to the size of the individual particles that make up the fine earth fraction (<2 mm) of the soil and the proportions in which they occur. The coarsest particles are **sand**, and they give a gritty feel when aggregates that form the soil structure are wetted and broken down by rubbing between fingers and thumb. The sand component can be divided into **very fine**, **fine**, **medium** and **coarse grades**. **Clay** particles are the finest of all and give the soil its body and stickiness. Particles intermediate in size between sand and clay are termed **silt**, which give the moist soil a silky smooth feel. The relative proportions of sand, silt and clay give a soil its textural class (Fig. A2.1).

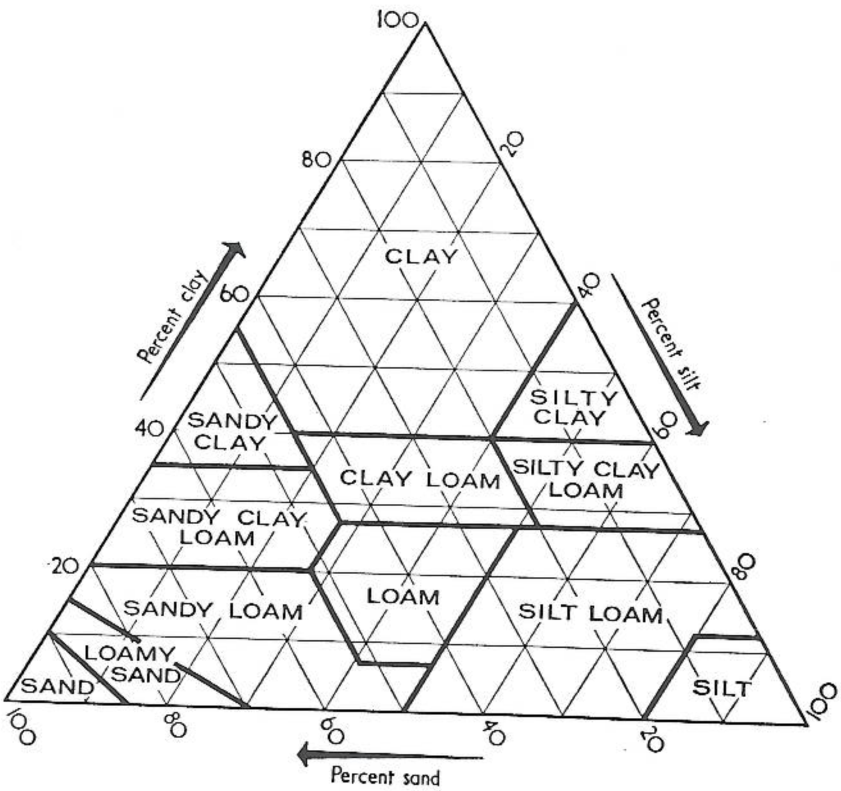

Figure A2.1 Textural classes

In this report (*e.g.* Annex 1) the following abbreviations are given to the texture classes:

C	clay	S	sand
CL	clay loam	LS	loamy sand
ZC	silty clay	SL	sandy loam
ZCL	silty clay loam	SCL	sandy clay loam
ZL	silt loam	SC	sandy clay
L	loam		

The following abbreviations refer to the sand grades:

vf	very fine	f	fine
m	medium	c	coarse

Peat (P) soil material consists of more than 50% organic matter (Hodgson 1976). It may be humified, semi-fibrous or fibrous depending on the degree of decomposition. **Loamy peat** (LP) or **sandy peat** (SP) has 50 to 35% organic matter content; **peaty loam** (PL) between 35 and 20%. Below this the mineral soil material is prefixed by **humose** (h) down to 10% organic matter for clays and 6% organic matter for sands.

Mottles are ochreous or grey spots in a brown or grey soil matrix and can indicate degree and duration of waterlogging in a soil. However, mottling may bear little relationship to the present soil moisture regime, being a relict feature of an earlier regime.

A2.3 SOIL CLASSIFICATION AND CORRELATION

It had initially been intended to classify and map the soils using conventional taxa, especially soil series. Discussion at the Institute of Resource Assessment, University of Dar es Salaam with Mr J P Magoggo, Soil Surveyor of the National Soil Service, Mlingano, on 26 January 1993 established that:

- there are no existing officially named soil series in the Mufindi area of the Southern Highlands.
- the Tanzanian soil classification is based on the Revised Legend of the FAO/UNESCO Soil Map of the World (FAO 1990a).
- the National Soil Service would welcome any technical, non-commercial details of our survey that BBT feels able to release.

Unfortunately it was not possible in the time available to devise a simple classification of the soils of the Estate that is both useful for the assessment of land for irrigated tea and is completely compatible with the FAO Legend. This is mainly due to the different depth frames of reference. The FAO Legend focuses entirely on the top 1.25 m of the profile, all that is normally examined in most soil surveys and some of its depth boundaries are as shallow as 50 cm. We were augering deeper than is usual, and considering the soil characteristics, especially in relation to moisture retention, down to three metres. Accommodation of criteria based on the deeper horizons would tend to subdivision of FAO-based classes, and accommodation of FAO top metre criteria would lead to subdivision of deep-defined classes. This would lead to considerable and unhelpful proliferation of soil classes, so the FAO criteria were regretfully abandoned. Because of this we did not name our classes as 'soil series', as some of them transgress FAO unit and subunit boundaries, and instead use the non-specific term 'soil type'.

Although the systems are not wholly compatible, the approximate equivalents of the soil types in the units of the FAO Legend are summarised in Table A2.1 The approximate equivalents in the American Soil Taxonomy (Soil Survey Staff 1975 and 1992) are also given. Although not an official system in Tanzania, Soil Taxonomy is used in other parts of Africa and the tropics.

Table A2.1

Approximate Equivalents of Soil Types of The Ngwazi Estate in International Systems of Soil Classification

Soil Type	Approximate Equivalent: Legend of Soil Map of the World (FAO 1990a)	Approximate Equivalent: Soil Taxonomy (Soil Survey Staff 1975 & 1992)
Nz Nz(m) Nz(g)	Haplic Ferralsol, Xanthic Ferralsol	Typic Haplustox, Xanthic Haplustox
Mk(d)	Haplic Ferralsol, Xanthic Ferralsol, Plinthic Ferralsol	Typic Haplustox, Xanthic Haplustox, Plinthic Haplustox
Mk(s)	Plinthic Ferralsol Ferralic Cambisol	Plinthic Haplustox Ustoxic Dystropept
No(d)	Petroferric Plinthic Ferralsol	Petroferric Haplustox, Plinthic Haplustox
No(s)	Petroferric Dystric Plinthosol, Petroferric Plinthic Ferralsol	Petroferric Haplustox, Petroferric Dystropept
Lg(d)	Haplic Ferralsol, Xanthic Ferralsol, Ferralic Cambisol	Typic Haplustox, Xanthic Haplustox, Ustoxic Dystropept
Lg(s)	Ferralic Cambisol	Ustoxic Dystropept
He(d)	Haplic Ferralsol	Typic Haplustox
He(g)	Haplic Ferralsol, Plinthic Ferralsol	Typic Haplustox, Plinthic Haplustox
Kg(d) Kg(s)	Xanthic Ferralsol, Haplic Ferralsol	Xanthic Haplustox, Typic Haplustox
Ng	Haplic Ferralsol, Xanthic Ferralsol	Typic Haplustox, Xanthic Haplustox
Bc	Gleysol, Umbric Fluvisol, Ferralsol	Tropaquept, Tropic Fluvaquent, Haplustox

Even the fairly loose correlations in Table A2.1 involve a number of assumptions and approximations: –

- the majority of the soils appear to be Ferralsols (Ustox in Soil Taxonomy) on account of having a diagnostic ferralic (oxic) horizon in the subsoil. In fact some of the subsoils fail to meet all of the requirements of a ferralic horizon as they have silt:clay ratios greater than 0.2. These horizons fit the Soil Taxonomy definition of an oxic horizon rather better, as this does not stipulate a maximum silt:clay ratio.

- the assignment of some of the Makabila and Ngongwa soils to plinthic subgroups depends on the acceptance of the ferruginous gravel as plinthite. It fits the concept in that it is either derived from, or can develop into, material that can indurate to form massive petroferric material, but does not match the definitions in some other respects.

- the classification of Longstaff (shallow) as a Ferralic Cambisol (Ustoxic Dystropept) assumes that the underlying red and yellow varicoloured material is very intensively weathered rock, and has not been transformed to plinthite, and will not irreversibly indurate on exposure and desiccation.

- for the climatic criteria in Soil Taxonomy it is assumed that all of the soil temperature regimes are isomesic or warmer, and that all of the soil moisture regimes are ustic, except in the Bottomland Complex.

- none of the soils has geric (Acric and Anionic are the approximate Soil Taxonomy equivalents) properties even though effective cation exchange capacities are very low in some subsoils.

The problems of correlating even a small number of soil types from a limited area to the classes of the international systems indicate the complexity of using either of them as a basis for national soil classification.

A2.4 AVAILABLE MOISTURE CAPACITIES AND TEA IRRIGATION INTERVALS

One of the features of an earlier Silsoe/SSLRC report (Weatherhead *et al.* 1992) and the experimental work at Ngwazi (Stephens 1991, Burgess 1992) is that quite low (40-100 mm) soil moisture deficits appear to be critical for tea yields, even on soils with rooting zones several metres deep and apparent root zone available moisture capacities of up to 500 mm (Ngwazi soil type, Profile RWP 1990). After initial doubts about the determinations of available moisture, it now appears that shoot growth, and hence tea yield, is very sensitive to fairly slight moisture depletion within the upper few decimetres. It is therefore necessary to irrigate frequently and keep the upper horizons close to field capacity if the potential for high yields is to be realised. In this case it may be asked, why bother surveying for and characterising soils with deep rooting zones and high available water capacities? There are two possible benefits of having the crop on deep, medium textured well drained soils.

Firstly, it is probable that the yield reduction due to mild moisture stress is lessened on deep and well watered soils. Secondly, the survival and vigour of the tea plants in the event of an interruption or shortfall of irrigation is likely to be enhanced on well watered soils, even if the crop is not yielding profusely during the period of moderate or severe stress. This means that resumption of high yields is likely to be more rapid and more complete, once full irrigation is back in operation.

A2.5 THE SOILS OF AREAS OF POOR TREE GROWTH

The 1979 aerial photograph shows a number of areas in the Nzivi and northern blocks of the estate where the planted pines or wattles appear to be languishing. Visits to the more prominent of these apparent trouble spots showed that the poor and patchy growth has usually persisted, affecting the second rotation in the case of the pine plantations. The soils of the largest areas affected were specifically examined to see if there are obvious and simple edaphic reasons for the poor growth.

1. **White Rock Peninsula – Square E4**

   This is the largest area of poor pine growth. The 1979 photograph shows the patch to lie entirely on the eastern side of the main forest road down the centre of the peninsula. By 1993 and into a new rotation of pines, the problem has spread westwards across the road, with many gaps, severely kinked new shoots, a tendency for multiple 'candelabra foxtailing', and slightly chlorotic looking light green needles. The soils were examined in augerings (Nos C57-C60) and a pit (Profile PC2). All show the soils of the area to be of the modal Nzivi type, indistinguishable from those of much of the rest of the Nzivi block. Augering in the base of profile pit PC2 reached to 5.8 m, and showed no sign of a mechanical or drainage barrier to very deep rooting. The absence of obvious soil morphological indicators of an edaphic constraint, and the fact that the affected area seems to be slowly expanding suggests that the problem is a soil-borne pest or disease, possibly eelworms (T.C.E. Congdon, pers. comm. 1993). Another possibility is a micronutrient deficiency but this seems less likely in an area of uniform parent materials and soils. As this patch occurs in the middle of one of the most extensive and promising blocks for irrigated tea development, it warrants further investigation, particularly to check that the problem is not going to affect tea plants.

2. **Nzivi block -- square D4**

This is an area of poor growth with a rather striated appearance on the 1979 aerial photograph. It is fairly low-lying, and the road has patches that are permanently wet and muddy. The Forestry Department has dug shallow drains, but pine growth is still poor. Augerings showed that there are drainage (R6) and ferricrete (C107) impediments to deep rooting. A pit (Profile PR2) showed pale matrix colours, mottles and fresh-looking iron accumulations, all indicators of intermittently impeded drainage. However it should be noted that the profile pit was never seen to contain water, even after heavy rain.

3. **Southwestern slope of Factory Hill -- square D5**

This is a relatively small area of poor growth. It lies at the head of a minor valley draining into the lake. Augering (R111) shows that it is a fine textured and compact soil, with pale matrix colours, mottling and some ferruginous nodules and concretions in the second metre. All of these are thought to indicate intermittently impeded drainage.

4. **The top of Factory Hill -- square D6**

This area was used by workers of the Forestry department as a maize shamba until fairly recently. There are still some maize stovers on the ground, and remnants of a shelter or hut. Augerings (C72 and C73) showed the soils to be of the Nzivi type, possibly gravelly in the third metre but free of any physical or drainage impediment to rooting in the upper two metres.

5. **Northwestern slope of Factory Hill -- square D7**

This is an area with a spotty appearance on the aerial photograph, rather than large swathes of blanks or stunting. Augering (C115) showed the soil to be well drained, but with dense gravelly and gritty subsoil, which was unaugerable below 185 cm. The main impediment to penetration was the high frequency of quartz gravel and small stones in the strongly weathered rock below 160 cm. The ferruginous gravel above (at 135-160 cm) was fairly thick but penetrable. This soil is similar to others on the upper slopes of Factory Hill, an intergrade between the Makabila and Longstaff types, and with a tight and compact subsoil.

6. **Southern and southeastern lower slopes of Makabila Hill -- squares F5 and G5**

This is an area of wattle that has been planted across the slope in contour belts. In contrast to the vigour of this species on the rest of the Estate, the wattle is patchy and poor. As the slopes are rather steeper than elsewhere, it had previously been assumed that the soils have been impoverished by sheet erosion and that the land is slightly degraded. Augerings (R66-69, R153-4, R170) and a pit (Profile PR1) do not show particularly pale coloured, low organic matter topsoils. Nor is sheet erosion noticeably more severe than on other soils on lower slopes in the northern block. The poor growth is mostly on the red and fine soils of the Hehe type, which may have significant capacity for phosphate sorption and fixation, and impose P deficiency on their vegetation. Apart from that and the possibility of an imbalance in the micronutrients, we cannot offer a reason for the poor wattle growth. Despite their apparently promising morphology, we have taken account of the poor wattle by downrating the suitabilities of these soils to S2en for both irrigated tea and rainfed gums.

NOTES