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Bhutan Soil Survey Project  
National Soil Services Centre, Simtokha  
Research, Extension, and Irrigation Division  
Ministry of Agriculture

TECHNICAL REPORT  
ON THE DETAILED SOIL SURVEY OF  
KHANGMA RNR-RC

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## CONTENTS

SUMMARY.....	4
ACKNOWLEDGEMENTS.....	4
ABBREVIATIONS AND GLOSSARY.....	5
1. INTRODUCTION.....	7
1.1 Bhutan Soil Survey Project .....	7
1.2 Khangma RNR-RC .....	7
1.3 Aims of the Khangma RNR-RC soil survey .....	7
2. SURVEY AREA .....	8
2.1 Location and extent.....	8
Figure 2.1 Location map of the survey area.....	8
2.2 Climate .....	9
2.3 Geology and soil parent materials.....	9
2.4 Topography and drainage.....	9
2.5 Land use and vegetation.....	10
Table 2.2 Climatic summary for Kanglung 1990-1998.....	10
Table 2.1 Climatic summary for Khangma RNR-RC.....	11
3. PREVIOUS SOILS INFORMATION.....	12
4. METHODS .....	13
4.1 Field.....	13
4.2 Mapping .....	14
4.3 Laboratory.....	14
5. SOIL CLASSIFICATION, CHARACTERISTICS AND CORRELATION.....	15
5.1 Soil classification .....	15
5.2 Characteristics of soil classes at Khangma, RNR-RC.....	15
Table 5.1 Soil classes at RNR-RC site, Khangma.....	16
5.3 Soil correlation.....	19
Table 5.2 Ranges of chemical analyses, by soil classes, Khangma, RNR-RC .....	20
Table 5.3 International correlation of soil classes at Khangma RNR-RC .....	21
Table 5.4 Geotechnical correlation of soils of Khangma RNR-RC .....	21
6. SOIL DISTRIBUTION AND MAPPING .....	22
6.1 Soil distribution.....	22
6.2 Soil mapping units .....	22
Table 6.1 Composition of soil mapping units at Khangma RNR- RC .....	22
Table 6.2 Areas of soil mapping units, Khangma RNR-RC .....	22
7. OVERVIEW AND IMPLICATIONS.....	23

7.1	Overview of soils .....	23
7.2	Implications of results.....	23
	REFERENCES .....	24
APPENDIX A:	SUMMARY OF SOIL ANALYSES METHOD USED AT SPAL .....	25
Table APPA.1	Recommendations for interpretation of SPAL soil analyses .....	27
APPENDIX B:	SOIL PROFILE DESCRIPTIONS AND ANALYSES .....	28
Table APPB.1	Summary of soil profiles .....	28
APPENDIX C:	CORRELATION OF KHANGMA SOILS .....	62
APPC. 1	Soil classification and correlation in Bhutan. ....	62
APPC. 2	General criteria.....	62
APPC. 3	Correlation of Khangma soils .....	63
APPENDIX D:	SOIL MAP OF KHANGMA RNR-RC.....	64

## SUMMARY

The fieldwork for a detailed soil survey for the Renewable Natural Resources Research Centre, Khangma in the Eastern Region was carried out during April 1997. This was the fifth soil survey done by the Bhutan Soil Survey Project, and was partly used as field training exercise.

The survey area covers about 35 ha (88 acres) in the catchment of Gong Ri. It lies about 3 km south of Kanglung. The area is underlain by deep bouldery colluvium (hill wash) derived from Thimphu Formation gneiss. Most of the area is located on the middle section of a long northwest-facing slope down from Yonphula. At present the area is used for research and seed production of rainfed improved pastures, field crops and some tree crops.

The soils were examined in 120 routine observations and 16 detailed description and sampling profiles.

Many of the soils have buried topsoils, presumably due to recent natural hillwash or to agricultural terracing. In some profiles the buried topsoils are close to the surface and merge with the modern topsoils, making the surface layers darker and thicker than usual. In other profiles the buried topsoil is located deeper in the subsoil and is separate from the modern topsoil.

The soils are divided into six soil classes. There are scattered areas of very shallow soils, which are less than 50 cm deep to weathered or hard rock. The overlying soils have dark brown sandy loam – loam topsoils, and narrow subsoils of brown, stony, sandy loam. The main hill soils are deeper but not very varied. They mostly have dark brown sandy loam topsoils over brown and yellowish brown sandy loam subsoils. They are divided into four classes according to the presence and absence of common boulders, and whether the depth to weathered rock is more or less than one metre. There are also small areas of wet soils, with predominantly grey colours. All of the soils are slightly acid and have low-moderate contents of exchangeable cations, including potassium. Topsoil contents of organic matter, nitrogen and available phosphate are variable, and partly depend on the recent cultivation and fertilisation history of the site.

The soil pattern shows a certain amount of random variation, and some of the area is mapped as complex soil units. There are also two miscellaneous mapping units: disturbed ground (buildings, roads etc.), and the jumbled gully wash of rocks in the drainage line that runs through the Centre.

We have little data so far on the soils of Eastern Bhutan, but the soils of the Centre appear to be typical of large areas of agricultural land in the region. Experimental results on the Centre should not be invalidated by atypical soils. Because the soils of the Centre do not vary greatly, they need not be an important factor in the siting of facilities and different kinds of research trials.

## ACKNOWLEDGEMENTS

The field work for this soil survey was done by Kado Tshering, H B Tamang, Tsheten Dorji and I C Baillie. This report was prepared by Pema Wangmo. The mapping was done by Deki Wangmo of the Geographic Information System Unit, of the Land Use and Statistics Section, of the Planning and Policy Division, of the Ministry of Agriculture, Thimphu.

We are grateful to the Director, staff, and labourers of the Khangma RNR-RC for their logistic support and assistance during the fieldwork and especially to Mr J N Pradhan, who acted as our liaison officer.

## ABBREVIATIONS AND GLOSSARY

(Simple metric units and chemical element symbols are not included)

AAS	Atomic absorption spectrophotometry
ACB	Austrian Co-operation Bureau
AMC	Agricultural Machinery Centre
AmOAc	Ammonium acetate (extractant for exchangeable cations and for measuring CEC)
Av	Available
asl, a.s.l.	Above sea level
BS%	Base saturation percentage
BSSP	Bhutan Soil Survey Project
C	Clay
ca	Approximately
CEC	Cation exchange capacity
CL	Clay loam
Colluvium	Local hillwash, moved by surface erosion or slow non-glacial creep processes.
Creep	Slow gravitational mass movement of colluvium downslope.
Danida	Danish International Development Assistance.
Dzongkhag	Administrative district
EC	Electrical conductivity
ESCAP	Economic and Social Commission for Asia and the Pacific (agency of United Nations)
Exch	Exchangeable (for cations)
Extr	Extractable (for soil nutrients)
FAO	Food and Agriculture Organisation of United Nations
FCB	Food Corporation of Bhutan
fe	fine earth (particle size < 2mm)
FEZAP	Far Eastern Zone Agricultural Project
FYM	Farmyard manure
Geog	Block or sub-district, administrative subdivision of Dzongkhag.
GIS	Geographical information system
Gley	Sol that is permanently wet and poorly aerated, and has predominately greyish colours, due to reduction of free iron to ferrous valency state. May have local oxidising conditions giving rust - coloured mottles, especially around root channels.
GSI	Geological Survey of India
GPS	Global positioning system
Gully wash	Rapid movement of coarse unlayered materials down beds of steep streams.
ha	Hectare
HCl	Hydrochloric acid
L	Loam
MAF	(former) Ministry of Agriculture and Forestry (now MoA)
me	milli-equivalent (unit for exchangeable cations)
me%	milli-equivalents per 100 g fine earth
MoA	Ministry of Agriculture
mS/cm	milliSiemens per centimetre (unit of electrical conductivity)
MTI	Ministry of Trade and Industry.
MLT	Miscellaneous Land Type
Nd	No data.
NH <sub>4</sub> OAc	Ammonium acetate
NSSC	National Soil Services Centre, REID, Semtokha
OC	Organic carbon
OM	Organic matter
P	Phosphate

PDOP	Position dilution of precision (measure of GPS accuracy)
pH	Measure of acidity - alkalinity
PM	Parent material
PPD	Planning and Policy Division, MoA
ppm	Parts per million
PSC	Particle size class (Soil Taxonomy)
RAMC	Regional Agricultural Machinery Centre
REID	Research, Extension and Irrigation Division, of MoA
RGOB	Royal Government of Bhutan
RNR	Renewable natural resources (includes agriculture, animal husbandry and forestry, in RGOB sense)
RNR-RC	RNR Research Centre.
RPPC	Regional plant protection centre
S	Sand
Saprolite	Soft weathered rock beneath solum, often reddish.
Si	Silt
Sk	Skeletal (high stone content)
SMU	Soil mapping unit
SoB	Survey of Bhutan
Solum	True soil, with no remaining rock structures.
sp, spp	Species (singular & plural)
SPAL	Soil and Plant Analytical Laboratory, REID, Semtokha.
ST	Soil Taxonomy (US system of soil classification)
Surface wash	Movement of individual soil particles by surface runoff.
Tr	Trace
TEB	Total exchangeable bases (= exchangeable Ca + Mg + Na + K)
TFMP	Third Forestry Management Project
USDA	United States Department of Agriculture
WR	Weathered rock
w/w	% by weight
X	Exchangeable (for cations)
Z,Zi	Silt

## 1. INTRODUCTION

### 1.1 Bhutan Soil Survey Project

The Bhutan Soil Survey Project (BSSP) was set up by an Agreement signed in September 1996 by the Royal Government of Bhutan (RGOB) and Danish International Development Assistance (Danida). It was initiated because of a perceived need for systematic information about the nature and distribution of the soils of Bhutan. The Project is part of the National Soil Services Centre (NSSC) of the Research, Extension and Irrigation Division (REID) in the Ministry of Agriculture (MoA). It began field activities in June 1997.

The emphasis in the initial stages of the Project is on training of Bhutanese nationals as soil surveyors, and the establishment of a functioning soil survey organisation. The main method of training is on-the-job instruction and close supervision of actual soil surveys, carried through from initial planning to final presentation. In the early stages detailed surveys are best for instruction purposes. They enable soil patterns to be worked out by direct observation and with the minimum of extrapolation and assumptions. This survey for the Khangma Renewable Natural Resources Research Centre (RNR-RC) is the fourth of the detailed surveys/training exercises.

### 1.2 Khangma RNR-RC

Khangma is one of the four main RNR Research Centres in REID. It has a national mandate for the coordination of research in rainfed production systems. It also has a regional mandate to coordinate all RNR research in the Eastern region. Khangma has outlying sub-centres at Lingmithang at low altitude in Mongar Dzongkhag, which specialises in subtropical fodder crops and essential oils, and one at Pemagatshel, which is used for fodder trials. There is also a site at Wangkhar in Mongar Dzongkhag for the establishment of a new Centre, to include offices, workshops, stores, and some land for trial plots. The site has been demarcated, but has not yet been topographically surveyed. As with the other RNR-RC's, Khangma coordinates its research activities with the extension work in its region (REID 1995).

### 1.3 Aims of the Khangma RNR-RC soil survey

This detailed soil survey was undertaken with objectives of:

- Continued training in soil survey techniques for BSSP staff.
- Continued adjustment of standard soil survey practice to suit Bhutan conditions.
- Providing Khangma RNR-RC with detailed information on the nature and distribution of their soils.
- Indicating the extent of the applicability of research results on the soils of the Centre to soils in other parts of the region.
- Providing BSSP with further data for the development of a national soil classification, and for national and regional soil maps.

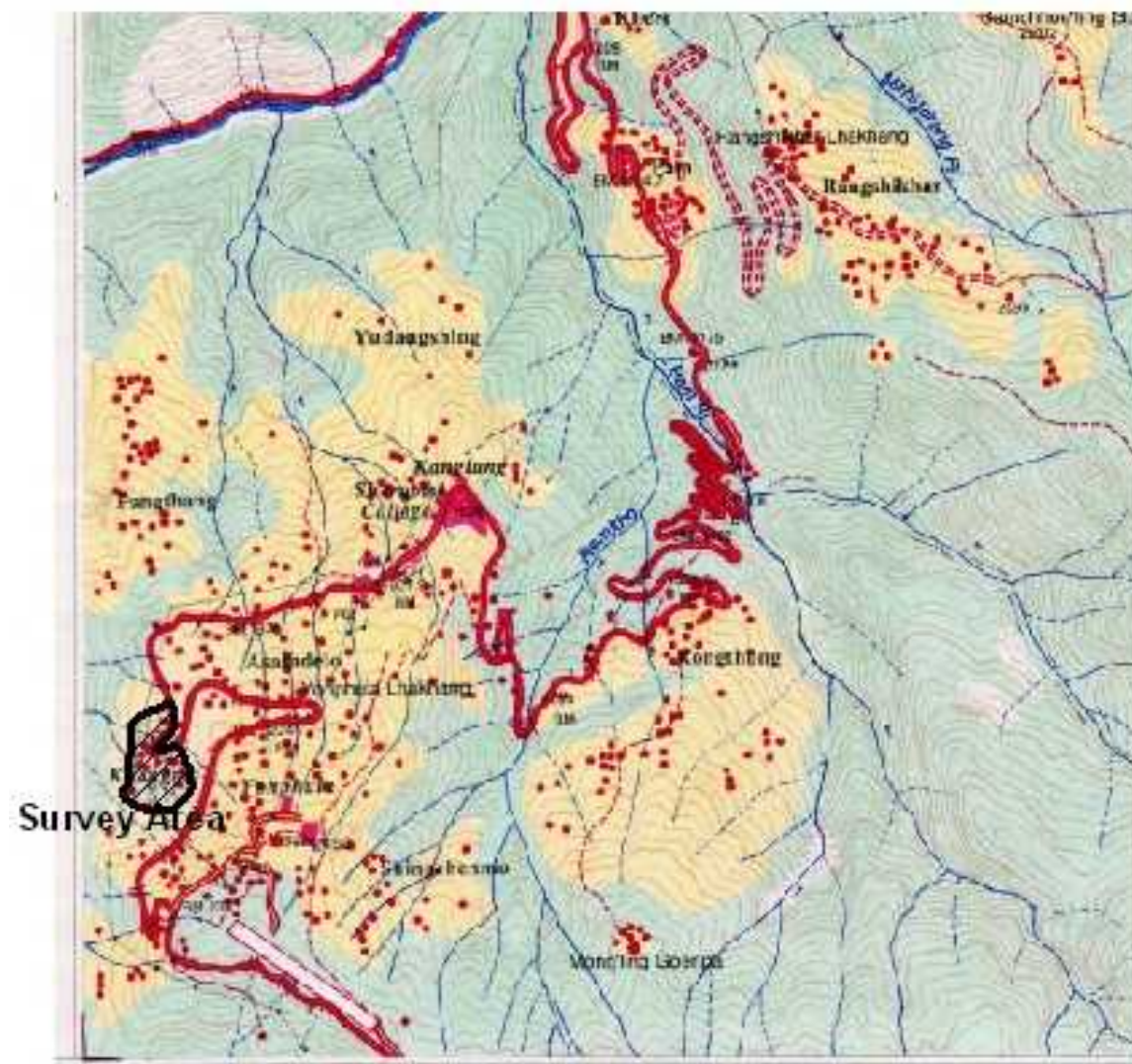
## 2. SURVEY AREA

### 2.1 Location and extent

Khangma RNR-RC is located to the east of the river Gong Ri (Dangme Chhu), about 3 km south of Kanglung. It stretches in latitude from 27°16.1' to 27°16.5' N and in longitude from 91° 30.0' to 91° 30.3' E. It is in Kanglung geog of Trashigang Dzongkhag, in the Eastern region. It is located on the blacktop Trashigang - Samdrup Jongkhar highway, about one hour's drive south of Trashigang. The site is elongated up-and-down slope, with a greatest length of about 1.25 km and greatest width of about 0.7 km. The Centre covers about 35.4 ha (87.5 acres).

The site was transferred to the RNR-RC in 1994. Before then the land was still under the ownership and direct management of MoA. It was used for improved pastures, the production and multiplication of potatoes and horticultural crops, and training courses. The Far Eastern Zone Agricultural Project (FEZAP) and the Third Forestry Management Project (TFMP) have offices at the Centre. The Regional Plant Protection Centre (RPPC), a Food Corporation of Bhutan (FCB) go-down, and the Regional Agricultural Machinery Centre (RAMC) are also located at the Centre. Figure 2.1 gives the detail of the location of the survey area.

Figure 2.1 Location map of the survey area





## 2.2 Climate

The Centre is located at about 2000 m a. s. l and has a warm temperate climate. Table 2.1 summarises the limited available meteorological data for the RNR-RC. Mean maximum temperatures range from about 15 °C in January to about 25 °C in July. Mean minimum temperatures range from about 3 °C in January to about 16 °C in July – August. Mean annual rainfall totals about 820 mm. About 74% of this (ca 600 mm) falls during the monsoon months of May – September, but showers can occur in all other months. The spring (March – April) appears to be somewhat wetter than the autumn and early winter (October – December). Due to the warm summer temperatures, evapotranspiration can exceed precipitation at any time of the year. However the rainfall and soil moisture replenishment in the monsoon are sufficient to sustain rainfed cropping.

Because the meteorological data from the Centre are limited, we also examined the fuller data for Kanglung. These are summarised in Table 2.2. Kanglung is slightly lower (about 1800 m a.s.l) than the RNR-RC, and slightly warmer. Mean temperatures rise from about 7° C in January to about 20° C in June and remain at about that level until September. Mean minimum temperatures are about 3° C in January, with only rare nights below freezing point. Mean maxima are about 23 – 24° C in June – September, and an absolute maximum of > 30° C has been recorded in September.

The mean annual rainfall at Kanglung is just under 1200 mm, ranging from 965 to 1350 mm for individual years. The rainfall is seasonal, with about a mean of 917 mm (77 %) falling in the monsoon months of May – September. The winter months are characterised by low rainfalls, and November – December are very dry. Winter monthly means range from about 20 mm in November and December to about 70 mm in January – April. The transition months of April and October are variable, being quite dry in some years, with April totals ranging from 30 to 125 mm, and October totals from 7 to 180 mm. The heaviest daily rainfalls, of about 130 mm/day, occur in the monsoon months of June and July but there are occasional heavy storms in October (up to 80 mm/day). The fuller rainfall data for Kanglung give considerably higher values than the limited data from the RNR-RC. Until superceded by fuller data from the Centre, Table 2.2 probably gives a truer picture of its rainfall than Table 2.1.

## 2.3 Geology and soil parent materials

The most recent geological description of Bhutan (Bhargava 1995) indicates that the Centre is underlain by rocks of the Thimphu Group. This accords with earlier general accounts (ESCAP 1991), and with the original geological survey reports (Ray & Ganesan 1983; Ray & Razan 1975). The dominant rock types in the Thimphu Group are highly metamorphosed gneisses, with mixed muscovite and biotite micas, plagioclase feldspars, and quartz as the main minerals. These rocks were greatly affected by the folding and shearing that occurred in the thrusting from the north during the intense Himalayan compressions and uplifts in the Tertiary.

Some of the soils on the Centre are residual and have shallow sola overlying weathered metamorphics. Most of the soil parent materials are hillwash (= colluvium). This has moved locally downslope by wash and creep. The colluvium is poorly sorted, with a range of particle sizes including many stones and boulders, and is not layered. The colluvium tends to contain a higher proportion of stones and boulders downslope, but even bouldery colluvia often have relatively stone-free surface layers. There is a strip of very bouldery gully wash in the bed of the stream that runs through the Centre.

## 2.4 Topography and drainage

The topography of the Centre is simple. The Centre lies on the middle section of a long slope down from Yonphula to the valley of Gunchikar Chhu, a true left (east) bank tributary of Gong Ri. The whole slope stretches from about 2900 m a.s.l at the Yonphula airstrip to about 900 m a.s.l at Gunchikar Chhu, giving a

total relief of about 2000 m. The Centre is located on the central section of this slope, and has an altitude range from about 1950 to about 2200m a.s.l. Slope gradients are moderately steep – steep, mostly in the range 20% - 60%. A steep stream runs through the Centre, from the eastern to the northwestern boundary.

## 2.5 Land use and vegetation

The Centre lies on a mesic northwest-facing slope in the warm temperate ecoclimatic zone, with evergreen broadleaf forest as its natural vegetation. There is an area of oak forest to the west of the Centre, which has not been cleared although it has been heavily exploited for timber, fuel and sokshing (leaf litter collection for livestock bedding and organic fertilizer).

However there is virtually no natural vegetation left on the Centre. It appears to have been used for rainfed arable cropping for many years. Much of the land has been terraced. The main crops were maize and potatoes. Since the establishment of the MoA demonstration farm and then the RNR-RC, a greater variety of crops have been cultivated. Current crops on the Centre include maize, potatoes, vegetables, tree fruit crops, improved pasture species, and a range of shrubs grown for soil conservation, such as *Leucaena* sp. Some of this cultivation is for research purposes, but some land is used for seed production.

Common weeds in the cultivated areas include *Artemesia myriantha*, *Pteridium aquilinum*, *Rumex nepalensis*, *Plantago erosa*, *Rubia cordifolia*, *Rubus elliptica*, *Solanum khasainum*, *Cannabis sativa*, *Pouzolzia hirta*, *Fagopyrum dibotrys*, and *Bidens pilosa*.

Table 2.2 Climatic summary for Kanglung 1990-1998

	J	F	M	A	M	J	J	A	S	O	N	D	Year mean or total
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Temperature °C

n (number of complete records)	9*	9*	9*	6*	8*	8*	8*	8*	8*	7*	7*	8*	4*
Mean	7.4	8.8	12.1	15.6	17.5	19.6	20.2	20.2	20.1	15.3	12.4	9.0	14.9
Mean minimum	3.1	4.8	7.1	11.3	13.2	16.0	16.7	16.5	17.1	10.2	6.8	3.9	10.6
Absolute minimum	-0.5	-0.5	0.0	2.5	7.0	11.0	13.5	14.5	11.0	4.0	2.5	0.5	-0.5
Mean maximum	11.7	12.8	17.0	19.9	21.8	23.2	23.6	23.9	23.0	20.3	17.9	14.1	19.1
Absolute maximum	17.0	19.5	23.0	26.0	27.0	29.9	28.5	28.0	30.1	25.0	22.8	19.0	30.1

Rainfall (mm)

n (number of complete records)	9*	9*	9*	6*	8*	8*	8*	8*	8*	7*	7*	8*	5*
Mean	22.3	31.3	46.6	71.6	115.5	255.7	257.3	216.3	127.3	60.4	2.3	7.3	1214
Monthly maximum	57.7	96.7	99.3	124.7	176.8	353.2	372.1	269.6	175.8	178.9	16.0	21.8	1354
Monthly minimum	0.3	4.8	6.5	28.4	50.7	167.4	150.6	125.3	25.6	7.4	0.0	0.0	965
Highest daily rainfall	34.4	32.0	31.2	24.2	43.6	129.4	129.4	63.7	45.8	80.5	5.4	12.0	129.4

\* Includes records with monthly summaries but incomplete daily data

Source: Data from MTI

Table 2.1 Climatic summary for Khangma RNR-RC

	J	F	M	A	M	J	J	A	S	O	N	D	Year mean or total
Mean minimum temperature °C	2.7	2.5	6.0	6.4	10.4	15.5	15.4	15.6	14.0	8.3	5.8	2.9	8.8
Mean maximum temperature °C	12.6	11.4	14.6	19.4	21.4	22.4	23.0	22.1	22.1	21.0	19.0	17.1	18.8
Mean rainfall (mm)	30.5	22.2	25.3	89.8	71.3	175.1	142.1	160.0	65.0	23.3	10.2	2.8	818

Sources: Data abstracted from Khangma Annual Reports for 1993 – 1995.

### 3. PREVIOUS SOILS INFORMATION

As far as is known, there have been no previous soil surveys of the Centre, or elsewhere in the Khangma area. As far as can be seen from SPAL records, no analyses have been done for soil samples from the Centre.

The area with soils data closest in distance and environmental conditions to Khangma is Drometse (also spelt as Drametse) geog in Mongar Dzongkhag. This was studied by LUPP (1996), as one of their planning areas. It was chosen as representative of the predominantly rainfed arable areas in Eastern Bhutan, similar to the farming systems investigated at Khangma. Drometse is about 7-8 km from Khangma in a straight line, but is on the opposite side of the deeply entrenched valley of Gong Ri (Dangme Chhu), and the road journey is about 40 km and takes well over an hour. Drometse geog covers about 10800 ha and has an altitudinal range from about 550 to about 3350 m a.s.l. It therefore includes areas that are lower, warmer and drier than Khangma, and also some that are higher, cooler and wetter. The lower slopes of the main valley of Gong Ri (Dangme Chhu) are considerably drier, and probably have annual rainfall totals only about one half of that at Khangma.

Drometse is underlain more or less equally by gneisses of the Thimphu Group and phyllites and quartzites of the Shumar Formation. There are 26 described profiles (25 of them sampled) in soils derived from gneissic parent materials. Granite and quartzite occur as subordinate components in the parent materials of some of these soils. Amphibolite, limestone or skarn rocks are not mentioned in the gneiss areas, but some of the soils are fairly red and have medium – fine textures. However most of the gneiss soils are greyish or yellowish brown sandy loams and sandy clay loams. They are moderately leached, with acid – slightly acid pH levels and low – moderate base saturations.

## 4. METHODS

### 4.1 Field

The fieldwork for this survey was done in April 1998. As the soil surveyors have several months of field experience, they did all of the routine field work independently. The time taken for this survey was shorter (one team/week) than for the Bathpalathang soil survey of a similar sized area (see BSSP Report 2(a) 1998).

The soils were examined on a routine basis at 120 sites, mainly with a 1.2 m Edelman auger, fitted with a 7 cm combination head where possible, but switching to a 7cm stony soil head where necessary. Duplicate augerings were done at 15 of the sites, where the first attempt was stopped by stones at less than 50 cm. A few of the routine examinations were done in road cuttings, cut back at least 15 cm to expose fresh soil. The routine sites were located at measured intervals (usually 25 m) along compass traverses, which started at points that could be identified on the large scale map of the Centre. The locations of the start points, some way-points, and the ends of the traverses were checked with a Magellan GPS.

For routine soil observations the following site data were collected:

Location, (GPS); general topography and site position; gradient (in %), aspect, length and form of the slope; solid and drift parent material; general land use and crops/vegetation; irrigation type; artificial land shaping features; fertiliser use, if known; surface stones; and site drainage.

The soils were described by natural layers (= horizons), as shown on the auger, with the following data collected for each horizon:

Munsell colour of matrix (in field moisture condition); number, size, contrast and colour of mottles; field texture; number, size and type of stones; moisture condition; and consistence on the auger.

The soils were described in more detail at 16 sites. Five of the detailed descriptions were done in freshly exposed cuttings and the rest in purpose-dug profile pits. The site data were the same as for the routine sites, with addition of a detailed description of surface features, including:

Microrelief, rock outcrops, litter, cracks, faunal activity, and capping.

The soils were described by horizons according to international conventions (FAO 1990). The data collected for each horizon were as in the routine descriptions, with the addition of:

Strength, size, and type of soil structures; number and size of pores, presence, thickness, and continuity of cutans (shiny coatings on surfaces of soil structural units); consistence in situ and in hand; number, size, and type of roots; reaction to HCl (to test for presence of free carbonate minerals); concretions of iron, manganese or other secondary formations; presence and effects of animals (wormcasts etc.); any other features (e.g. charcoal); and clarity and shape of lower boundary.

The main horizons of all profiles described in detail were sampled for analysis.

## 4.2 Mapping

The site is covered by the Survey of Bhutan (SoB) topographic sheet # 78 M -11, at scale 1:50 000. The basic topographic data were collected by the Survey of India in 1959 - 1961. The scale of this is too small to be used as a base for a 1:2500 soil map. However the main infrastructure of the Centre has been mapped by the Irrigation Section of REID, at a scale of 1:2500, and we used this as our base map.

The map is not tied into a national x-y spatial frame and no control points are shown. This means that, although it can be used for a free-floating drawing, it is difficult to locate this as a proper map in the national spatial frame in the LUSS GIS. SoB supplied some cadastral point data, but these did not tally with the LUSS coordinates and did not enable accurate location of the Centre in the GIS.

The infrastructure, sites of the soil augerings and profile pits, and the soil boundaries were plotted on hard copies of the base map. These data were digitised as three separate covers in the LUSS GIS: infrastructure, soil inspection sites, and soil boundaries. The printing scale of the soil map in the end pocket is 1:2 500.

## 4.3 Laboratory

The 74 soil samples collected from the main horizons of the 16 detailed profiles were analysed by the Soil and Plant Analytical Laboratory (SPAL) of the Research, Extension and Irrigation Division (REID) of the Ministry of Agriculture, at Semtokha. The methods of analysis used by SPAL are summarised in Appendix A.

The only methodological points that need to be mentioned here concern the measurement of cation exchange capacity (CEC) and calculation of base saturation (BS%). CEC is usually measured by saturating the soil with ammonium cations, and measuring the quantity adsorbed. This is referred to as CEC (NH<sub>4</sub>OAc). An alternative is to estimate CEC by summing the total exchangeable bases (Ca + Mg + K + Na = TEB) and the extractable aluminum. This is known as the 'effective cation exchange capacity' (TEB + Extr Al = ECEC). SPAL does not currently measure extractable Al in soils with pH (in water) greater than 4.5. As none of our Khangma samples are that acid, there are no determinations for extractable Al. In such cases the ECEC is identical with the TEB, and is not informative and has not been given in this report. Base saturation is the quotient TEB/CEC. If the TEB and the ECEC are identical (as is the case where there is no extractable aluminum), the 'effective base saturation' (EBS %) is automatically 100 %. Such values are not informative, and have not been given in this report. The base saturations in the soil class descriptions in Section 5.2 and in the soil profile data in Appendix B refer to TEB/CEC (NH<sub>4</sub>OAc).

## 5. SOIL CLASSIFICATION, CHARACTERISTICS AND CORRELATION

### 5.1 Soil classification

As BSSP is still in its early stages, soil classification is being done in an interim and ad hoc way for the present. Until we have formulated and tested a national system of soil classification, we are treating each survey as a separate task, and setting up simple local soil classes.

The soils of the Centre have a limited range of profile features, with many of them well-drained, brown, medium textured and of medium depth. The main variations are in the contents of stones and boulders, and in the occurrence of buried topsoils. They are less uniform in their chemical characteristics but the chemical variations do not appear to be systematic.

The soils are separated into six classes, based on field features, as summarised in Table 5.1. They are:

- Very shallow, well-drained hill soils
- Bouldery, well-drained hill soils, subdivided into deep and moderately deep classes
- Boulder-free, well-drained hill soils, subdivided into deep and moderately deep classes
- Imperfectly and poorly drained hill soils.

There are also areas of disturbed ground and gully-wash, which are not treated as proper soil classes.

### 5.2 Characteristics of soil classes at Khangma, RNR-RC

#### 5.2.1 Buried topsoils.

A feature of all of the soil classes is the frequent but patchy occurrence of buried topsoils. Some of these appear to be natural, and are caused by irregular hillwash. Others are probably artificial, and were formed during the construction of agricultural terraces. Some of these dark-coloured organic horizons are located deep in the subsoil and have brown or reddish yellow subsoil horizons above them. They are therefore quite separate from the modern topsoils. Others are quite shallow, and merge with the modern topsoils. These cases can usually be distinguished from simple topsoils by a darkening in colour, rather than lightening, in the lower part of the combined surface layers. The combined dark layers also tend to be quite thick, often more than 25 cm deep.

#### 5.2.2 Very shallow soil (VS).

These soils are not extensive but patches have been mapped in all the sections of the Centre. They have been described in detail and sampled in one profile (see PC002 in Appendix B).

These soils are very shallow by definition, with hard or weathered rock at less than 50cm from the surface. In the described profile, the topsoil is brown coarse sandy loam. There is a narrow subsoil horizon of brownish yellow sandy loam between the topsoil and the weathered rock. In other profiles the topsoils grade directly into variegated red, yellow and grey weathered gneiss.



The single analysed profile (PC002) has moderate topsoil organic carbon and a good C:N ratio. Topsoil available phosphate is high. This is not due to recent fertiliser application, as this site has not been cultivated. The soil is slightly acid, and has low – very low exchangeable base saturation, especially in the subsoil. However exchangeable potassium contents are moderate.

Table 5.1 Soil classes at RNR-RC site, Khangma

SOIL CLASS		Main Features	Representative profile and analyses (see App. B)
Code	Name		
Well drained hill soils.			
VS	Very shallow, brown to yellowish brown hill soil.	Brown coarse sandy loam to loamy sand topsoil; over weathered rock within 50 cm.	PC002
B	Shallow, bouldery, brown to reddish yellow hill soil.	Dark greyish brown sandy loam topsoil; over bouldery brown to yellowish brown sandy loam subsoil; over weathered rock within 50 – 100 cm.	PK036, PK045
SF	Shallow, boulder-free, brown to strong brown hill soil.	Grey to very dark greyish brown sandy loam topsoil; over brown to yellowish brown sandy loam subsoil with few or no stones & boulders; over weathered rock within 50 – 100 cm.	PC001, PH035
DB	Deep, bouldery hill soil.	Very dark greyish brown sandy loam topsoil; over bouldery brown to yellowish brown sandy loam subsoil; over weathered rock at more than 100 cm.	Pd012, Pd014, Pd015, PH033, PH034, PK047.
DF	Deep, boulder-free hill soil.	Very dark greyish brown sandy loam top; over brown to yellowish brown subsoil with few or no stones and boulders; over weathered rock at more than 100 cm.	Pd013, PC003, PK032
Imperfect or poorly drained hill soils			
HG	Imperfectly or poorly drained hill soil.	Dark brown to dark grey topsoil with distinct dark and brown mottles; over wet, yellowish to pale brown subsoil with grey and rust mottles.	PC006, PK046
Miscellaneous land types			
GW	Gully wash.	Bouldery deposits along gully floor.	-
DG	Disturbed ground.	Roads, building and other infrastructure	-

### 5.2.3 Shallow bouldery soils (SB).

These are extensive soils, and occur in all parts on the Centre, especially in areas where soils have been truncated by road or other infrastructural works. These soils were described and sampled in two profiles (see PK036 and PK045 in Appendix B)

By definition these soils are 50-100 cm deep to weathered rock, and have at least one horizon with common or more frequent stones and/or boulders. Topsoils are dark brown-dark greyish brown sandy loams and about 10 - 20 cm deep. Some topsoils may be extended downwards by merging with shallow, black, buried topsoils (e.g. PK045). The subsoils are brown or reddish yellow sandy loams, with some fine earth textures as coarse as loamy coarse sand. The structure in the subsoils is difficult to determine because of the high contents of boulders and stones. These may be concentrated in the subsoil, but some profiles are bouldery to the surface (e.g. PK045). The boundary to the underlying weathered rock is not easy to determine in augering, because of weathering of the boulders.

The topsoils in the two analysed profiles in these soils have variable contents of organic matter, with organic carbon ranging from low (0.3%) to moderate (2.2%). This is probably due to differences in recent management history. C:N ratios are good, at less than 10. Available phosphate contents range from moderate to high and available potassium contents are in the range 5 – 75 (very low – low). Both topsoils and subsoils are slightly acid. Topsoil base saturations are very variable, ranging from low (41%) to 100%, but both subsoils have very low base status, with base saturations ranging from 28 to 35 %. Topsoil contents of exchangeable potassium are variable, but subsoil levels are low – moderate.

### 5.2.4 Shallow boulder-free soil (SF).

These soils are found in all parts of the Centre, but are dominant on the eastern slopes. They were described in detail and sampled in two profiles (see PC001 and PH035 in Appendix B).

By definition these soils are 50 -100 cm deep to weathered rock, with no horizon having more than a few stones and/or boulders. Nonetheless few of these soils are completely free of stones or boulders. The limited stone contents increase with depth in many profiles, and most topsoils are stone-free. They consist of greyish - very dark greyish brown sandy loams, of 10-20 cm depth. In some soils they are extended downward by merger with a shallow buried topsoils (e.g. PH035). The subsoil is brown - strong brown, sandy loam with moderately developed subangular blocky structures. It is underlain by soft weathered gneiss. The weathered rock cannot always be easily distinguished in augering.

The content of organic matter is low in the topsoil of profile PC001 (i.e. organic carbon 0.9 %), but high in PH035 (organic carbon 4.1 %), and C:N ratios are good in both. Both profiles are slightly acid, but have moderate – very high base status, with base saturation ranging from 55% to 92 %. Topsoil contents of exchangeable potassium are variable, but subsoil levels are low – moderate (0.2 – 0.4 me%). Available phosphate ranges from moderate to high (21 – 35 ppm), and the contents of available potassium are variable, ranging from 44 to 323 ppm (low – very high).

### 5.2.5 Deep bouldery soil (DB).

These soils are extensive and have been mapped in all sections of the Centre. They have been described in detail and sampled for analysis in six profiles (see Pd012, Pd014 Pd015, PH033, PH034, and PK047, in Appendix B).

By definition these soils are more than 100 cm deep to weathered rock. The topsoils are very dark greyish brown sandy loams. In some profiles their depths are extended downward by merging with a shallow dark buried topsoil (e.g. Pd015). The subsoil is brown – yellowish brown sandy loam with at least one horizon with common to abundant stones and/or boulders. In many of these soils, the fine earth texture becomes coarser with depth. The subsoil structure is dominated by the presence of frequent boulders and stones. In some of these soils, there are layers and pockets of sand, especially in profiles affected by road construction (e.g. Pd012). Weathered rock occurs at more than 100 cm, but was not seen in all profiles.

The laboratory analyses from the six profiles in these soils show that topsoil contents of organic matter are variable, with organic carbon ranging from very low (0.1%) to high (6.7%). This is probably due to variations in recent management, especially the application of organic fertiliser. C:N ratios are also variable, ranging from 4 (good) to 25 (poor). Contents of available phosphate range from low to high, and of available potassium from very low to very high, probably due to differences in recent fertiliser application. The topsoils are slightly acid, and the subsoils vary from very acid – neutral. Base saturations are equally variable, ranging from very low (7%) to high (73%). Contents of exchangeable potassium are very variable in the topsoils, but are low – very low in all of the subsoils.

#### 5.2.6 Deep boulder-free soil (DF).

This is an important soil and is found in all parts of the Centre. It is most extensive on the shelf in the centre of the lower, northern slope and southwestern corner on the upper, southern slope. These soils were described in detail and sampled for analysis in three profiles (see PC003, Pd013, and PK032 and in Appendix B)

By definition these soils are more than 100 cm deep to weathered rock. The topsoils are deep, very dark greyish brown sandy loams. In some profiles, they are extended downward by merger with shallow buried topsoil (e.g. Pd013). They have moderately developed subangular blocky structures, which have a tendency to break into crumbs. The subsoils are brown – yellowish brown sandy loams with no horizon containing more than a few stones and boulders. The structure is moderate medium subangular blocky, often breaking into fine crumbs. In some profiles the subsoil ped faces have weak and discontinuous organic cutans (e.g. Pd013). The subsoils are friable, both in the face and in the hand. The boundary to soft weathered gneiss was not seen in all profiles.

The analysed profiles show that these soils are acid – slightly acid (pH 5.3 – 5.9) but have variable exchangeable base status, with base saturations ranging from very low (8%) to moderate (50%). Organic carbon contents in the topsoils are moderate (1.5%) to very high (5.1%) and C:N ratios are good (<10). Available potassium is variable and available phosphate contents are low - high (2 – 35 ppm). Exchangeable potassium contents are moderate in the topsoils (0.3 – 0.4 me%) but low in subsoils (0.1 – 0.2 me%).

#### 5.2.7 Wet soil (HG).

These soils occur in small areas in the corners of upper and lower slopes. Although these soils are not extensive, two profiles has been examined in detail and sampled for analysis (see PC006 and PK046 in Appendix B).

These soils have imperfect or poor drainage by definition. The topsoil is dark brown - dark grey fine sandy loam with distinct dark and rust brown mottles. In both of the described profiles, topsoil depth appears to be extended downward by the presence of a shallow buried topsoil. The subsoil is wet, yellowish brown or pale

brown sandy loam, with many distinct grey, brown and reddish brown mottles. The subsoil structure is weak medium subangular blocky. The solum is underlain by wet, soft, weathered gneiss at depths of more than 50 cm, usually at more than 100 cm. These soils are fed by subsurface throughflow, and the deeper subsoil horizons are mostly drier than those above. In some of profiles the perched water-table reaches to the surface (e.g. PC006 in Appendix B), but the middle horizons are generally the wettest.

The topsoils of the two analysed profile have moderate (2.6 %) to high (3.2 %) contents of organic carbon and good C:N ratios (both 11.8). These soils are acid – slightly acid (pH 5.5 – 6.2). Base saturations range from moderate (45 %) to high (70 %). Exchangeable potassium contents are moderate (0.3 – 0.4 me %) in topsoils, and low in subsoils (0.1 – 0.2 me %). Contents of available potassium are variable, ranging from very low to very high, but available phosphate levels are low (6 – 9 ppm).

#### 5.2.8 Gully wash (GW).

This is a miscellaneous land type (MLT), and not a proper soil class. It is located in the bed of the stream, which runs down from the eastern to the northwestern boundary, and cuts the Centre in two. Its soil cover has not been described or differentiated. It contains variable but high quantities of boulders, some of them are very large. They are not layered and are hardly rounded. This indicates that they have been moved for only short distances, either by seasonal spates or by colluviation. The distribution of the boulders is fairly chaotic, but they tend to increase downslope.

#### 5.2.9 Disturbed ground (DG).

Areas seriously affected disturbed by infrastructure are mapped as another undifferentiated MLT – disturbed ground. This includes the areas occupied by the RNR – RC, FEZAP and TFMP offices, and the RPPC, RAMC, staff quarters and FCB buildings. Their soils were not examined.

#### 5.2.10 Analytical summary

The chemical characteristics of the soil classes are summarised in Table 5.2. It can be seen that the soil classes, which are defined on field features, are chemically variable and overlap considerably. Organic matter, nitrogen and available P levels appear to be greatly affected by local variations in recent management history. The base status indicators are also variable, and the soils range from highly to moderately leached, with acid-slightly acid pH values, base saturations ranging from very low to 100%, and exchangeable and available contents of potassium ranging from very low to high. The Centre has some soils, which are very infertile with respect to nutrients. Similar poor soils were noted at Drametse (LUPP 1996).

### 5.3 Soil correlation.

#### 5.3.1 Correlation with international soil classifications.

The local classification used in Table 5.1 and in section 5.2 aims to be simple and to indicate the main soil features to those interested in the soils of Bhutan and Khangma. The classes are too generally defined to convey much to people outside Bhutan. The classes are therefore correlated with the two main international systems of soil classification in Table 5.3. There is further discussion of the correlations in Appendix C. The

versions of the international systems used are those that were available at the time of our fieldwork. Correlations with recent versions will follow in BSSP Working Papers on soil classification.

Table 5.2 Ranges of chemical analyses, by soil classes, Khangma, RNR-RC

SOIL CLASS (number of profiles analysed)	TOPSOIL ONLY				TOPSOIL AND SUBSOIL (T/S)				
	Org. C (%)	Total N (%)	C:N	AvP (ppm)	pH	TEB me %	BS (%)	Exch K (me %)	AvK (ppm)
VS (1)	2.1	0.2	10	35	5.5 / 5.9	5.7 / 5.1	43 / 15	0.5 / 0.4	155/101
SB (2)	0.3-2.2	0.1-0.2	3 -10	7-35	5.5-6.3 / 5.7-6.2	1.0-12.1 / 2.4-4.8	41-100 / 28-35	0.3-1.2 / 0.1-0.5	13-76 / 5-37
SF (2)	0.9-4.1	0.3 (both)	4-13	21-35	5.8 / 6.0-6.1	7.2-16.6 / 4.2-5.9	56-92 / 55-60	0.3-1.4 / 0.2-0.4	44-323 /50-122
DB (6)	0.1-6.7	0.1-0.6	4-25	6-35	5.6-6.1 / 4.6-6.6	2.1-14.7 / 0.5-9.7	15-73 / 7-56	0.3-2.2 / 0.1-0.3	52-400 5-48
DF (3)	1.5-5.1	0.3-0.6	6-9	2-35	5.5-5.9 / 5.3-5.8	7.1-11.2 / 0.7-2.3	37-50 / 8-23	1.0-1.4 / 0.1-0.2	134-197 /24-72
HG (2)	2.6-3.2	0.2-0.3	12 (both)	6-9	5.5-5.9 / 5.5-6.2	10.7-11.5 / 3.8-12.5	65-74 / 45-70	0.3-0.4 / 0.1-0.2	60-762 /15-858

See Table APPA.1 in Appendix A for interpretation of these values.

### 5.3.2 Correlation with the soils of Drametse.

The eastern part of Drametse geog is underlain by Thimphu Group gneisses. 26 profiles were described (25 of them analysed) in the gneissic soils, and they show that the Drametse gneiss soils are similar to those at Khangma in colour, texture, depth, and chemical characteristics. Of the 26 gneissic soil profiles at Drametse:

- 2 are equivalent to the Khangma VS class (DP3 & DP21)
- 3 are equivalent to class SB (DP2, DP6 & DP7)
- 13 are equivalent to class DB (DP1,4,5,9,18,19,23,26,28,29,32,34, & 38).
- 8 are equivalent to class DF (DP20, 22, 25, 27, 31, 33, 35 & 36).
- None match the definition of class SF.

As is to be expected in a study area that is 300 times larger, the Drometse soils are more variable than those of Khangma. They include some very sandy soils, and some that are redder than any at Khangma. They tend to have gravel and stones rather than boulders as their main coarse materials (LUPP, 1996).

### 5.3.3 Correlation with geotechnical classification of soils.

Stability of soil terraces and water conveyance systems are critical features of soils for agricultural development in Bhutan. The Irrigation Section of REID of MoA has prepared a geotechnical classification of soils specifically for canal and terrace stability in Bhutanese conditions. Irrigation is not extensive in

Khangma but some crops receive supplementary water, so that the classification is useful. More importantly it indicates the general stability of the soils, and their susceptibility to slumping and other forms of mass movement. Table 5.4 correlates the soils of Khangma with the geotechnical classification.

Table 5.3 International correlation of soil classes at Khangma RNR-RC

Khangma soil class		Subunit in FAO Soil Map of the World Legend of (FAO 1974 & 1988)	Great group in USDA Soil Taxonomy (Soil Survey Staff 1975 & 1992) [Family in italics]
Code	Name		
VS	Very shallow	Dystric Leptosol, Lithic & Dystric Cambisol	Lithic Ustochrept & Lithic Ustorthent [mesic, coarse loamy or skeletal loamy, mixed]
SB	Shallow bouldery	Ochric & Umbric Regosol	Typic Ustorthent [mesic, loamy skeletal, mixed]
SF	Shallow boulder – free		Typic Ustorthent [mesic, loamy, mixed]
DB	Deep bouldery		Typic Ustorthent [mesic, loamy skeletal - fine loamy, mixed]
DF	Deep boulder – free		Typic Ustorthent [mesic, loamy, mixed]
HG	Wet	Mollic & Umbric Gleysol	Typic & Mollic Epiquent [mesic, sandy & loamy, mixed]

Table 5.4 Geotechnical correlation of soils of Khangma RNR-RC

Khangma soil class	REID Irrigation Section Geotechnical Soil Classification	
	Land unit	Soil class
VS	3A/B	CL (Inorganic lean clays)
SB		
SF		
DB		
DF		
HG		SC & CL (Clayey sand & inorganic lean clays)

Source for class criteria: CIP (1993)

## 6. SOIL DISTRIBUTION AND MAPPING

### 6.1 Soil distribution

Some of the minor soil classes are related to particular topographic locations. The gully wash soils are restricted to the stream bed. The wet soils are found along minor drainage lines and in flatter areas. However the distributions of the main classes of well-drained soils, i.e. shallow and deep, bouldery and boulder-free, do not show an obvious topographic pattern. Their boundaries on the soil map are based mainly on our routine soil observations, and not on topographic interpretation and extrapolation.

### 6.2 Soil mapping units

It possible to map only part of the area as simple units (consociations) in which one class of soil is predominant. The consociations are not pure, and contain minor inclusions of other soil classes. The rest of the area is mapped as complexes, which are units with two or more classes that are more or less co-equal. The composition of the mapping units is summarised in Table 6.1. There are two miscellaneous land types (MLT), which are defined, not in terms of soil profile characteristics but in terms of general land features. They are the gully wash and disturbed ground.

The areas and proportions of the soil mapping units are summarised in Table 6.2. This shows that the deeper well-drained hill soils are the most extensive, accounting for 55% of the area between them. They are more or less equally divided between the bouldery and boulder-free complexes.

Table 6.1 Composition of soil mapping units at Khangma RNR- RC

Map unit	Type	Main soil classes	Minor soil classes
VS	Consociation	VS	SF, SB
BX	Complex	SB, DB	SF, DF
BFX	"	SF, DF	SB, DB
HX	"	SF, DF, SB, DB	VS
W	Consociation	HG	VS
GW	MLT	-	-
DG	"	-	-

Table 6.2 Areas of soil mapping units, Khangma RNR-RC

Soil Mapping Unit	Area		
	Ha	Acres	% of survey area
VS	6.1	15.1	17.3
BX	10.2	25.2	28.7
BFX	9.9	24.5	28.0
HX	2.5	6.2	7.1
W	0.9	2.2	2.5
GW	1.5	3.7	4.2
DG	4.3	10.6	12.2
TOTAL	35.4	87.5	100

## 7. OVERVIEW AND IMPLICATIONS

### 7.1 Overview of soils.

The Centre is located on limited range of soils. Much of the arable land is on soils of medium texture, moderate depth, and good drainage. The main variations are in the depth to weathered rock, the number and distribution of stones and boulders, and the occurrence of buried topsoils. The distributions of these features are somewhat random, and were difficult to map. There are also areas of shallow soils and of poorly drained soils. The soils are more varied chemically but most are moderately leached and slightly acid. Organic matter, N and P status appear to vary according to recent management

### 7.2 Implications of results

In addition to supplying general information on an important aspect of the production environment, the results of the soil survey can be applied to specific queries about the suitability of the location of the Centre.

In particular the results can contribute to the following:

- Are the soils of the Centre found elsewhere, and to what extent will it be possible to extrapolate research findings at the Centre to other parts of the region?
- What trials should be located on which of the Centre's soils?
- What land, from a soil point of view, is best used for infrastructure and other non - trials uses?

The Soil Survey unit is just over a year old and this was its first soil survey in Eastern Bhutan. It has so far seen little of the soils elsewhere in the region. It is therefore not in a position to generalise confidently about the typicality of the Centre's soils. However the correlations with the soils found at Drometse (see section 5.3.2) indicate that the Khangma soils are similar to those found elsewhere on the extensive gneissic parent materials in Eastern Bhutan. Therefore experimental results on the Centre are not likely to be invalidated by atypical soils.

The relative uniformity of the soils of the Centre means that soils need not be a crucial factor in the siting of facilities or of particular types of trial and experiments. This allows for layouts to be determined by other factors, such as the availability of water and ease of access. However soil erosion monitoring and soil conservation trails are most usefully located, as at present, on steep slopes.



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## APPENDIX A: SUMMARY OF SOIL ANALYSES METHOD USED AT SPAL

The full details of the methods used at SPAL are given in 'Soil Analysis' (SPAL 1993).

The SPAL methods vary slightly according to soil pH. The methods summarized below are those for soils of pH (water) > 4.5 and < 7, as these apply to all of the samples from Khangma.

### Sample preparation

Samples are air dried, aggregates are hand crushed, and the soil is sieved to 2 mm.

### pH

Soil pH is measured in suspensions of the soil in distilled water and 1 M KCl (1:2.5) using a PHM 83 automatic pH meter.

### Soil extracts

The fine earth fraction is subject to a number of extraction procedures:

- Total N is extracted and converted into ammonium form by micro-Kjeldahl digestion with H<sub>2</sub>SO<sub>4</sub> and a Se-based catalyst
- Ammonium – N and nitrate – N are extracted by shaking with 0.01 M CaCl<sub>2</sub> for two hours.
- Available P is extracted by shaking 5 g of fine earth with 35 ml of the Bray and Kurtz extractant of 0.5 M HCl and 1 M NH<sub>4</sub>F for 1 minute.
- Available K is extracted by shaking 5 g of fine earth with 50 ml of 0.01 M CaCl<sub>2</sub> for 2 hours.
- Exchangeable Ca, Mg, K and Na are extracted by leaching 5 g of fine earth with 100 ml of 1 M ammonium acetate (NH<sub>4</sub>OAc).
- The ammonium is extracted by leaching the soil with excess 1 M KCl, and measured to give the Cation Exchange Capacity.

### Assays of extracts

The NH<sub>4</sub> from the Total N digestion, and from the KCl leaching for CEC determination, the NH<sub>4</sub> – N, NO<sub>3</sub> – N, available P, available K, and exchangeable K and Na in the various extracts are measured with the Skalar Segmented Flow Analyser system which includes colourimeters for NH<sub>4</sub>, NO<sub>3</sub> and available P, and a flame spectrophotometer for available K, and exchangeable K and Na.

Exchangeable Ca and Mg in the NH<sub>4</sub>OAc leachate are measured with a Unicam Atomic Adsorption Spectrophotometer.

### Organic carbon

OC is measured by the Walkley – Black method of low temperature oxidation with acidified  $K_2Cr_2O_7$  and titration of the excess dichromate.

#### Particle size analysis

Particle size fractions are measured by the pipette method after treatment of the fine earth with  $H_2O_2$  to remove organic binding effects, HCl to remove aggregation effects by carbonates, Fe and Al oxides and other mineral cementing agents, and sodium hexametaphosphate to disperse the clay minerals.

#### TEB, ECEC, BS and C:N.

Total exchangeable bases, Effective cation exchange capacity, base saturation, and C:N ratios are derived by simple computation, i.e.

- TEB = Exchangeable Ca + Mg + K + Na.
- ECEC = TEB + Extractable Al.
- BS ( $NH_4OAc$ ) = TEB / CEC ( $NH_4OAc$ ).
- EBS = TEB / ECEC.
- C:N = Organic C / Total N.

The analytical results from SPAL are interpreted as indicated in Table AppA.1.

Table APPA.1 Recommendations for interpretation of SPAL soil analyses

	V. High	High	Moderate	Low	V. Low
pH	> 7.6 * (alkaline)	6.6 - 7.5 (neutral)	5.6 - 6.5 (s. acid)	4.6 - 5.5 (v. acid)	< 4.5 (ext. acid)
EC mS/cm	> 2.00	0.8 - 1.99	0.4 - 0.79	0.15 - 0.39	< 0.15
CEC (NH <sub>4</sub> OAc) me%	> 40	25 - 39.9	15 - 24.9	5 - 14.9	< 5
XCa me%	> 20	10 - 19.9	5 - 9.9	2 - 4.9	< 2
XMg me%	> 8	3 - 7.9	1.5 - 2.9	0.5 - 1.4	< 0.5
XK me%	> 1.2	0.6 - 1.19	0.3 - 0.59	0.1 - 0.29	< 0.1
XNa me%	> 2	0.7 - 1.99	0.3 - 0.69	0.1 - 0.29	< 0.1
TEB me%	> 30	15 - 29.9	7.5 - 14.9	3 - 7.4	< 3
XAl me%	> 10	5 - 9.9	2 - 4.9	0.5 - 1.9	< 0.5
ECEC me%	> 30	20 - 29.9	12 - 19.9	4 - 11.9	< 4
BS % (NH <sub>4</sub> OAc)	> 80	65 - 79	50 - 64	35 - 49	< 35
EBS %	> 80	50 - 79	35 - 49	20 - 34	< 20
Ca:Mg	> 10	6 - 9.9	2 - 5.9	0.8 - 1.9	< 0.8
AvK (ppm)	> 300	200 - 299	100 - 199	40 - 99	< 40
AvP (ppm)	> 30		15 - 29	5 - 14	< 5
Org. C %	> 5	3.1 - 4.9	1.2 - 3	0.6 - 1.1	< 0.6
Total N %	> 1	0.5 - 0.99	0.2 - 0.49	0.1 - 0.19	< 0.1
C:N	> 50	20 - 49	15 - 19	10 - 14	< 10

Source: AHT, 1995

## APPENDIX B: SOIL PROFILE DESCRIPTIONS AND ANALYSES

This appendix includes the detailed descriptions and analyses of the 16 soil profiles. The profiles are in the sequence in Table APPB.1

Table APPB.1 Summary of soil profiles

Profile number	Khangma soil class	Number of horizons analysed
PC001	SF	4
PC002	VS	3
PC003	DF	4
PC006	HG	2
Pd013	DF	5
Pd014	DB	3
Pd015	DB	4
PH033	DB	5
PH034	DB	6
PH035	SF	5
PK032	DF	7
PK036	SB	3
PK045	SB	3
PK046	HG	3
PK047	DB	6
Pd012	DB	11
TOTAL	16	74

Profile: PC001

Map unit: BFX

Soil Classification: Khangma soil class: SF  
 Soil Taxonomy: Typic Ustorthent [Mesic, coarse loamy, mixed]  
 FAO: Ochric Regosol

Survey area: Khangma RNR-RC  
 Location: Southern block, above staff quarters  
 GPS: Not available  
 Altitude: 2195m a.s.l

Described & sampled: 9.4.1998, IC Baillie

Climate: General: Warm temperate, P = ca 1200 mm p.a  
 Recent weather: Showery

Regional topography: Low mountain  
 Site position: Midslope

Slope: 35%, 1km long, terraced concave, aspect W NW (285<sup>0</sup>)  
 Site drainage: Good

Parent material: Solid: Gneiss & quartz  
 Drift: Thimphu Colluvium

Land use: Rough grazing in abandoned orchard, formerly terraced  
 Vegetation: Low shrubs, mainly Artemisia myriantha, with grasses & Rumex nepalensis.

Surface: Litter: 0.3 cm discontinuous grass  
 Outcrops: None  
 Stones: Few angular gneiss & quartzite boulders in bund faces  
 Cracks: None  
 Roots: None  
 Microrelief: Terraced, 1-2 m high, 3 m wide  
 Faunal activity: None  
 Other features: None

Profile description: (Colours are moist unless indicated)

Cm

- 0 -9 10YR 3/2 (very dark greyish brown) with few medium faint red, grey & reddish brown mottles; sandy loam; weak fine subangular blocky breaking to weak medium crumb; common fine pores; moist & slightly friable; many fine roots; few medium hard grey & brown weathered gneiss; few faecal pellets; few fine charcoal; HCl negative; abrupt regular boundary to: [Sample PC001/1 @ 0-9]
- 9 – 23 10YR 4/3 (brown) with many medium very faint yellowish red mottles; sandy loam; weak fine subangular blocky; few fine pores; moist & very friable; common fine roots; rare hard angular quartz & granite stones; HCl negative; many fine muscovite flakes; clear regular boundary to: [Sample PC001/2 @ 10 – 20]
- 23 – 45 10YR 4/3 (brown) with many medium red, dark red & orange mottles; sandy loam; weak medium subangular blocky; few fine pores; moist & very friable; few fine roots; rare hard angular quartz, granite & few gneiss stones; HCl negative; many fine muscovite flakes; clear regular boundary to: [Sample PC001/3 @ 30 – 40]
- 45 – 63 10YR 5/3 (brown) with many medium faint orange & orange yellow mottles; loamy sand; moderate medium subangular blocky; common fine pores; moist & friable; few fine roots; common soft medium yellow & grey weathered gneiss & few hard quartz stones; HCl negative; many fine muscovite flakes; clear regular boundary to: [Not sampled]
- 63 – 108 2.5Y 5/2 (greyish brown) with many medium dark, black, yellow & orange mottles; weathered rock, hand texture as sandy loam; weak medium breaking to fine subangular blocky; common fine pores; moist & friable - soft; rare fine roots; common soft medium yellow & grey weathered gneiss & many fine quartz stones; common black stains on parting faces; HCl negative; many fine muscovite flakes; clear regular boundary to: [Sample PC001/4 @ 80 – 90]
- 108 – 170 Soft grey, silvery & yellow grey weathered gneiss with abundant muscovite flakes; few pores:

[Not sampled]

170 – 175+ 7.5YR 5/6 (strong brown) with white streaks & grey patches of weathered gneiss; sandy loam; weak medium angular blocky; common fine pores; moist & slightly friable; no roots; common soft grey & yellow weathered gneiss; few faecal pellets; common fine muscovite flakes; common medium soft black manganese stains; HCl negative; abrupt regular boundary to: [Not sampled]

Comments: Weathered rock at 108 – 170 appears to be a large boulder.

SPAL analytical results for BSS

Profile PC001

Survey area: Khangma RNR-RC

Reaction, P &amp; organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PC001/1	0-9	5006	5.8	4.3	1.5	0.00	21	0.9	0.3	4
/2	10-20	5007	6.1	5.1	1.0	0.00	2	0.2	0.1	4
/3	30-40	5008	6.1	5.2	0.9	0.00	2	0.1	0.1	2
/4	80-90	5009	5.9	4.1	1.8	0.00	3	1.4	0.1	35

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PC001/1	6.1	0.7	0.3	0.1	7.2	nd	12.9	nd	56	nd
/2	3.0	0.7	0.4	Tr	4.1	nd	6.8	nd	60	nd
/3	3.4	1.1	0.3	Tr	4.8	nd	8.1	nd	59	nd
/4	3.2	1.3	0.2	0.1	4.8	nd	7.3	nd	65	nd

Fine earth granulometric.

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PC001/1	nd	nd	nd	nd	nd	59.3	8.8	18.9	27.7	14.0	SL
/2	nd	nd	nd	nd	nd	69.4	6.5	17.4	23.9	6.6	SL
/3	nd	nd	nd	nd	nd	66.6	13.5	11.1	24.6	8.8	SL
/4	nd	nd	nd	nd	nd	69.9	12.1	5.1	17.2	12.9	SL

Profile: PC002

Map unit: VS

Soil Classification: Khangma soil class: VS  
 Soil Taxonomy: Lithic Ustochrept [Mesic, loamy skeletal, mixed]  
 FAO: Lithic Cambisol

Survey area: Khangma RNR-RC  
 Location: Top internal road of South block, near the fence, ca 25 m in from boundary.  
 GPS: Not available  
 Altitude: 2190 m a.s.l

Described & sampled: 9.4.1998, IC Baillie

Climate: General: Warm temperate, P = ca 1200 mm p.a  
 Recent weather: Rainy overnight

Regional topography: Low mountains  
 Site position: Small knoll on midslope

Slope: 70%, 100m long, convex, aspect W (275°)  
 Site drainage: Good

Parent material: Solid: Gneiss & quartz  
 Drift: Thimphu Residual

Land use: Waste scrub  
 Vegetation: Mix broad leaf scrub regrowth, with Rhododendron & Artemisia myriantha

Surface: Litter: 5 cm discontinuous broad leaves  
 Outcrops: None  
 Stones: Common subangular soft – slightly hard grey & brown weathered gneiss  
 Cracks: None  
 Roots: None  
 Micro relief: Stepping due to undercutting by road  
 Faunal activity: None  
 Other features: None

Profile description: (Colours are moist unless indicated)

Cm

- 0 - 16 10YR 3/3 (dark brown) with patches of 10YR 4/3 (brown); coarse sandy loam – loamy sand; moderate – weak fine crumb; abundant fine pores; moist & very friable; abundant fine & medium; common medium – fine hard angular quartz & soft – slightly hard weathered gneiss stones; HCl negative; ants seen; clear regular boundary to:  
 [Sample PC002/1 @ 0-10]
- 16 - 30 10YR 5/4 (yellowish brown) with many faint yellow & brown mottles; gravelly loamy coarse sand; very weak medium crumb breaking to single grains; abundant fine pores; moist & very friable; many fine & medium roots; common medium – fine hard angular quartz & soft – slightly hard weathered gneiss stones; HCl negative; clear regular boundary to:  
 [Sample PC002/2 @ 20-30]
- 30 – 120 + In situ weathered foliated gneiss, with band of quartzite. Gneiss is soft yellowish, greyish & olive with spots of yellow, black and dark brown; quartzite is moderately hard white & pale yellow; few medium roots down cracks.  
 [Sample PC002/3 @ 50-60]



SPAL analytical results for BSS

Profile PC002

Survey area: Khangma RNR-RC

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PC002/ /1	0-10	5003	5.8	4.2	1.6	nd	35	2.1	0.2	10
/2	20-30	5004	5.9	4.2	1.7	nd	35	0.4	0.1	7
/3	50-60	5005	6.3	4.9	1.4	nd	10	0.3	0.0	30

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PC002 /1	3.8	1.4	0.5	0.0	5.7	nd	13.4	nd	43	nd
/2	0.2	0.5	0.4	0.0	1.1	nd	7.3	nd	15	nd
/3	1.2	0.2	0.2	0.0	1.6	nd	3.8	nd	43	nd

Fine earth granulometric.

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PC002 /1	nd	nd	nd	nd	nd	70.9	10.6	10.1	20.7	8.3	SL
/2	nd	nd	nd	nd	nd	64.8	10.8	12.3	23.1	12.0	SL
/3	nd	nd	nd	nd	nd	75.6	8.6	9.9	18.5	5.9	LS

Profile: PC003

Map unit: BFX

Soil Classification: Khangma soil class: BF  
 Soil Taxonomy: Typic Ustorthent [Mesic, loamy, mixed]  
 FAO: Umbric Regosol

Survey area: Khangma area  
 Location: Ca 25 m N of PC002, on access road in southern block.  
 GPS: Not available  
 Altitude: 2120m a.s.l

Described & sampled: 9.4.1998, IC Baillie

Climate: General: Warm temperate, P = ca 1200 mm p.a  
 Recent weather: Showery

Regional topography: Low mountains  
 Site position: Midslope

Slope: 48%, 1km long, formerly terraced convex, aspect WNW (300°)  
 Site drainage: Good

Parent material: Solid: Gneiss & quartz  
 Drift: Thimphu Colluvium

Land use: Rough grazing in abandoned apple orchard  
 Vegetation: Low shrubs, mainly Artemisia myriantha, with grasses, Rumex nepalensis, moss on ground surface

Surface: Litter: 1 cm discontinuous grass & moss  
 Outcrops: None  
 Stones: Few gneiss & quartzite  
 Cracks: None  
 Roots: None  
 Micro relief: formerly terraced, 1-2 m high, 3 m wide  
 Faunal activity: None  
 Other features: None

Profile description: (Colours are moist unless indicated)

Cm

0 -30 10YR 3/2 (very dark greyish brown); medium sandy loam; moderate medium – fine crumb; abundant fine pores; moist & friable; common - many fine & medium roots increasing to abundant (root mat) at base; few medium slightly hard orange, yellow, & brown weathered gneiss stones; few charcoal; HCl negative; clear oblique boundary to:  
 [Sample PC003/1 @ 0-10]

30 - 40 10YR 4/4 (dark yellowish brown) with many very coarse dark brown patches; gritty coarse sandy loam; moderate coarse crumb; abundant fine pores; moist & friable; many fine & medium roots; few fine & medium slightly hard orange, yellow, & brown weathered gneiss gravel; HCl negative; clear oblique boundary to:  
 [Sample PC003/2 @ 30-40]

40 – 49 10YR 2/1 (black); fine sandy loam; weak fine subangular blocky breaking to moderate medium crumb; many fine pores; moist & friable; common fine & medium roots; few fine & medium slightly hard orange, yellow & brown weathered gneiss & hard angular quartz stones; HCl negative; gradual oblique boundary to:  
 [Sample PC003/3 @ 40-49]

49 - 62 10YR 4/2 (dark greyish brown); medium sandy loam; weak medium - fine subangular blocky; common medium pores; moist & slightly friable; many fine & medium roots; few fine & few medium slightly greyish green weathered gneiss, schist & soft quartz stones; HCl negative; gradual oblique boundary to:  
 [Not sampled]

62 – 80 10YR 4/4 (brown) with common medium faint dark brown mottles; medium sandy clay loam; moderate fine subangular – angular blocky; weak discontinuous clayskins; common fine pores; moist & slightly firm; many fine & medium roots; few fine & medium slightly orange & yellow weathered gneiss & hard angular quartz stones; HCl negative; clear regular boundary to:  
 Not sampled]

- 80 - 100 10YR 5/6 (yellowish brown) with many fine yellow & black weathered rock spots; gritty loamy coarse sand; very weak medium subangular blocky breaking to fine crumb; many fine pores; moist & friable; few fine & medium roots; few fine & medium slightly orange & yellow weathered gneiss stones; HCl negative; gradual regular boundary to: [Not sampled]
- 100 – 115/170 7.5YR 6/6 (reddish yellow) with rare coarse patches of brown soil from the old bund; fine sandy loam; weak fine - medium subangular blocky; common fine pores; moist & friable; few - rare fine & medium roots; rare very soft weathering gneiss stones; HCl negative; clear very wavy boundary to: [Sample PC003/4 @ 110 – 120 cm]
- 115/170 – 190 + 10YR 5/4 (yellowish brown) with many yellow, black & few weathered spots; gravelly loamy coarse sand; weak medium subangular blocky breaking to single grain; many fine pores; moist & very friable; rare fine roots; many hard quartz & soft grey, orange & black weathered gneiss stones; HCl negative: [Not sampled]

SPAL analytical results for BSS

Profile PC003

Survey area: Khangma RNR-RC

## Reaction, P &amp; organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PC003/1	0-10	4976	5.9	4.6	1.3	0.01	35	3.1	0.3	9.1
/2	30-40	4977	5.8	4.4	1.4	0.01	15	1.3	0.2	6.5
/3	40-49	4978	5.9	4.4	1.5	0.01	6	4.3	0.6	7.6
/4	110-120	4979	5.8	4.4	1.4	0.01	35	0.1	0.1	1.6

## Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PC003/1	5.5	1.4	1.0	Tr	7.9	nd	15.7	nd	50	nd
/2	3.4	0.5	0.2	Tr	4.1	nd	11.9	nd	35	nd
/3	10.9	1.4	0.3	0.1	12.6	nd	26.5	nd	48	nd
/4	0.2	0.5	0.1	0.1	0.8	nd	5.5	nd	14	nd

## Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PC003/1	nd	nd	nd	nd	nd	61.5	10.1	14.6	24.7	13.7	SL
/2	nd	nd	nd	nd	nd	64.3	10.5	13.6	24.1	11.6	SL
/3	nd	nd	nd	nd	nd	58.4	2.8	24.1	26.9	14.7	SL
/4	nd	nd	nd	nd	nd	69.9	11.6	10.4	22.0	8.1	SL

Profile: PC006

Map unit: W

Soil Classification: Khangma soil class: HG  
 Soil Taxonomy: Mollic Epiaquent [Mesic, loamy, mixed]  
 FAO: Mollic Gleysol

Survey area: Khangma RNR-RC  
 Location: Ca 25m N of PK036, below road & RNR-RC, southern block.  
 GPS: Not available  
 Altitude: 2175m a.s.l

Described & sampled: 15.4.1998, IC Baillie

Climate: General: Warm temperate, P = ca 1200 mm p.a  
 Recent weather: Sunny for two days

Regional topography: Low mountains  
 Site position: Flush site on mid slope

Slope: 45%, 1km long, rectilinear & terraced, aspect NW (315<sup>o</sup>)  
 Site drainage: Poor - wet

Parent material: Solid: Gneiss & quartz  
 Drift: Colluvium

Land use: Old pasture trial  
 Vegetation: Juncus spp, white clover (*Trifolium repens*) & few grasses

Surface: Litter: Dense Juncus root mat  
 Outcrops: None  
 Stones: Common angular quartz & gneiss stones  
 Cracks: None  
 Roots: None  
 Microrelief: Terraced  
 Faunal activity: None  
 Other features: None

Profile description: (Colours are moist unless indicated)

Cm

0 -12 7.5YR 3/2 (dark brown) with no mottles; very fine sand – silt; root bound crumb; few fine pores; abundant fine & medium roots; very wet & root bound firm; HCl negative; clear regular boundary to:  
 [Sample PC006/1 @ 0-10cm]

12-45 5YR 2.5/1 (black) with few fine faint reddish brown mottles; fine sandy loam+; massive breaking to weak medium blocky; few fine pores; many medium & fine roots; slightly wet & friable; common flakes of muscovite; HCl negative:  
 [Sample PC006/2 @25-35 cm]

Continued by auger

45-60 5YR 2.5/1 (black) with few fine faint reddish brown mottles; fine sandy loam+; massive breaking to weak medium blocky; few fine roots; very wet & friable; common fine flakes of muscovite; HCl negative;  
 [Not sampled]

60-70+ 10YR 4/4 (yellowish brown) with common medium distinct red & yellow mottles; coarse sandy clay loam+; moist – wet & firm with slight plasticity; common quartz fine gravel & few coarse stones; HCl negative:  
 [Not sampled]

Comment: clearly formed in multiple colluvia, with 12 - 60 cm as accreting topsoil.

SPAL analytical results for BSS

Profile PC006

Survey area: Khangma RNR-RC

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PC006/1	0-10	5065	5.5	4.4	1.1	0.01	9	3.2	0.3	11.8
/2	25-35	5066	5.5	4.1	1.4	0.01	10	4.4	0.2	18.3

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
	PC006/1	7.2	2.9	0.4			0.2	10.7	nd	16.4
/2	9.3	2.9	0.1	0.1	12.5	nd	17.8	nd	70	nd

Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PC006/1	nd	nd	nd	nd	nd	60.9	8.2	9.5	17.7	21.4	SCL
/2	nd	nd	nd	nd	nd	54.6	7.7	16.2	23.9	21.5	SCL

Profile: Pd013

Map unit: BX

Soil Classification: Provisional Khangma soil class: DF  
 Soil Taxonomy: Typic Ustorthent [Mesic, coarse loamy, mixed]  
 FAO: Umbric Regosol

Survey area: Khangma, RNR - RC  
 Location: Approximately 30 m SE above PFO office, southern block  
 GPS: 27°16.18' N, 91° 30.26' E  
 Altitude: 2130 m asl

Described & sampled: 9. 4. 1998, Tsheten Dorji

Climate: General: Warm temperate, P = ca 1200 mm p.a  
 Recent weather: Cloudy

Regional topography: Low mountain  
 Site position: Midslope

Slope: 65%, ca 1 km +, convex, aspect NNW (322°)  
 Site drainage: Good

Parent material: Solid: Thimphu gneiss & quartz  
 Drift: Colluvium

Land use: Wasteland  
 Vegetation: Fagopyrum dibotrys, Pteridium aquilinum, Artemisia myriantha, Trifolium repens, & local grasses.

Surface: Litter: Discontinuous grass litter of approximately 2 – 3 cm thick  
 Outcrops: None  
 Stones: None  
 Cracks: None  
 Roots: None  
 Microrelief: None  
 Faunal activity: None  
 Other features: None

Profile description: (Colours are moist unless indicated)

Cm

0 - 40 10YR 3/2 (very dark greyish brown) with no mottles; loam; moderate coarse breaking to medium breaking to fine subangular blocky weak discontinuous organic cutans; abundant fine & medium pores; moist & friable; abundant fine, medium & coarse grass and bracken roots; few fine gneiss & quartz stones; HCl negative; many earthworms seen; few muscovite flakes; clear regular boundary to: [Sample Pd013/1 @ 10 – 20 cm]

40 - 63 2.5Y 2.5/1 (black) with no mottles; loam; moderate coarse breaking to medium breaking to moderate fine subangular blocky; weak discontinuous organic cutans; many fine & medium pores; moist & friable; common fine & few medium roots; few fine & medium gneiss & quartz stones; HCl negative; many earthworms seen; few muscovite flakes; clear regular boundary to: [Sample Pd013/2 @ 50 – 60 cm]

63 - 89 10YR 4/4 (dark yellowish brown) with common coarse faint light grey mottles; coarse sandy loam +; weak coarse breaking to fine subangular blocky; common fine & medium pores; moist & friable; few fine roots; few medium weathering gneiss stones; HCl negative; clear gradual boundary to: [Sample Pd013/3 @ 70 – 80 cm]

89 - 133 10YR 4/3 (brown) with no mottles; coarse sandy loam +; weak coarse breaking to fine subangular blocky; common fine & medium pores; moist & friable; few fine roots; common medium weathering gneiss stones; HCl negative; few charcoal; diffuse boundary to. [Sample Pd013/4 @ 90 – 100 cm]

133 - 186+ 10YR 4/3 (brown) with no mottles; coarse sandy loam; weak coarse breaking to fine subangular blocky; common fine & medium pores; moist & friable; few fine roots; common medium weathering gneiss stones; HCl negative: [Sample Pd013/5 @ 150 – 160 cm]

Comments: 40-63 cm is a buried topsoil that is merged with the modern topsoil. The first horizon is the recent developed topsoil.

SPAL analytical results for BSS

Profile Pd013

Survey area: Khangma RNR-RC

## Reaction, P &amp; organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
Pd013 /1	10-20	4987	5.5	4.1	1.4	0.01	2	1.5	0.3	6
/2	50-60	4988	5.4	4.1	1.3	nd	2	5.9	0.2	33
/3	70-80	4989	5.5	4.1	1.4	nd	1	0.1	0.1	2
/4	90-100	4990	6.1	4.9	1.2	nd	5	0.1	0.1	1
/5	150-180	4991	6.1	4.9	1.2	nd	3	1.0	0.1	17

## Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
Pd013 /1	4.6	1.0	1.4	0.0	7.1	nd	19.0	nd	37	nd
/2	2.6	0.8	0.2	0.0	3.6	nd	17.3	nd	21	nd
/3	1.6	0.6	0.1	0.1	2.3	nd	10.0	nd	23	nd
/4	1.2	0.4	0.1	0.1	1.7	nd	10.1	nd	17	nd
/5	1.6	0.4	0.1	0.1	2.1	nd	10.0	nd	21	nd

## Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
Pd013 /1	nd	nd	nd	nd	nd	39.7	13.0	28.6	41.6	19.8	L
/2	nd	nd	nd	nd	nd	46.2	10.5	21.7	32.2	21.6	L
/3	nd	nd	nd	nd	nd	56.7	20.7	17.7	34.8	4.9	SL
/4	nd	nd	nd	nd	nd	59.4	8.8	14.4	23.2	17.4	SL
/5	nd	nd	nd	nd	nd	63.8	7.5	13.5	21.6	15.2	SL

Profile: Pd014

Map unit: BX

Soil Classification: Khangma soil class: DB  
 Soil Taxonomy: Typic Ustorthent  
 FAO: Ochric & Umbric Regosol

Survey area: Khangma RNR - RC  
 Location: Ca 20 m above irrigation channel & 20 m above West fence

GPS: 27°16. 21N', 91° 30. 01E  
 Altitude: 2000 m a.s.l.

Described & sampled: 14.4.1998, T. Dorji

Climate: General: Warm temperate, P = 1150 mm p.a.  
 Recent weather: Dry sunny

Regional topography: Low mountain  
 Site position: Midslope

Slope: 70%, ca 500m +, convex, aspect NW (305°)  
 Site drainage: Good

Parent material: Solid: Gneiss & quartz  
 Drift: Colluvium

Land use: Wasteland  
 Vegetation: Pteridium aquilinum, Artemesia myrantha, Rhus elliptica, & local grasses.

Surface: Litter: Discontinuous bracken leaf of 1-2 cm.  
 Outcrops: None  
 Stones: Few medium & coarse subangular blocky gneiss & quartz stones.  
 Cracks: None  
 Roots: None  
 Micro relief: None  
 Faunal activity: None  
 Other features: None

Profile description: (Colours are moist unless indicated)

Cm

- 0 - 13 10YR 3/2 (very dark greyish brown) with no mottles; loam; moderate coarse breaking to medium subangular blocky; weak discontinuous organic cutans; abundant fine, medium & coarse pores; moist & friable; abundant fine, medium & coarse bracken roots; few fine & medium hard subangular gneiss & quartz & few soft weathering gneiss; HCl negative; few fine muscovite flakes; clear regular boundary to: [Sample Pd014/1 @ 0 – 10 cm]
- 13 - 41 10YR 4/4 (dark yellowish brown) with common medium faint light grey & orange mottles; fine sandy loam; weak medium subangular blocky breaking to single grain; abundant fine & medium pores; moist & friable; abundant fine, medium & coarse bracken roots; few fine, medium & coarse hard subangular gneiss & quartz stones; HCl negative; diffuse boundary to: [Sample Pd014/2 @ 20 – 30 cm]
- 41 - 55 10YR 4/4 (dark yellowish brown) with common medium faint light grey & orange mottles; very strong medium sandy loam; weak medium subangular blocky breaking to single grain; common pores; moist & very friable; abundant fine, medium & coarse hard subangular gneiss & quartz stones; HCl negative; diffuse boundary to: [Sample Pd014/3 @ 40 – 50 cm]
- 55 - 80 10YR 4/4 (dark yellowish brown) with common medium faint light grey & orange mottles; strong medium sandy loam; very weak medium subangular blocky breaking to single grain; common pores; moist & very friable; many fine & medium roots; many fine & coarse hard subangular gneiss, quartz & boulders; HCl negative; common decayed roots; diffuse boundary to: [Not sampled]
- \_80 – 134 + 10YR 4/4 (dark yellowish brown) but darker than (55 – 80) horizon with common medium faint light grey and orange mottles; loamy coarse sand; very weak fine subangular blocky breaking to single grain; common pores; moist & very friable; common fine & medium roots; abundant fine, medium & coarse hard subangular gneiss, quartz & abundant boulders; HCl negative. [Not sampled]



SPAL analytical results for BSS

Profile Pd014

Survey area: Khangma RNR-RC

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
Pd014 /1	1-10	5021	5.6	4.1	1.5	nd	1	3.2	0.3	11
/2	20-30	5022	5.6	4.5	1.1	nd	1	2.0	0.2	13
/3	40-50	5023	5.9	4.8	1.1	0.01	1	2.2	0.4	2

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAC	EBS%
Pd014 /1	1.2	0.4	0.4	0.1	2.1	nd	14.2	nd	15	nd
/2	0.2	0.1	0.2	0.1	0.6	nd	8.3	nd	7	nd
/3	0.2	0.1	0.2	0.1	0.6	nd	11.6	nd	5	nd

Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
Pd014 /1	nd	nd	nd	nd	nd	63.0	15.2	21.1	36.3	0.7	SL
/2	nd	nd	nd	nd	nd	45.2	13.5	17.8	31.3	23.4	L
/3	nd	nd	nd	nd	nd	59.3	15.2	6.9	22.1	18.6	SL

Profile: Pd015

Map unit: VS

Soil Classification: Khangma soil class: DB  
 Soil Taxonomy: Mollic Ustorthent [Mesic, loamy over loamy skeletal, mixed]  
 FAO: Umbric Regosol

Survey area: Khangma RNR - RC  
 Location: Southern block, above PFO.  
 GPS: 27° 16.19' N, 91° 30.32' E  
 Altitude: 2120 m asl

Described & sampled: 15.4.98, Tsheten Dorji

Climate: General: Warm temperate, P = 1200 mm p.a.  
 Recent weather: Sunny

Regional topography: Low mountain  
 Site position: Midslope

Slope: 15 %, Ca 1 km +, convex, aspect WNW (296°)  
 Site drainage: Good

Parent material: Solid: Thimphu gneiss & quartz  
 Drift: Colluvium

Land use: Abandoned agricultural land (mainly potato plot)

Vegetation: Pteridium aquilinum, Artemisia myriantha, Rhododendron, Gaultharia spp, & Rubus elliptica

Surface Litter: Discontinuous bracken fronds, 5 – 8 cm thick  
 Outcrops: none  
 Stones: Many imported medium hard subangular gneiss & quartz, coarse stones & boulders  
 Cracks: None  
 Roots: None  
 Microrelief: Very irregular  
 Faunal activity: None  
 Other features: None

Profile description: (Colours are moist unless indicated)

Cm

- 0 - 16 10YR 3/2 (very dark greyish brown) with no mottles; fine sandy loam; moderate medium subangular blocky; abundant fine & many medium pores; moist & friable; abundant fine, many medium & coarse roots; few fine & medium hard subangular gneiss & quartz stones; HCl negative; many earthworms seen; clear regular boundary to: [Sample Pd015/1 @ 0 – 10 cm]
- 16 - 36 2.5Y 2.5/1 (black) with no mottles; humic silty loam; weak medium subangular blocky breaking to fine crumb; weak faint discontinuous organic cutans; abundant fine & medium pores; moist & very friable; abundant fine, many medium & coarse roots; common fine, medium & coarse hard subangular gneiss & quartz stones; HCl negative; many earthworms seen; clear gradual boundary to: [Sample Pd015/2 @ 20 – 30 cm]
- 36 - 55 Mixed colours of 10YR 4/2 (dark greyish brown) & 10YR 3/2 (very dark greyish brown); humic loam; moderate medium breaking to fine subangular blocky; weak faint discontinuous organic cutans; abundant fine & medium pores; moist & slightly friable; common fine, medium & few coarse roots; common fine, medium & coarse hard subangular gneiss & quartz stones; HCl negative; clear regular boundary to: [Sample Pd015/3 @ 40 – 50 cm]
- 55 - 76 10YR 3/3 (dark brown) with no mottles; very stony coarse sandy clay loam; moderate coarse breaking to medium subangular blocky; weak faint discontinuous organic cutans; common fine & medium pores; moist & slightly friable; few fine & medium roots; abundant fine, medium & coarse hard subangular gneiss & quartz stones; HCl negative; few patches of dark organic matter (possibly very old krotovinas); diffuse boundary to: [Sample Pd015/4 @ 60 – 70 cm]
- 76 - 115 10YR 4/3 (brown) with no mottles; very stony medium sandy clay loam; moderate medium subangular blocky; weak faint discontinuous clayskins; common fine & medium pores; moist & slightly friable; few fine, medium & coarse

roots; abundant fine, medium & coarse stones & hard subangular gneiss and quartz boulders; HCl negative; clear regular boundary to: [Not sampled]

115 - 145 + 10YR 4/4 (dark yellowish brown) with no mottles; stony loamy coarse sand; weak medium - fine subangular blocky; common fine & medium pores; moist & friable; few fine, medium & coarse roots; common fine, medium & coarse hard subangular gneiss & quartz stones; HCl negative: [Not sampled]

Comments: Buried topsoil (16-36) merges with the modern topsoil. Stone content increases with depth. The structures have distinct organic or clay cutans down to 1 m+.

SPAL analytical results for BSS

Profile Pd015

Survey area: Khangma RNR-RC

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
Pd015 /1	0-10	5044	6.1	4.9	1.2	0.02	35	6.7	0.3	3
/2	20-30	5045	6.1	4.9	1.2	0.02	12	5.5	nd	nd
/3	40-50	5046	6.6	5.0	1.6	0.01	5	2.1	0.2	10
/4	60-70	5047	6.7	4.9	1.8	0.01	1	0.7	0.1	6

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
Pd015 /1	9.9	2.6	1.4	Tr	13.9	nd	19.1	nd	73	nd
/2	24.8	2.0	0.9	Tr	27.7	nd	41.6	nd	67	nd
/3	7.9	1.5	0.3	Tr	9.7	nd	17.4	nd	56	nd
/4	3.8	1.2	0.3	0.1	5.4	nd	8.1	nd	66	nd

Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
Pd015 /1	nd	nd	nd	nd	nd	69.3	5.9	21.8	27.7	3.1	SL
/2	nd	nd	nd	nd	nd	55.6	6.3	17.1	23.4	21.1	SCL
/3	nd	nd	nd	nd	nd	64.7	5.3	16.8	22.1	13.2	SL
/4	nd	nd	nd	nd	nd	62.2	6.4	27.5	33.9	3.8	SL

Profile: PH033

Map unit: BX

Soil Classification: Khangma soil class: DB  
 Soil Taxonomy: Umbric Ustorthent [mesic, loamy skeletal, mixed]  
 FAO: Umbric Regosol

Survey area: Khangma RNR-RC  
 Location: 20m above from bottom barbed fence in northern block  
 GPS: 27° 16.48' N, 91° 30.05' E  
 Altitude: 1940m a. s. l

Described & sampled: 13.4.1998, H B Tamang

Climate: General: Warm temperate, P = ca 1200 mm p.a  
 Recent weather: Warm sunny

Regional topography: Lower mountains  
 Site position: Lower slope

Slope: 32%, ca 200m long, convex, aspect W (270°)  
 Site drainage: Good

Parent material: Solid: Mixed  
 Drift: Colluvium

Land use: Fallow  
 Vegetation: Cannabis sativa, Artemisia myriantha & Bracken (Pteridium aquilinum)

Surface: Litter: None  
 Outcrops: Few big & medium prismatic & platy boulders  
 Stones: Many fine hard angular stones  
 Cracks: None  
 Roots: None  
 Micro relief: None  
 Faunal activity: None  
 Other features: None

Profile description: (Colours are moist unless indicated)

Cm

- 0 - 12 7.5YR 2.5/1 (black) with no mottles; loamy fine sand; weak medium & fine subangular blocky; common fine pores; many fine & medium roots; moist & friable; few fine hard quartz & gneiss stones; HCl negative; diffuse boundary to:  
 [Sample PH033/1 @ 0-10 cm]
- 12 - 40 7.5YR 2.5/1 (black) with no mottles; loamy fine sand; weak medium & fine subangular blocky; common fine pores; common medium & fine roots; moist & friable; few fine hard quartz & gneiss stones; HCl negative; abrupt boundary to:  
 [Sample PH033/2 @ 20-30 cm]
- 40 - 77 10YR 4/4 (dark yellowish brown) with no mottles; medium sandy loam; weak medium & fine subangular blocky; few fine pores; common fine roots; moist & friable; many medium & fine angular & subangular weathered gneiss stones; flakes of muscovite; HCl negative; gradual regular boundary to:  
 [Sample PH0 33/3 @ 50-60 cm]
- 77 - 114 10YR 6/6 (brownish yellow) with no mottles; stony coarse sandy loam; weak medium subangular blocky; few fine pores; common fine roots; moist & very friable; many medium & fine angular & subangular weathered gneiss stones; HCl negative; flakes of muscovite; gradual regular boundary to:  
 [Sample PH033/3 @ 80-90 cm]
- 114 - 150+ 2.5Y 4/4 (olive brown) with no mottles; bouldery coarse sandy loam; massive structure; few fine pores; few fine roots; moist & very friable; common huge platy gneiss boulders; flakes of muscovite; HCl negative:  
 [Sample PH033/5 @ 120-130 cm]

Comment: This soil has been formed from two different processes; the top 40cm is colluvium from higher areas, and the lower horizons are by weathering of in-situ parent material (as seen from weathered gneiss).

SPAL analytical results for BSS

Profile PH033

Survey area: Khangma RNR-RC

## Reaction, P &amp; organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PH033/1	0-10	5016	5.7	4.6	1.1	0.02	35	2.2	0.6	3.9
/2	20-30	5017	5.2	4.2	1.0	0.00	6	2.7	0.2	12.8
/3	50-60	5018	5.8	4.3	1.5	0.02	1	0.2	0.1	2.8
/4	80-90	5019	4.6	3.7	0.9	0.01	18	0.5	0.1	10.0
/5	120-130	5020	4.6	3.6	1.0	0.02	30	0.2	0.0	13.3

## Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PH033/1	3.0	4.4	2.2	0.1	14.7		21.2		69	
/2	1.2	1.0	0.9	0.1	3.2		12.4		26	
/3	0.2	0.7	0.1	0.1	1.1		11.7		9	
/4	0.2	0.1	0.1	0.1	0.5		2.0		23	
/5	0.2	0.1	0.2	0.1	0.6		2.0		28	

## Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PH033/1						60.4	2.7	20.0	22.7	16.9	SL
/2						60.8	8.6	14.1	22.7	16.5	SL
/3						59.6	12.0	7.5	19.5	20.8	SCL
/4						69.6	7.6	12.0	19.6	10.8	SCL
/5						74.0	8.9	10.6	19.5	6.4	SL - LS

Profile: PH034

Map unit: BX

Soil Classification: Khangma soil class: DB  
 Soil Taxonomy: Typic Ustorthent [Mesic, loamy, mixed]  
 FAO: Ochric Regosol

Survey area: Khangma RNR-RC  
 Location: 50 m below FCB godown, northern block  
 GPS: 27° 16.48' N, 91° 30.05' E  
 Altitude: 2000m a.s.l

Described & sampled: 13.4.1998, H.B Tamang

Climate: General: Warm temperate, P = ca 1200 mm p.a  
 Recent weather: Hot, sunny

Regional topography: Lower mountains  
 Site position: Middle slope

Slope: 20%, ca 300m long, straight, aspect WNW (290°)  
 Site drainage: Good

Parent material: Solid: Mixed  
 Drift: Colluvium

Land use: Fallow  
 Vegetation: Trifolium repens, Artemisia myriantha, Rumex nepalensis & Dactylis glomerata

Surface: Litter: None  
 Outcrops: Common medium gneiss boulders  
 Stones: Many subrounded & angular gneiss stones.  
 Cracks: None  
 Roots: None  
 Microrelief: Traces of ploughing  
 Faunal activity: None  
 Other features: None

Profile description: (Colours are moist unless indicated)

Cm

0 -8 10YR 4/1 (dark grey) with common medium distinct yellow red & grey mottles; medium sandy loam+; moderate medium & fine subangular blocky; few fine pores; common fine roots; moist & slightly firm; few fine stones; HCl negative; gradual slightly wavy boundary to: [Sample PH034/1 @ 0-8cm]

8-20 10YR 5/4 (yellowish brown) with many fine & medium distinct grey & red mottles; medium sandy clay loam; moderate medium & fine subangular blocky; few fine pores; few fine roots; moist & friable; few medium boulders; HCl negative; gradual slightly wavy boundary to: [Sample PH034/2 @ 10-20 cm]

20-50 10YR 5/4 (yellowish brown) with few medium distinct grey & black mottles; medium sandy clay loam; strong medium & fine angular blocky; weak clayskins; few fine pores; few fine roots; moist & slightly firm; few medium boulders; HCl negative; wormcasts; few flakes of mica; gradual irregular boundary to: [Sample PH034/3 @ 30-40 cm]

50-85 10YR 4/4 (dark yellowish brown) with few fine faint dark mottles; coarse sandy loam; weak fine & medium subangular blocky; few fine pores; moist & slightly firm; few fine stones; HCl negative; flakes of mica muscovite; clear regular boundary to: [Sample PH034/4 @ 60-70 cm]

85-120 10YR 5/4 (yellowish brown) with no mottles; fine sand; single grain; moist & very friable; HCl negative; flakes of mica muscovite; clear regular boundary to: [Sample PH034/5 @ 95-105 cm]

120-150+ 2.5Y 6/4 (light yellowish brown) with no mottles; fine sand; single grain; moist & very friable: [Sample PH034/6 @ 130-140 cm]

SPAL analytical results for BSS

Profile PH034

Survey area: Khangma RNR-RC

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PH034/1	0-8	5010	5.7	4.3	1.4	0.00	16	0.1	0.1	0.8
/2	10-20	5011	5.8	4.3	1.5	0.01	5	0.6	0.1	7.5
/3	30-40	5012	6.0	4.3	1.7	0.00	2	0.6	0.1	5.4
/4	60-70	5013	5.6	4.3	1.3	0.00	35	0.1	1.1	0.1
/5	95-105	5014	6.0	4.1	1.9	0.01	35	0.1	Tr	3.3
/6	130-140	5015	5.7	4.5	1.2	0.04	3	0.2	Tr	20.0

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PH034/1	2.0	0.5	0.3	0.1	2.8		7.3		39	
/2	2.2	0.5	0.3	0.1	3.0		9.0		33	
/3	2.2	0.6	0.1	Tr	3.0		10.0		30	
/4	0.2	0.1	0.1	0.1	0.5		9.2		5	
/5	0.2	0.2	0.1	0.1	0.6		8.1		8	
/6	0.6	0.4	0.1	0.1	1.2		6.0		19	

Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PH034/1						75.4	5.2	9.1	14.3	10.3	SL
/2						51.3	10.5	18.9	29.4	19.3	L
/3						51.1	10.5	9.7	20.2	28.7	SCL
/4						76.8	11.8	7.1	18.9	4.3	SL - LS
/5						70.0	9.8	5.8	15.6	14.5	SL
/6						68.4	25.1	6.1	31.2	0.4	SL

Profile: PH035

Map unit: Sf

Soil Classification: Khangma soil class  
Soil Taxonomy:  
FAO:

Survey area: Khangma RNR-RC  
Location: 30m below RNR-RC Office  
GPS: 27° 16'26 N 91° 30'21 E  
Altitude: 1990 m a.s.l

Described & sampled: 15.4.1998, H B Tamang

Climate: General: cool Temperate, P = ca 1100 mm p.a  
Recent weather: Sunny

Regional topography: Lower mountain  
Site position: Middle terrace

Slope: 26%, ca 400m long concave & NW(320°)  
Site drainage: Good  
Parent material: Solid: Mixed  
Drift: Colluvium

Land use: Fallowland  
Vegetation: Canabies, Artemesia & Rumex

Surface: Litter: None  
Outcrops: Common medium gneiss  
Stones: many medium & fine boulders  
Cracks: None  
Roots: None  
Micro relief: None  
Faunal activity: None  
Other features: None

Profile description: (Colours are moist unless indicated)

Cm

0 -10 7.5YR 5/1 (grey) with no mottle; fine sandy loam; common fine roots; slightly dry & very friable; many medium & fine gneiss & quartz; few earthworms; HCl negative; gradual regular boundary to:  
[Sample PH035/1 @ 0-10 cm]

10-32 10YR 3/1 (very dark grey) with no mottle; fine sandy loam; moderate medium subangular blocky structure; common fine pores; few fine roots; moist & slightly friable; HCl negative; few earthworms; gradual regular boundary to:  
[Sample H035/2 @ 15-25 cm]

32-74 7.5 YR 2.5/1 (black) with no mottle; fine sandy loam; moderate medium subangular blocky structure; few fine roots; moist & slightly friable; few fine gneiss; HCl negative; diffuse boundary to:  
[Sample PH035/3 @ 50-60]

74-100 10YR 4/4 (dark yellowish brown) with common fine faint black mottles; medium sandy loam+; weak medium & fine subangular blocky structure; common fine roots; moist & friable; few fine medium weathering boulders; HCl negative; clear regular boundary to:  
[Sample PH035/4 @ 80-90]

100-150+ 10YR 5/6 (yellowish brown) with no mottle; coarse sand; weak medium & fine subangular structure; moist & very friable; HCl negative; few fine & medium weathering boulders:  
[Sample PH035/5 @ 120-130]



SPAL analytical results for BSS Profile PH035 Survey area: Khangma RNR-RC

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PH035/1	0-10	5057	5.8	4.5	1.3	0.02	35	4.1	0.3	12.8
/2	15-25	5058	5.7	4.1	1.6	0.01	35	2.9	0.3	11.6
/3	50-60	5059	5.6	4.4	1.2	0.02	35	3.6	0.3	12.4
/4	80-90	5060	6.0	4.2	1.8	0.01	9	0.9	0.1	10.0
/5	120-130	5061	6.1	4.7	1.4	0.01	4	0.3	Tr	7.5

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAC	EBS%
PH035/1	12.8	2.3	1.4	0.1	16.6		18.1		92	
/2	6.4	2.9	0.2	Tr	9.5		15.1		63	
/3	13.5	2.9	0.1	0.1	16.6		20.7		80	
/4	4.2	1.4	0.2	Tr	5.9		10.6		55	
/5	1.5	0.9	0.1	Tr	2.5		4.3		58	

Fine earth granulometric.

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PH035/1											
/2						60.3	9.8	16.0	25.8	13.9	SL
/3						48.9	8.5	16.6	25.1	25.9	L
/4						49.1	6.3	15.0	21.3	29.6	SCL
/5						61.5	6.5	15.1	21.6	16.9	SL

Profile: PK032

Map Unit: BFX

Soil classification: Provisional Bhutan soil class: SF  
 Soil Taxonomy: Typic Ustorthent [Mesic, loamy, mixed ]  
 FAO: Ochric Regosol

Survey area: RNR-RC Khangma  
 Location: Mid way between PFO and BNPP staff quarters  
 GPS: 27° 16.15' N, 91° 30. 30' E.  
 Altitude: 2130 m asl

Described & Sampled: 10.4.1997, Kado Tshering

Climate: General: Warm temperate, P = ca 1200 mm p.a  
 Recent weather: Cloudy, heavy shower

Regional topography: Mid mountain  
 Site position: Midslopes

Slope: 35% convex, ca 3km long, aspect NW (335°)  
 Site drainage: Good

Parent material: Solid: Mixed  
 Drift: Colluvium

Land use: Improved pasture within horticulture block  
 Vegetation: Trifolium repens, Artemisia myriantha & Quercus seedlings

Surface: Litter: Few dry Artemisia leaves  
 Outcrop: None  
 Stone: None  
 Cracks: None  
 Microrelief: Discontinuous cattle poaching up to 8 cm deep  
 Roots: None  
 Faunal activity: Ants seen  
 Other features: None

Profile description: (colours are moist unless indicated)

Cm

0-8 10YR 3/3 (dark brown) with few medium distinct greyish brown mottles; fine sandy loam; moderate weak subangular blocky breaking to fine crumb; few medium & fine pores; moist & very friable; few coarse & many fine roots; HCl negative; gradual straight boundary to: [Sample PK032/1@ 0-8 cm]

8-35 10YR 4/6 (dark yellowish brown) with no mottles; silty clay loam; very weak - moderate angular blocky breaking to fine crumb; many fine pores; moist - slight wet & very friable; few medium coarse & fine roots; few coarse hard gneiss stones; HCl negative; rare coarse faunal burrow; gradual straight boundary to: [Sample PK032/2 @ 15-25 cm]

35-55 7.5YR 3/4 (dark brown) with no mottles; medium sandy loam +; very weak - moderate angular blocky breaking to fine crumb; few fine pores; moist - slightly wet & very friable; rare fine roots; rare coarse hard quartz stones; HCl negative; gradual regular boundary to: [Sample PK032/3 @ 40 - 50cm]

55-73 7.5YR 5/3 (brown) with no mottles; loamy medium sand; moderate medium angular blocky breaking to fine crumb; few fine pores; moist - wet & very friable; rare fine roots; rare coarse biotite flakes; HCl slightly positive; gradual straight boundary to: [Sample PK032/4 @ 60-70 cm]

73-89 7.5YR 4/4 (brown) with no mottles; loamy medium sand; moderate medium weak angular blocky breaking to fine crumb; rare medium & few fine pores; moist - slight wet & very friable; few patches of hard quartz & granite; HCl negative; some ants; gradual wavy boundary to: [Sample PK032/5 @ 75-85 cm ]

89-130 5YR 4/4 (brown) with few reddish mottles; loamy coarse sand; medium moderate weak angular blocky breaking to fine crumb; very fine pores; moist- slight wet & friable; highly weathered gneiss & partially hard quartz stones; HCl negative; gradual slightly wavy boundary to: [Sample PK032/6 @ 100-110]

130-163 7.5YR 5/4 (brown) with no mottles; medium sandy loam, with many mica flakes; moderate weak subangular blocky breaking to very fine crumb; few fine pores; moist - slight wet & very friable; very weathered gneiss & granite stones; HCl slightly positive; many muscovite flakes; gradual wavy boundary to:  
 [Sample PK032/7 @140-150 cm]

Comments: Slightly positive HCl reactions and presence of biotite not matched by pH or base status.

SPAL analytical results for BSS

Profile PK032

Survey area: Khangma RNR-RC

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK032/1	0-8	4980	5.7	4.6	1.1	0.01	6	5.1	0.6	8.5
/2	15-25	4981	5.7	4.3	1.4	0.02	1	0.2	0.1	1.5
/3	40-50	4982	5.5	4.2	1.3	0.00	1	0.3	0.1	4.2
/4	60-70	4983	5.3	4.3	1.0	0.00	2	0.1	Tr	2.5
/5	75-85	4984	5.2	3.4	1.8	0.00	2	0.1	Tr	3.3
/6	100-110	4985	5.2	3.6	1.6	0.00	1	0.1	Tr	3.3
/7	140-150	4986	5.2	4.0	1.2	0.00	2	0.1	Tr	5.0

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PK032/1	7.7	2.1	1.4	Tr	11.1		24.5		46	
/2	3.6	0.4	0.9	Tr	4.9		10.2		48	
/3	0.2	0.1	0.5	Tr	1.0		9.7		9	
/4	0.4	0.1	0.2	Tr	0.7		8.8		8	
/5	0.4	0.1	0.1	Tr	0.7		8.0		9	
/6	0.4	0.1	0.1	Tr	0.6		8.3		8	
/7	0.8	0.1	0.1	Tr	1.0		4.4		23	

Fine earth granulometric.

BSS No.	Sand					Total sand	Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106		20-50 micron	2-20	Total silt		
PK032/1						25.6	11.0	29.0	40.0	34.5	CL
/2						25.4	8.8	24.0	32.8	41.9	C
/3						65.3	6.1	6.5	12.6	22.1	SCL
/4						65.5	11.1	7.3	18.4	16.1	SL
/5						67.5	9.0	5.1	14.1	18.5	SL
/6						75.0	7.4	4.6	12.0	12.9	SL
/7						69.3	9.8	9.0	18.8	12.0	SL

Profile: PK036

Map unit: BX

Soil classification: Provisional Bhutan soil class: SB  
 Soil Taxonomy: Typic Ustorthent [Mesic loamy over loamy skeletal mixed]  
 FAO: Ochric Regosol

Survey area: RNRC - RC Khangma  
 Location: Ca 100 m below road & Druk seed corporation store  
 GPS: 27°16.28' N, 91°30.11' E.  
 Altitude: 2010 m a s l

Described & sampled: 10.4.1998, Kado Tshering

Climate: General: Warm temperate, P = ca 1200 mm p.a  
 Recent weather: Showers and cloudy

Regional topography: Low mountain  
 Site position: Midslope  
 Slope: 30%, ca 2km long, convex, aspect NW (325°):  
 Site drainage: Good

Parent material: Solid: Mixed rocks  
 Drift: Colluvium

Land use: Improved pasture  
 Vegetation: Trifolium repens, Festuca arundinacea, Lolium multiflorum, Artemisia myriantha,  
 Bracken (Pteridium aquilinum) & Rumex nepalensis

Surface: Litter: Few pats of cow dung  
 Outcrops: None  
 Stones: Many hard coarse angular blocky gneiss & granite stones  
 Cracks: None  
 Roots: None  
 Microrelief: Discontinuous livestock poaching 2-8 cm deep  
 Faunal activity: Few earthworm & ants seen  
 Other features: None

Profile description: (Colours are moist unless indicated)

Cm

0– 16 10YR 3/2 (very dark greyish brown) with common medium distinct greyish brown mottles; fine sandy loam; weak moderate subangular blocky breaking to fine crumb; very few pores; moist & friable; few medium & fine roots; few medium hard quartz & gneiss stones; HCl negative; gradual regular boundary to:  
 [Sample PK036/1 @ 0-10 cm]

16-70 10YR 4/4 (dark yellowish brown) with few fine distinct greyish brown & reddish brown mottles; coarse sandy loam +; weak moderate subangular blocky breaking to very fine crumb; abundant fine & medium pores; moist & very friable; abundant fine & rare medium roots; common coarse hard quartz, gneiss & granite stones; HCl negative; clear wavy boundary to:  
 [Sample PK036/2 @ 30 - 40 cm]

70-120+ 10YR 5/4 (yellowish brown) with no mottles; coarse loamy sand; very weak medium subangular blocky with massive stones; few medium pores; slightly wet & friable; common fine roots; common coarse hard quartz, gneiss & granite stones; HCl negative; clear wavy boundary to:  
 [Sample PK036/3 @ 90 - 100 cm]

Comment: All rocks and boulders are found to be very weathered throughout the three horizons.

SPAL analytical results for BSS

Profile PK036

Survey area: Khangma RNR-RC

## Reaction, P &amp; organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK036/1	0 – 10	5028	6.3	4.6	1.7	0.00	35	0.3	0.1	2.7
/2	30 – 40	5029	6.1	4.5	1.6	0.01	2	1.0	0.2	4.3
/3	90 - 100	5030	5.7	4.3	1.4	0.00	1	2.9	0.3	10.0

## Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PK036/1	0.2	0.1	1.2	0.2	1.7		1.0		169.0	
/2	1.0	0.4	0.3	0.1	1.8		6.9		26.3	
/3	4.0	0.1	0.5	0.2	4.8		13.9		34.7	

## Fine earth granulometric.

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total Sand	20-50 micron	2-20	Total silt		
PK036/1						81.2	4.0	0.1	4.1	14.7	S
/2						63.1	8.3	14.2	22.5	14.3	SL
/3						57.4	4.6	23.8	28.4	14.1	SL

Profile: PK045

Map unit: BFX

Soil classification: Provisional Bhutan soil class: SB  
 Soil Taxonomy: Typic Ustorthent [Mesic, loamy skeletal, mixed]  
 FAO: Umbric Regosol

Survey area: RNR-RC Khangma  
 Location: Near gully, NE corner of southern block.  
 GPS: 27°16.26' N, 91° 30.22' E  
 Altitude: 2010 m a s l

Described & sampled: 10.4.1998, Kado Tshering

Climate: General: Warm temperate, P = ca 1200 mm p.a  
 Recent weather: Showers and cloudy

Regional topography: Mid mountains  
 Site position: Depression on midslope

Slope: 55% concave, ca 1 km long, aspect NW (338°)  
 Site drainage: Good

Parent material: Solid: Gneiss  
 Drift: Colluvium

Land use: Improved pasture with scrub forest  
 Vegetation: Bracken (*Pteridium aquilinum*), *Artemisia myriantha*, white clover (*Trifolium repens*), and local strawberries

Surface: Litter: *Artemisia* & bracken leaves  
 Outcrops: None  
 Stones: Many hard mixed stones & boulders  
 Cracks: None  
 Roots: Few coarse & many medium  
 Microrelief: None  
 Faunal activity: None  
 Other features: None

Profile description: (Colours are moist unless indicated)

Cm

- 0-16 10YR/ 3/3 (dark brown) with no mottles; fine sandy loam; very weak moderate subangular blocky breaking to fine crumb; very few fine pores; moist & very friable; few coarse & many medium roots; many medium hard quartz, gneiss & granite stones; HCl negative; grubs & earthworm seen; diffuse boundary to:  
 [Sample PK045/1 @ 0-10 cm]
- 16-40 10YR 2/1 (black) with no mottles; fine sandy loam +; very weak - moderate subangular blocky breaking to fine crumb; few coarse, medium & fine pores; moist & very friable; rare coarse & many medium roots; common coarse & many medium hard quartz & gneiss stones; HCl negative; clear gradual boundary to:  
 [Sample PK045/2 @20-30 cm]
- 40-110 10YR 4/3 (brown) with no mottles; fine sandy clay loam; very weak medium subangular blocky breaking to fine crumb; abundant fine & few medium pores: moist - slight wet & very friable; rare coarse & many fine roots; common coarse & medium hard quartz & gneiss stones; HCl negative; diffuse boundary to:  
 [Sample PK045/3 @ 60-70 cm]
- 110-150 10YR 5/3 (brown) with no mottles; medium sandy loam +; very weak medium subangular blocky breaking to fine crumb; abundant fine pores; moist - slightly wet & very friable; few medium roots; common coarse & many medium hard quartz & granite stones; HCl negative; diffuse boundary to: [Not sampled]

Comment: Field description mentions weathered rock as starting at 40+ cm. Hence classified as SB (many quartzite stones in 16-40 cm)

SPAL analytical results for BSS

Profile PK045

Survey area: Khangma RNR-RC

## Reaction, P &amp; organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK045/ /1	5-10	5037	5.5	4.2	1.3	0.01	7	2.2	0.2	9.5
/2	20-30	5038	5.8	4.4	1.4	0.01	3	3.0	0.2	14.2
/3	60-70	5039	6.2	4.2	2.0	0.00	13	1.0	8.0	0.1

## Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PK045 /1	4.0	0.6	0.3	0.1	4.9		12.1		41	
/2	5.1	0.9	0.1	0.1	6.1		15.2		40	
/3	1.2	1.0	0.1	0.1	2.4		8.5		28	

## Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PK045 /1						60.8	9.1	18.1	27.2	12.0	SL
/2						57.9	8.0	21.4	29.4	12.7	SL
/3						65.4	8.2	18.6	26.8	7.8	SL

Profile: PK046

Map unit: W

Soil classification: Provisional Bhutan soil class: HG  
 Soil Taxonomy: Mollic Epiaquent [Mesic, loamy, mixed]  
 FAO: Mollic Gleysol

Survey area: RNR-RC Khangma  
 Location: NW corner of fence & 25 m inside fence, northern block  
 GPS: 27°16.57' N, 91° 30.12' E.  
 Altitude: 1900 m a. s. l.

Described & sampled: 14.4. 1998 Kado Tshering

Climate: General: Warm temperate, P = 1200 mm p.a  
 Recent weather: Partly cloudy

Regional topography: Middle mountains  
 Site position: Depression on midslope

Slope: 15°, ca 0.5 km long concave, aspect WNW (300°)  
 Site drainage: Imperfect

Parent material: Solid: Gneiss  
 Drift: Colluvium

Land use: Abandoned terrace  
 Vegetation: Artemisia myriantha, Trifolium repens; Rumex nepalensis; & Bracken (Pteridium aquilinum)

Surface: Litter: Discontinuous up to 2-5 cm, thick.  
 Outcrops: None  
 Stones: Abundant medium hard subangular gneiss stones  
 Cracks: None  
 Roots: None  
 Microrelief: None  
 Faunal activity: None  
 Other features: None

Profile description: (Colours are moist unless indicated)  
 cm

0-16 7.5YR 4/1 (dark grey) with many medium distinct dark brown mottles; fine sandy loam; weak medium subangular blocky breaking to fine crumb; few fine pores; moist & very friable; many fine & few medium roots; few fine hard angular gneiss stones; HCl negative; many insect holes; few charcoal & decayed roots; gradual regular boundary to: [Sample PK046/1 @ 0-10 cm]

16-60 7.5YR 2.5/1 (black) with no mottles; fine sandy loam +; weak medium angular blocky breaking to fine crumb; few fine pores; moist & very friable; few coarse & many fine roots; many fine & medium hard angular gneiss stones; few insect holes; HCl negative; clear wavy boundary to: [Sample PK046/2 @ 30-40 cm]

60 -120 10YR 5/3 (brown) with many medium grey brown & coarse reddish dark brown mottles; coarse sandy clay loam +; weak medium angular blocky breaking to fine crumb; few fine pores; moist - slight wet & very friable; few medium & fine roots; few coarse & many medium angular & subangular gneiss stones; HCl negative; gradual abrupt boundary to: [Sample PK046/3 @ 80-90]

120-150 10YR 6/3 (pale brown) with no mottles; coarse loamy sand; medium weak subangular blocky breaking to fine crumb; few fine pores; moist - slightly wet & very loose; rare fine roots; few coarse & many medium subangular & angular gneiss stones; HCl negative: [Not sampled]

Comment: Advanced weathering in gneiss and granite from third horizon down.



SPAL analytical results for BSS

Profile PK046

Survey area: Khangma RNR-RC

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK046 /1	0 -10	5062	5.9	4.4	1.5	0.01	6	2.6	0.2	11.8
/2	30-40	5063	6.1	4.4	1.7	0.01	3	1.6	0.1	12.3
/3	80-90	5064	6.2	4.2	2.0	0.01	25	0.6	0.1	10.4

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PK046 /1	8.8	2.3	0.3	0.1	11.5		15.6		74	
/2	5.6	2.0	0.2	0.1	7.9		12.7		62	
/3	1.6	1.9	0.2	0.1	3.8		8.4		45	

Fine earth granulometric.

BSS No.	Sand					Total sand	Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106		20-50 micron	2-20	Total silt		
PK046 /1						49.3	10.8	16.9	27.7	23.0	L
/2						54.0	10.1	13.5	23.6	22.4	SCL
/3						56.7	10.0	15.5	25.5	17.8	SL

Profile: PK047

Map unit: BX

Soil classification: Provisional Bhutan soil class: SF  
 Soil Taxonomy: Typic Ustorthent [mesic, loamy skeletal, mixed]  
 FAO: Ochric Regosol

Survey area: RNR-RC Khangma  
 Location: On North side of RPPC; half way down hill  
 GPS: 27°16. 40' N. 91° 30.16' E.  
 Altitude: 1940 m a. s. l.

Described & sampled: 15.4.1998, Kado Tshering

Climate: General: Warm temperate, P = 1200 mm pa  
 Recent weather: Sunny

Regional topography: Middle mountain  
 Site position: Bench on midslope

Slope: 25%, concave; ca 0.5 km long; aspect WSW (240°)  
 Site drainage: Good

Parent material: Solid: Gneiss  
 Drift: Colluvium

Land use: Abandoned terraced  
 Vegetation : Artemisia myriantha, Trifolium repens, bracken (Pteridium aquilinum) & Rubia cordifolia

Surface: Litter: Very thin irregular layer of burnt organic matter  
 Outcrops: None  
 Stones: Abundant medium hard gneiss & granite angular stones  
 Cracks: None  
 Roots: None  
 Microrelief: Discontinuous steps, 1-5 cm high.  
 Faunal activity: Earthworms  
 Other features: None

Profile description: (Colours are moist unless indicated)

Cm

- 0-5 10YR/ 4/2 (dark greyish brown) with many medium distinct reddish orange & grey brown mottles; fine loamy sand; crumb bound by root; few fine pores; moist & slightly firm; many medium & abundant fine roots; many medium & few coarse hard gneiss stones; HCl negative; gradual regular boundary to: [Sample PK047/1 @ 0-5 cm]
- 5-38 10YR/ 6/4 (light yellowish brown ) with common coarse distinct reddish orange mottles; silty clay; strong medium angular blocky; few fine pores; moist & slight firm; many fine & few medium roots; common fine & medium hard gneiss quartz angular stones; HCl negative; earthworm seen; gradual wavy boundary to: [Sample PK047/2 @ 20-30 cm]
- 38-60 10YR 3/1 (very dark grey) with common coarse distinct greyish brown and dark brown mottles; fine sandy clay; very strong medium angular blocky; weak discontinuous clay cutans; few medium & many fine pores; moist & very firm, plastic & sticky; many fine roots; rare fine hard angular quartz & gneiss stones; HCl negative; clear straight boundary to: [Sample PK047/3 @ 45-55 cm]
- 60-100 10YR 6/6 (brownish yellow) with few medium distinct reddish orange mottles; stony medium sand; weak moderate angular blocky breaking to fine crumb; few coarse & many fine pores; moist; & friable; few fine roots; abundant mixed weathered quartz & granite stones; HCl negative; few medium decomposed roots; gradual wavy boundary to: [Sample PK047/4 @ 70-80]
- 100-164 10YR 6/6 (brownish yellow) with many medium distinct dark red & dark brown mottles; loamy medium sand; very weak angular blocky breaking to moderate fine subangular blocky & crumb; abundant fine pores; moist & friable between stones; abundant mixed colours weathered stones; HCl negative; abundant quartz & gneiss stones; gradual wavy boundary to: [Sample PK047/5 @ 110-120 cm]

140-160+ 10YR 7/4 (very pale brown) with mixed weathered colours; loamy medium sand; very weak medium angular blocky breaking to massive crumbs; moist - wet & loose; highly weathered stones;  
[Sample PK047/@140-160]

SPAL analytical results for BSS

Profile PK047

Survey area: Khangma RNR-RC

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK047 /1	0-5	5048	6.0	4.7	1.3	0.02	29	2.2	0.2	9.5
2	20-30	5049	5.5	3.9	1.6	0.01	1	0.2	0.1	5.0
/3	45-55	5050	5.3	3.9	1.4	0.01	2	0.5	Tr	10.0
/4	70-80	5051	5.7	3.9	1.8	0.00	4	0.2	Tr	10.0
/5	110-120	5052	5.4	3.6	1.8	0.01	3	0.2	Tr	10.0
/6	140-160	5053	5.8	3.8	2.0	0.00	4	0.1	0.1	1.0

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PK047 /1	2.8	0.4	1.3	0.1	4.5	7.7		59		
/2	0.2	0.1	0.4	0.1	0.8	14.2		6		
/3	0.2	0.1	0.3	0.1	0.6	17.2		4		
/4	0.2	0.1	0.2	0.1	0.5	5.6		10		
/5	0.8	0.3	0.2	0.1	1.4	16.4		8		
/6	0.8	0.5	0.2	0.1	1.5	4.9		31		

Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PK047 /1						58.6	11.3	18.3	29.6	11.9	SL
2						57.4	5.7	19.4	25.1	17.4	SL
/3						43.3	7.1	23.4	30.5	26.3	L
/4						71.1	11.4	9.4	20.8	8.1	SL
/5						62.2	17.5	11.3	28.8	8.9	SL
/6						75.5	9.8	11.4	20.5	3.9	LS

Profile: Pd012

Map unit: BX

Soil classification: Khangma soil class: DB  
 Soil Taxonomy: Typic Ustorthent [Mesic, coarse loamy, mixed]  
 FAO: Ochric Regosol

Survey area : Khangma RNR-RC  
 Location: Approximately 8 m above telephone pole along feeder road in southern block  
 GPS: 27° 16.13' N, 91° 30.39' E  
 Altitude: 2190 m asl

Described & sampled: 9.4.1998, Tsheten Dorji

Climate: General: Warm temperate, P = ca 1200 mm p.a  
 Recent weather: Foggy

Regional topography: Low mountain  
 Site position: Upper slope

Slope: 36%, ca 1 km, convex, aspect WNW (296°)  
 Site drainage: Good

Parent material: Solid: Thimphu Gneiss & quartz  
 Drift: Colluvium

Land use: Abandoned apple orchard  
 Vegetation: Pteridium aquilinum, Rubus elliptica, Artemisia myriantha & Gaultharia spp.

Surface: Litter: Discontinuous litter of 1 cm,  
 consisting of bracken fronds and grasses  
 Outcrops: None  
 Stones: Few medium very hard subangular gneiss & quartz boulders  
 Cracks: None  
 Roots : None  
 Microrelief: None  
 Faunal activity: None  
 Other features: None

Profile description : (Colours are moist unless indicated)  
 cm

- 0 - 8 10YR 3/2 (very dark greyish brown) with common fine distinct reddish mottles; loamy fine sand; moderate medium subangular blocky; abundant pores; moist & friable; abundant fine & very fine grass roots; common hard quartz & gneiss stones; HCl negative; common fine muscovite flakes; clear regular boundary to:  
 [Sample Pd012/1 @ 0 - 8cm]
- 8 - 16 10YR 4/2 (dark greyish brown) with weathering rock colours of grey, white & dark; coarse sand; weak medium subangular blocky breaking to single grain; abundant pores; moist & very friable; abundant very fine grass roots & few medium bracken roots; common medium hard gneiss & quartz stones; HCl negative; abundant muscovite flakes; diffuse boundary to:  
 [Sample Pd012/2 @ 8 -16 cm]
- 16 - 24 10YR 4/3 (brown) with weathering rock colours of grey, white and dark & few orange mottles; gravelly sand; single grain; abundant pores; moist & very friable; many fine & few medium roots; common fine hard gneiss & quartz gravel; HCl negative; few ants seen; abundant muscovite flakes; clear regular boundary to:  
 [Sample Pd012/3 @ 16 - 24 cm]
- 24-34 10YR 3/2 (very dark greyish brown) with no mottles; fine sandy loam; moderate medium breaking to fine subangular blocky; abundant pores; moist & friable; many fine & medium roots; common medium hard gneiss & quartz stones; HCl negative; abundant muscovite flakes; clear gradual boundary to:  
 [Sample Pd012/4 @ 24 - 30]
- 34 - 41 10YR 4/3 (brown) with weathering rock colours of grey, white, orange and black; very gravelly sand; single grain; common pores; moist & very friable; common fine roots; abundant gravels & common medium hard gneiss & quartz stones; HCl negative; abundant muscovite flakes; clear gradual boundary to:  
 [Sample Pd012/5 @ 34 - 40]

- 41-51 10YR 3/1 (very dark grey) with common coarse faint yellowish brown mottles; coarse sandy loam+; moderate coarse breaking to medium subangular blocky; many fine & medium pores; moist & slightly friable; many fine & few coarse roots; few medium hard gneiss & quartz stones; HCl negative; abundant muscovite flakes; diffuse boundary to: [Sample Pd012/6 @ 41-50 cm]
- 51-62 10YR 3/1 (very dark grey) but darker than 41 – 51 cm with common coarse faint yellowish brown mottles; coarse sandy loam+; moderate coarse breaking to medium subangular blocky; many fine & medium pores; moist & slightly friable; common fine roots; few medium hard gneiss & quartz stones; HCl negative; few termites & centipedes seen; abundant muscovite flakes; diffuse boundary to: [Sample Pd012/7 @ 51-60]
- 62-79 2.5Y 2.5/1 (black) with no mottles; coarse sandy loam+; moderate coarse breaking to moderate medium subangular blocky; weak discontinuous organic cutans; many fine & medium pores; moist & slightly friable; common fine roots; common coarse & few medium gneiss & quartz stones; HCl negative; abundant muscovite flakes; clear regular boundary to: [Sample Pd012/8 @ 65-75]
- 79-93 10YR 4/2 (dark greyish brown) with common coarse faint grey mottles; coarse sandy loam; moderate medium breaking to fine subangular blocky; common medium & fine pores; moist & slightly friable; few fine roots; common coarse & medium hard gneiss & quartz stones; HCl negative; few muscovite flakes; clear wavy boundary to: [Sample Pd012/9 @ 80-90]
- 93-155 10YR 4/4 (dark yellowish brown) with few fine distinct reddish brown & few faint grey mottles; coarse sandy loam; moderate medium breaking to fine sub angular blocky; common medium fine pores; moist & slightly firm (due to presence of boulders); rare fine roots; common boulders (up to 70 x 35 cm) common coarse & medium hard gneiss & quartz stones; HCl negative; few muscovite flakes; clear regular boundary to: [Sample Pd012/10 @ 95-105]
- 155-197 2.5Y 4/4 (olive brown) with no mottles; loamy coarse sand; weak medium breaking to fine subangular blocky; common medium & fine pores; moist & slightly friable; rare fine roots; abundant coarse & medium hard gneiss & quartz stones; HCl negative; few muscovite flakes: [Sample Pd012/11 @ 160-170]
- Comments: Very complex profile affected mainly by naturally active colluviation. There may be three buried topsoils. The first (8 – 16) merges with the modern topsoil. The second is at 24 – 34 cm, and the third at 62 – 79. The burial may be due to accumulation of road construction spoil.

SPAL analytical results for BSS

Profile Pd012

Survey area: Khangma RNR-RC

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC MS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
Pd012 /1	0-8	4992	5.9	4.2	1.7	0.00	6	0.9	0.1	6.9
/2	8-16	4993	5.9	4.3	1.6	0.01	6	0.9	0.1	11.2
/3	16-24	4994	5.9	4.0	1.9	0.00	4	0.2	0.1	3.3
/4	24-30	4995	5.9	4.2	1.7	0.00	4	0.7	0.1	5.8
/5	34-40	4996	6.0	4.8	1.2	0.01	4	0.1	0.1	1.6
/6	41-50	4997	6.1	4.9	1.2	0.00	5	1.4	0.1	11.6
/7	51-60	4998	5.8	4.3	1.5	0.00	2	1.1	0.1	9.1
/8	65-75	4999	5.7	4.3	1.4	0.01	1	2.0	0.1	12.5
/9	80-90	5000	5.7	4.1	1.6	0.01	1	1.1	0.1	9.1
/10	95-105	5001	5.8	4.3	1.5	0.00	1	0.4	0.1	5.7
/11	160-170	5002	5.9	4.3	1.6	0.00	8	0.4	0.1	5.7

## Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
Pd012 /1	2.8	0.8	0.8	0.1	4.4	nd	9.4	nd	47	nd
/2	1.8	0.5	0.6	0.1	2.9	nd	6.7	nd	44	nd
/3	5.3	1.2	0.5	0.1	7.1	nd	5.4	nd	100	nd
/4	0.2	0.1	0.3	0.1	0.7	nd	8.3	nd	8	nd
/5	1.2	0.2	0.2	0.1	2.1	nd	5.5	nd	40	nd
/6	5.0	1.1	0.2	0.1	6.4	nd	12.2	nd	52	nd
/7	2.2	1.8	0.1	0.1	4.3	nd	17.1	nd	25	nd
/8	1.4	1.5	0.1	0.1	3.1	nd	21.0	nd	15	nd
/9	0.2	0.6	0.1	0.1	1.0	nd	15.8	nd	6	nd
/10	0.2	0.5	0.12	0.1	0.9	nd	13.6	nd	7	nd
/11	0.2	0.3	0.1	0.1	0.7	nd	8.2	nd	8	nd

## Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
Pd012 /1	nd	nd	nd	nd	nd	60.9	9.4	13.9	23.3	15.9	SL
/2	nd	nd	nd	nd	nd	64.7	14.2	12.7	26.9	8.3	SL
/3	nd	nd	nd	nd	nd	75.9	8.9	8.9	17.8	6.3	LS
/4	nd	nd	nd	nd	nd	79.2	6.3	7.9	14.2	6.7	LS
/5	nd	nd	nd	nd	nd	67.2	11.3	14.0	25.3	7.5	SL
/6	nd	nd	nd	nd	nd	80.1	7.0	7.9	14.9	4.9	SL
/7	nd	nd	nd	nd	nd	64.3	12.0	13.1	25.1	10.5	SL
/8	nd	nd	nd	nd	nd	54.8	12.3	17.8	30.1	15.1	SL
/9	nd	nd	nd	nd	nd	3.6	18.7	31.0	49.7	46.7	ZiC
/10	nd	nd	nd	nd	nd	3.6	18.7	31.0	49.7	46.7	LC
/11	nd	nd	nd	nd	nd	54.3	9.2	14.8	24.0	21.7	SCL

## APPENDIX C: CORRELATION OF KHANGMA SOILS

### APPC. 1 Soil classification and correlation in Bhutan.

Table 5.3 in the main report summarises the correlations of the Khangma soil classes with the two main international soil classifications. This appendix discusses the reasoning behind the correlations assigned. This is necessary because BSSP is still at an early stage of its operations and the soil correlations need to be worked out.

The Soil Taxonomy (ST) was originally developed to meet the needs of soil survey in the continental United States (Soil Survey Staff 1975). It has been extended since then, but it is still stronger on temperate than on tropical soils. It is detailed and comprehensive. For this survey we used the 1992 version of the identification keys (Soil Survey Staff 1992), but will use later versions in future. The FAO (1974 and 1988) system is more globally oriented, and is less detailed, but still quite comprehensive. One of its advantages is that it uses more traditional and comprehensible soil names. . For this survey we used the 1988 revision, but will use the 1998 update of the Word Reference base for Soil Resources in future

Nepal has used the Soil Taxonomy, but previous consultants in Bhutan have preferred the FAO system. At this stage it is not necessary for Bhutan to choose between them. It is intended that, at present, BSSP will continue to use local soil classes and names within Bhutan, and will correlate them against both of the international systems. For the future, BSSP is exploring the possibility of adapting the multi-horizon approach of the FitzPatrick and the French Referentiel Pedologique systems to Bhutan conditions (see BSSP Working Paper WP2, 1998).

### APPC. 2 General criteria

Before assigning individual soils to international classes, there are some general environmental considerations for the Centre as a whole that need to be determined for the application of Soil Taxonomy.

#### APPC.2.1 Soil moisture regime

This is necessary for the definition of suborders or great groups in ST. In the absence of soil moisture data, soil moisture regimes are normally approximated from the totals and seasonal distribution of the rainfall. Khangma appears to have an ustic climate, which is defined as having more than 90 consecutive dry days per year and having a summer rainfall distribution. However the frequent recurrence of a late-ending monsoon with early spring rains in the following year could give an udic regime. For the present all of the soils at Khangma have been assigned to ustic categories, except for the poorly drained soils (Hg). However the ustic-udic assignment should be re-examined when more rainfall data are available. The poorly drained soils have an aquic moisture regime, as they are more or less permanently wet due to their topographic position.

#### APPC.2.2 Soil temperature regime

This is a criterion for classification at family level in ST. In the absence of soil temperature data, atmospheric temperatures are used. Kanglung has a temperature regime that is exactly on the mesic – thermic boundary, which is defined on an annual mean of 15<sup>0</sup> C and a summer – winter difference between monthly means greater than 5<sup>0</sup> C. As Khangma is slightly higher and cooler than Kanglung, it is assumed to have a mesic soil temperature regime.

#### APPC.2.3 Mineralogy class

This is another family criterion in Soil Taxonomy. Although muscovite is a visible component in some soils at Khangma, mica contents are less than 40 % of the combined sand and gravel fractions. The soils therefore do not qualify for the micaceous mineralogy class, and are classified as mixed.

APPC.2.4      Particle size class

This varies with stone content and fine earth texture, and is therefore different for the different soil classes at Khangma (see Table 5.3 in main text Section 5).

APPC. 3      Correlation of Khangma soils

APPC.3.1      Very shallow soils (VS).

Most of these soils are residual and not intensely weathered. They fit well into the Inceptisols of Soil Taxonomy or the Leptosols of FAO. Most of the dark topsoils are shallow (< 18 cm) so that the profiles qualify for the suborder of Ochrepts in ST. The soil moisture regime puts them into the Ustochrept great group. In the FAO Soil Map of the World, these soils mostly qualify as Lithic (where very shallow) or Dystric (indicating low pH and base status) Leptosols.

APPC.3.2      Well drained hill soils.

All four of these classes (SB, SF, DB and DF) appear to be developed in such mobile and polycyclic colluvium that they are best classified as Regosols (FAO) or Orthents (Soil Taxonomy). In the FAO system, the presence/absence of boulders is not significant and the soils are differentiated into Ochric (shallow topsoils) or Umbric (deep or merged topsoils) Regosols. In Soil Taxonomy they are all Typic Ustorthents. The bouldery and non – bouldery classes are separated on particle size class at family level, with the bouldery classes as loamy skeletal, and the boulder-free as loamy.

APPC.3.3      Poorly drained soils (Hg).

These soils are probably wet all year, and qualify as Aquepts in Soil Taxonomy and Gleysols in FAO. Some of them have low decomposition rates and have accumulated mucky topsoils with high organic matter contents. However none appear to be organic or deep enough to qualify as Histosols (in either system). Many of these soils are wet because of lateral throughflow seepage, so that they qualify for the Epi – rather than Endo – groups in Aquept suborder of Soil Taxonomy. Although insufficient for the Histosols, the organic matter contents are high enough in some of these soils for them to qualify as Umbric or Mollic subgroups or subunits in both systems.



APPENDIX D: SOIL MAP OF KHANGMA RNR-RC

