**Royal Government of Bhutan**

**Soil Survey Unit (SSU)**
National Soil Services Centre (NSSC), Semtokha
Council for RNR Research of Bhutan (CoRRB)
**Ministry of Agriculture**

# REPORT ON THE SOILS OF MERAK AND SAKTEN

**Report No. SS 8**

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## SUMMARY

A reconnaissance of the soils of Merak and Sakten in Trashigang Dzongkhag was carried out during October 1998. It was the first reconnaissance done by Soil Survey Unit.

The areas examined cover about 300 ha at Merak on the north bank of Nyera Ama Ri, and about 1000 ha at Sakten on both banks of Gum Ri. The areas include floodplain, river terrace and hill slopes. At present the sites are mostly under natural pastures and woodland. At Sakten some land is used for growing buckwheat and house vegetables. At Merak there is no cultivation, except for house garden vegetables.

The soils were examined in 61 routine observations and 11 detailed description but only 10 of the profiles were sampled. The soils are mainly classified according to the geomorphology of the site.

The soils seen at Merak are divided into three main groups: floodplain, terrace soils and hill soils. Terrace soils are further divided into those of low and medium terraces. The floodplain and lower terrace soils have many boulders. The medium terrace soils are fairly well drained and have few or no stones. The hill soils are predominantly bouldery and shallow. All of these soils have fairly uniform textures of silty loam to fine sandy clay loam.

The soils seen at Sakten are divided into floodplain, terrace, hill, and gley soils. The terrace soils are subdivided between low, medium and high terraces. The textures are mainly fine sandy clay loam topsoils over silty loam to sandy loam subsoils. These soils are generally free of stones but the subsoils contain few to common boulders and stones in places. The hill soils are subdivided into silty, fine sandy and granite hill classes, mainly on textures. The floodplain soils are shallow and stony overlying dense beds of hard angular boulders. Gley soils are permanently wet and have grey colours.

The soils in both areas are very acid and have high levels of organic carbon, except for the gley soils. Total nitrogen levels are moderate but available phosphate levels are very low.

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## ABBREVIATIONS AND GLOSSARY

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

| | |
|---|---|
| AAS | Atomic absorption spectrophotometery |
| ACB | Austrian Co-operation Bureau |
| AHT | Agrar - und HydrotechniK, GmbH, (Germany) |
| AHD | (former) Animal Husbandry Division (now LSD), MoA |
| Alluvial fan | Poorly stratified and sorted material deposited in side valley |
| AmOAc | Ammonium acetate (extractant for exchangeable cations and for measuring CEC) |
| AP | Arunachal Pradesh |
| Av | Available |
| AvP, AP | Available Phosphate |
| amsl | Above mean sea level |
| asl | Above sea level |
| BHU | Basic Health Unit |
| BP | Before present |
| BS% | Base saturation percentage |
| C | Clay |
| ca | Approximately |
| CEC | Cation exchange capacity |
| Chimi | Constituency Member of National Assembly |
| Chipon, Choepen | Village messenger |
| Chhu | Stream or river |
| CL | Clay loam |
| Colluvium | Local hillwash, moved by surface erosion and slow non-glacial creep processes. |
| Complex | Soil mapping unit with several co-equal soil classes |
| Consociation | Soil mapping unit with one soil class dominant but others as minor constituents |
| CoRRB | Council for RNR Research of Bhutan |
| Creep | Slow gravitational mass movement of colluvium downslope. |
| Danida | Danish International Development Assistance |
| Dzongda | District Officer or Administrator |
| Dzongrab | Deputy Administrator |
| Dungpa | Special Area Administrator |
| Dzongkhag | Administrative district |
| DSLR | Department of Survey and Land Records |
| EC | Electrical conductivity |
| ESCAP | Economic and Social Commission for Asia and the Pacific, United Nations |
| Exch | Exchangeable (for cations) |
| Extr | Extractable (for soil nutrients) |
| FAO | Food and Agriculture Organisation of United Nations |
| FC | Field capacity (0.1 bar) |
| fe | fine earth (particle size < 2mm) |
| FYM | Farmyard manure |
| Geog | Block or subdistrict, administrative subdivision of Dzongkhag. |
| GIS | Geographical information system |
| Gley | Soil that is permanently wet, poorly aerated and has predominantly 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 |
| GPS | Global positioning system |
| GSI | Geological Survey of India |
| Gully wash | Rapid movement of coarse, commonly bouldery, unlayered materials down steep streams. |
| Gup | Head of geog |
| GYT | Geog Yargay Tshogchung (Block development team) |
| ha | Hectare |
| HCl | Hydrochloric acid |
| IFMP | Integrated Forest Management Project, Ura |
| Kamsing, Kamshing | Rainfed agriculture |
| Krotovina | Old faunal burrow filled with dark soil from topsoil |
| L | Loam |
| LUPP | Land Use Planning Project, in PPD |
| LUSS | Land Use and Statistics Section, in PPD |
| MC% | Moisture content % (w/w) |
| me | milliequivalent (unit of exchangeable cations) |
| me% | milliequivalents per 100 g fine earth |
| MLT | Miscellaneous Land Type |
| MoA | Ministry of Agriculture |
| mS/cm | milliSiemens per centimetre (unit of electrical conductivity) |
| MTI | Ministry of Trade and Industry |
| Nd | No data |
| $NH_4OAc$ | Ammonium acetate |
| NSSC | National Soil Services Centre, REID, Semtokha |
| OC | Organic carbon |
| OM | Organic matter |
| Orogeny | Formation of mountains by uplift and buckling of Earth's crust |
| P | Precipitation, rainfall |
| P | Phosphate |
| PD | Programme Director |
| 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) |
| 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 |
| S | Sand |
| Saprolite | Soft weathered rock beneath solum, often reddish |
| Si | Silt |
| Sk | Skeletal (high stone content) |
| SMU | Soil mapping unit |
| SoI | Survey of India |

| | |
|---|---|
| Sokshing | Forest from which needle or leaf litter is collected for livestock bedding and FYM. |
| Solum | True soil, in which soil processes have removed most traces of parent material structure. |
| sp, spp | Species (singular & plural) |
| SPAL | Soils and Plant Analysis Laboratory, NSSC, REID, Semtokha. |
| ST | Soil Taxonomy (US system of soil classification) |
| Surface wash | Movement of individual soil particles by running surface water. |
| Tr | Trace |
| TEB | Total exchangeable bases (= exchangeable Ca + Mg + Na + K) |
| TLB | True left bank (facing downstream) |
| TN | Total nitrogen |
| TP | Total phosphate |
| TRB | True right bank (facing downstream) |
| Tshogpa | Headman of village |
| USDA | United States Department of Agriculture |
| v/v | % by volume |
| WR | Weathered rock |
| WRB | World Reference Base for Soil Resources (ISRIC development of FAO system of soil classification) |
| w/w | % by weight |
| X | Exchangeable (for cation) |
| Z,Zi | Silt |

Plus sign (+) with soil texture indicates slightly higher clay content than normal for the class, e.g. sandy loam + is transitional from sandy loam towards sandy clay loam.

# 1. INTRODUCTION

## 1.1 Merak and Sakten

Merak and Sakten form a restricted area under the Merak-Sakten Dungkhag in Trashigang Dzongkhag. The area is not served by roads, and walking is the only way to reach these places. They are in the most eastern and are one of the more inaccessible settled areas of Bhutan. Merak-Sakten shares a common boundary with Arunachal Pradesh (India). The mainly Brokpa people dwelling in these places are distinct in dress and language from the rest of Bhutan. Their main livelihood is their herds of yaks, zhos (crossbreed of yak and local cow), cattle and sheep. Most of these kept for dairy products, but at times they are slaughtered for meat. Even though there is some arable land, arable agriculture is not extensive. Arable crops are not grown at all in Merak but buckwheat is grown in Sakten. However some leaf and root vegetables are grown in house gardens in Merak.

Merak lies in the valley of Nyera Ama Ri and Sakten lies in the valley of Gum Ri. It is about one day (seven hours) walk from Merak to Sakten. The altitude of Merak is at about 3400-3500 m asl, and Sakten lies at an altitude of 2900 m and above. The pass between them, Nyakchung La, is at 4100 m +.

Merak and Sakten each have their own RNR Centre under the Trashigang RNR Coordinator. They are served by RNR-RC Khangma for research. They have each got Livestock and Agriculture extension staff. The livestock division is more active than the agriculture division, as there are limited areas of agricultural crops, such as mustard greens, radish and buckwheat.

## 1.2 Aims of the Merak and Sakten soil survey

This soil reconnaissance was undertaken with the objectives of:

- Providing Merak and Sakten administrators, people and RNR staff with general information on the nature and distribution of the soils in their arable and potential arable areas.
- Indicating the extent of suitable soils at Merak and Sakten for future establishment of temperate cereal crops such as wheat and barley.
- Training of SSU staff in the techniques of rapid soils reconnaissance.
- Providing SSU with data for the development of a national soil classification, and of national and regional soil maps.

# 2. SURVEY AREA

## 2.1 Location and extent

Administratively the Merak and Sakten geogs form the Merak – Sakten Dungkhag under Trashigang Dzongkhag. They are located in the extreme east of the country, and share a boundary with the Indian state of Arunachal Pradesh (see Figure 2.1).

Only limited observations were made of the soils in the areas near settlements, in order to check on the possibilities for arable crops, and the whole of the Dunghkahg was not surveyed.

The Merak area is located in the valley of Nyera Ama Ri, on true right bank. It stretches from latitude $27^0$ 17.84' to $27^0$ 18.51'N and from longitude $91^0$ 50.76' to $91^0$ 52.12' E.

The Sakten area is located on both banks of the valley of Gum Ri. It stretches from latitude $27^0$ 23.38' to $27^0$ 24.46' N and from longitude $91^0$ 55.30' to $91^0$ 56.97' E.

As these are only general soil observations, no survey boundaries have been defined. However the areas examined cover about 300 ha at Merak and 1000 ha at Sakten.

## 2.2 Climate

We have not found any climatic data for Merak or Sakten. The nearest meteorological station with substantial data is Radhi. This is 2000 m lower than Merak and 1500 m below Sakten, and is located on a north facing slope in a deeply entrenched valley. There is therefore little benefit in trying to extrapolate its climate up to Merak and Sakten.

In terms of agricultural potential the critical constraint for both Merak and Sakten is temperature. Probably the most informative climatic data are those from the IFMP area at Ura (Gratzer *et al,* 1997). Their data for Tangsurung (at 3400 m) and plot 3 (at 3510 m) are assumed to give a rough indication of the temperature regime at Merak. These indicate that the average temperature is below freezing for 3 – 4 months per year, the mean minimum is below freezing for 4 – 5 months per year, and the mean maximum is between 0 and 3 $^0$C in January and February and rises to about 15 – 18 $^0$C in the monsoon months of June – September. Occasional frosts can occur as late as April and as early as November.

The data for the IFMP compound at Ura (3100 m) probably gives a general indication of the temperature regime at Sakten. Gratzer *et al* (1997) found a similar seasonal temperature regime as for the higher stations, but with slightly higher minimum temperatures. Similarities in altitude suggest that the meteorological data for Lamey Gompa compound (at 2900 m asl) near Jakar can also give a rough indication of temperatures at Sakten. The Lamey Gompa data shows that the mean minimum temperature is about 1.5 $^0$C in January and rises to 10 $^0$C in July. The mean maximum is about 7 $^0$C in January and rises to about 18 $^0$C in July. These are slightly higher than at Ura.

*Table 2.1 Climatic summary for Lame Gompa*

| | J | F | M | A | M | J | J | A | S | O | N | D | Year average /total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mean daily temperature ($^0$C)** | | | | | | | | | | | | | |
| 1990-1996 | 3.7 | 5.5 | 8.6 | 11.0 | 14.2 | 16.7 | 17.8 | 17.7 | 15.9 | 12.8 | 7.7 | 4.3 | **11.3** |
| **Average rain fall (mm)** | | | | | | | | | | | | | |
| 1981-1996 | 6.7 | 14.7 | 27.3 | 40.8 | 69.8 | 127.9 | 164.3 | 160.9 | 113.0 | 38.7 | 12.6 | 1.3 | **741.2** |

Source: Data supplied by Jakar RNR-RC, 1997.

The IFMP data indicate that site aspect is an important influence on air temperatures when the skies are clear. During the monsoon, high cloud cover reduces the aspect effect and altitude appears to be the predominant factor. It is worth noting that the settlement and the main area of gently sloping land at Merak have a predominantly southerly aspect. Sakten is also in an east – west valley. The main settlement and cultivated area is on the north bank, i.e. it has a mainly southerly aspect, but there are also some habitations, cropped areas and pastures on the south bank, facing northwards.

Because of differences in the local macro- and meso-topographies and the spatial variability of weather data, it is not worthwhile trying to extrapolate rainfall data from the Ura or Lame Gompa meteorological stations to Merak or Sakten. Cloud and mist cover during the monsoon season is likely to be high, but it is not known how much this falls as rain. The winter months are fairly dry and the limited precipitation at Merak falls as snow. Snow is less frequent at Sakten.

## 2.3 Geology and soil parent materials

The Dungkhag is mostly underlain by rocks of the Merak-Sakten Tethyan block. These overlie the high grade metamorphic rocks of the Himalayan Central Crystalline Complex. The Tethyan rocks were laid down as marine sediments in the former Tethys Ocean, which used to lie between the Indian and Eurasian continental plates. As the Indian Plate moved northwards against Laurasia (Eurasia), the ocean was squeezed and eventually disappeared. Its floor was forced up and much of the Tibetan plateau is formed from marine sediments. These were subject to pressure, heat and deformation during their compression and uplift. The Tethyan of Merak-Sakten is a separate outcrop, and not a southwards extension of the Tibetan Tethyan basin. The Merak-Sakten Tethyan rocks are thought to have been carried into their present position when the underlying sheets of gneiss of the Himalayan Central Crystalline Complex were thrust southwards and outwards during the Himalayan orogeny. The Merak-Sakten block is the oldest Tethyan outcrop in Bhutan. The rocks are of Paleozoic age, and so far no fossils have been recorded in them.

The Merak-Sakten block was included in the Tirkhola Formation in some geological summaries (UNESCAP 1991), but has been amalgamated into the revised and expanded Chekha Formation in the recent synthesis of the geology of Bhutan (Tangri & Pande 1995). This designation accords with the original mapping in the area, in which the main formation mapped was Chekha (Verma 1972). The Chekha phyllite and quartzite beds are intruded by large bodies of the Tertiary Chomolhari leucogranites.

The dominant rocks at Merak are slate, quartzite and sandstone. The soft landslip – prone phyllites seen at Radhi are absent or unimportant.

The solid geology of Sakten is more complex. The slates and quartzites are both present. The slates and other related argillaceous rocks appear to predominate, judging from the mainly fine subsoil textures of the hill soils. However there are also some thick quartzite beds which weather to deep crumbly, pale, sandy saprolite. There are also extensive outcrops of the Chomolhari granite. The largest is downstream of the survey area and the settlement, and forms the barrier through which Gum Ri cuts down on its course westwards.

The soils in Merak are formed in alluvial, aeolian, glacial, colluvial and residual parent materials. However few of the glacial or residual soils were seen. The bulk of potential agricultural land around the settlement is located on old river terraces of Nyera Ama Ri, with some aeolian deposition. The most extensive and oldest terrace is about 50-60 m above the river, but we have no indication of its age. The hills above have a patchy distribution of glacial drift angular boulders, and pale smooth aeolian cover.

The dominant parent materials at Sakten are colluvial and residual, with or without aeolian additions. There are alluvial deposits on the low terrace along Gum Ri, but these are lower and probably younger than those at Merak. There are also fan alluvial deposits along the lower courses of the side streams. Some of the fans are distinctly asymmetrical, with longer flank tails on the downstream edge than on the upstream side.

## 2.4 Topography

Both of the areas are located in the Merak and Sakten block of Tethyan rocks that has been uplifted during the Himalayan orogeny. Both are located in valleys that have relatively flat sections of river, with steeper bed sections downstream. The relative importance in delayed knickpoints and lithological barriers in holding up river dissection has not yet been investigated.

The Merak survey area is located on the north bank of Nyera Ama Ri. From about 3150 m, the bed of the river is wide, gravelly, braided and rises gently to 3400 m at Ganggyu, over a distance of about six kilometers. It runs between steep and rocky slopes, with a sharp break of slope and with no terraces. The valley changes above Ganggyu. The river is more confined, but it still has a narrow bouldery and braided floodplain. The south bank still rises abruptly to steep rocky slopes which are characterised by landslips and talus – chutes.

The soil observation area, on the north bank, is located on three major river terraces. The lowest is at about 5 – 10 m above the current river level, is only 20 – 70 m wide, and is discontinuous. The middle terrace is at about 30 m relative height, and is also discontinuous. In places it is almost 100 m wide. The most extensive terrace, in which the main settlement of Merak is located, is at about 50 – 60 m relative altitude, and is up to 300 m wide. The upper terrace is at about 3550 m asl. The surrounding hills go up to 4000 m. The upper terrace is not wholly alluvial and appears to have some local hillwash material. It slopes up to the base of the hills at about 5 %, steepening in the slightly concave upper section.

Some of the hills are rock – covered spurs. Others appear much smoother. However, the difference is superficial and seems to relate to the relative importance of aeolian (sandy) and glacial stony drift deposits.

Sakten is also located in a high, relatively flat valley. The gradient of Gum Ri at Sakten is relatively gentle, falling from 3200 m to 2800 m over a distance of 19 km, compared with the steep descent of 1000 m (from 2800 to 1800 m) in 20 km downstream. The river bed of the flat Sakten section of the valley is wide, up to 300 m in places. It is highly braided and bouldery. The main channel appears to wander, and is at present close to the southern bank, undercutting the toe of a side valley alluvial fan near the village of Pusa.

There are two low terraces on the northern bank of the river in the vicinity of Sakten village. The village is located on the higher of the two. The lower is at about 3 – 8 m above the current river level, and the upper one is only about 5 m higher. There are several minor alluvial fans in the valleys of the side stream on the south bank. These are asymmetrical at their lower front ends, with an apparent 'tail' swept in the downstream direction by the main river. There is a larger fan at Sakten village on the north bank, and this has recently deposited a rocky and stony low angle subsidiary fan on top of the river terraces and reaching down to the river. This appears to have been a fairly sudden event. There are discontinuous patches of high terraces, which are 10 – 15 m high. Where seen these are embedded with angular boulders.

The surrounding hills have clear breaks of slope with the terraces and fans. The hills from the granite outcrop at the western end of the survey area form a barrier across the downstream end of the Sakten valley. The stream cuts a narrow gorge through these rocks. They are a barrier to the downcutting of the river and contribute to the contrast between the flattish upper and the steep downstream sections.

## 2.5 Land use and vegetation

The Brokpa people of Merak and Sakten are mainly pastoralists. They herd yaks, zhos, cattle and some sheep. Many of them practise transhumance and move their herds to lower altitudes in winter. The Merak people move southwards to Shingkhar – Lauri and beyond, southwestwards to Khaling, and westwards to the upper parts of Radhi and Phongmey geogs. The Sakten people move mostly westwards down towards Phongmey.

The livestock are grazed in forests and on grasslands, some of which have been created by forest clearance. They mostly graze but there is also some browsing of tree and shrub shoots. The stock is kept mostly for dairy production, with cheese, fermented cheese (yitpa) and butter as the main exports. Some animals are slaughtered for meat, which is exported, if at all, as dried strips.

There is some arable cultivation at Sakten. By far the most important crop is bitter buckwheat *(Fagopyrum* spp). The Sakten people still follow their traditional method of cultivation. These may be due to religious obligation. The fields are prepared by entrenching the soil in straight rows by axe. They are then turned over with the help of sharpened poles. The local administration is interested in starting trials for other field crops, especially temperate cereals.

There are no arable fields at Merak, but most households cultivate small kitchen – gardens. This is a fairly recent development and is being encouraged by the RNR staff. The main crops grown are radish, cabbage and mustard greens. The gardens appear to be heavily fertilised with carried–in animal dung that is collected from open grazing land.

The main vegetation around Merak is forest with some clearings. The dominant forest formation is silver fir, which in places stretches right down to the banks of the river. There are patches of mixed conifer forest on some lower slopes, and clumps of larch on the riverbanks. The forests are heavily exploited for firewood, and household trains of fully–laden yaks are a common sight in the autumn. The damage to the forest is increased by the practice of ring - barking so as to open the canopy and create grassland clearings. However the forest close to the village is mostly in reasonable condition because of the local rule prohibiting felling within 2 km. Because of the arable cultivation, there is less forest close to Sakten. However the south bank of Gum Ri is still mostly forested. The forest is a mixture of conifers and broadleaf. Common broadleaf species are *Sorbus* spp, *Rhododendron* spp, *Quercu*s spp and *Acer cambelli*. The main conifers are spruce and fir. A few blue pine were seen.

# 3. PREVIOUS SOILS INFORMATION

As far as is known, there have been no previous soil surveys done anywhere in the Merak and Sakten areas. As far as can be seen from SPAL records, no soil analyses have been done for the areas.

# 4. METHODS

## 4.1 Soil survey fieldwork

The soils were examined at measured altitudinal intervals (usually 10 – 20 m) along compass traverses starting at the identifiable points on the river banks.

The soils were examined on a routine basis at 61 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 a few of the sites where the first attempt was stopped by stones at less than 50 cm. Some routine examinations were done in cuttings, cut back at least 15 cm to expose fresh soil.

For routine soil observations the following site data were collected:

> Location, GPS; general topography, site position; the angle (in %), aspect, length and form of the slope; solid and drift parent material; general land use and crops/vegetation; irrigation and 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 11 sites. Nine of the detailed descriptions were done in freshly exposed cuttings and the other two in profile pits purpose-dug to almost 2 m. 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, faunal activity, cracks, 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 structure; number and size of pores, presence strength 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); clarity and shape of lower boundary.

32 samples were collected for laboratory analysis from the main horizons of the 11 described profiles. Also some composite auger topsoil samples were collected, from an area planned for temperate cereal trials at Sakten.

## 4.2 Soil sampling of cropping areas

As an aid to the RNR efforts to promote vegetable cultivation at Merak, four gardens were visited and soil samples collected. Three of the gardens are in Merak village and one is in Ganggyu, about 2 km to the West. Eight random topsoil samples were collected and amalgamated as one composite sample for each garden.

The Dungkhag administration proposes to initiate some trials for cold-tolerant strains of temperate cereals, such as wheat and barley, in an area on the spur running northwards from the government buildings at Sakten, about 1 km from the settlement.

The soils of the site were examined by auger at two points. Composite topsoil samples were collected from around each augering point. The composites were made up by digging to 15 cm depth at distances of 2.5 m out from each auger point along the four major compass axes (N, E, S and W).

## 4.3 Mapping

Because this is only a general reconnaissance, no soil mapping has been attempted. The location map (Figure 2.1) is derived from LUSS land cover map of Trashigang dzongkhag, at scale 1: 100 000.

## 4.4 Laboratory

The 32 samples from the soil profiles and the 6 composite topsoil samples were analysed by the Soil and Plant Analytical Laboratory (SPAL) of the Research, Extension and Irrigation Division of the Ministry of Agriculture at Simtokha. The methods of analysis used by SPAL are summarised in Appendix A.

The only chemical methodological points that need to be mentioned here concern the measurement of cation exchange capacity (CEC) and calculation of base saturation (BS%). CEC can be measured by saturating the soil with ammonium cations, and then displacing and measuring the amount adsorbed. This is referred to as CEC ($NH_4OAC$). An alternative is to estimate CEC by summing the total exchangeable bases (Ca + Mg + K + Na = TEB), and the extractable aluminium and hydrogen. This is known as the 'effective cation exchange capacity' (ECEC). Base saturation is the quotient TEB/CEC. Effective base saturation (EBS %) is TEB/ECEC. Since most of the soils from Merak and Sakten are very acid, determinations for extractable Al and H were done for all samples. The ECEC therefore is the sum of TEB, Extractable Al and H. Effective base saturation is the quotient TEB/ECEC.

# 5. SOIL CLASSIFICATION, CHARACTERISTICS AND CORRELATION

## 5.1 Soil classification

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

## 5.2 Characteristic of soil classes at Merak

The soils seen at Merak are divided into four classes, as summarised in Table 5.1 (a):

### *5.2.1 Floodplain bouldery soils (MFP)*

These soils occupy the wide braided bed of the Nyera Ama Ri. The land is subject to flooding and is not used, except for sporadic fuel gathering and some grazing. The vegetation is low Rhododendron scrub, with clumps of low trees, mainly Rhododendron and larch, on slightly higher parts that are less flooded.

There are no described or analysed profiles of these soils. The soil consists of gravel, stones and boulder beds, with interstitial sand and silt. In places there are shallow and relatively stone-free sandy surface layers, nowhere more than 50 cm deep.

### *5.2.2 Low terrace soils (MLT)*

These soils occupy the low terrace, which is about 5 – 10 m above the current river level. The land is mostly grassland with scattered clumps of juniper, *Berberis* spp, *Vaccinium* spp and ground mosses. It is used for grazing. There is one described and analysed profile in these soils (see PC028 in Appendix B).

These soils have dark brown fine sandy loam topsoils, with friable crumb structures. This grades into dull greyish brown subsoil with faint mottling. The subsoil textures vary according to the nature of the alluvial parent material. In profile PC028 the subsoil texture ranges from silt to loamy fine sand. In another exposure, silty clays and sandy gravel were seen. In our augerings the subsoils range from fine sandy clay loam to silty clay. Structure varies with the texture, from subangular blocky to single grain. These soils are mostly stone-free, up to 1 m depth. However, some augerings show weathering rock at 50 – 100 cm.

The single analysed profile has an acid topsoil, with pH (water) of 5.5. The pH increases to slightly acid (pH 5.9) in the subsoil. Base status is very poor (base saturation <15%) throughout. The organic carbon level is high (5.6 %) but total nitrogen is moderate (0.42 %) in the topsoil. C: N ratio is distinctly low (less than 15). Exchangeable K contents are very low. However available P is slightly better and grades to low (14 ppm).

### *5.2.3 Middle and upper terrace soils (MMT)*

These soils occur on the middle and upper terraces at heights of about 30-60 m above the current river level. These are the soils on which the main village of Merak is located. There is no remaining natural

vegetation. This is probably due to the impact of grazing. One profile has been analysed and described in detail (see Pd024 in Appendix B).

The topsoil consists of very dark grey sandy clay loam with a moderate coarse to medium subangular blocky structure. The subsoil is of dark brown – yellowish brown with distinct – prominent mottles. The texture becomes lighter with depth. It grades from sandy clay loam to gravely sandy loam. The stone contents are variable, but generally increase with depth. However augerings showed some of these soils as having few or no stones within the top metre.

The chemical analyses show that the single profile, Pd024 contains high organic carbon in the topsoil but moderate total nitrogen. C: N ratio is moderate (15). This soil is slightly acid, with pH values (5.7) in the upper horizons and gradually becomes more acid with depth. The base status is extremely low, with all base saturations less than 5 %. Exchangeable Mg contents are particularly low, and show as either zero or trace. Although Total N is moderate (0.42 %), available P (< 5 ppm) contents are very low.

*Table 5.1(a) Summary of soil classes at Merak*

| **SOIL CLASS** | | **Main Features** | **Representative profile and analyses (see App. B)** |
|---|---|---|---|
| **Code** | **Name** | | |
| MFP | Flood plain bouldery soils | Shallow sandy surface layers over dense boulders beds within 50 cm | - |
| MLT | Low terrace soils | Dark brown sandy loam topsoil, over greyish brown silty loam – sandy subsoil. Occasionally rounded and angular metamorphic stones | PC028 |
| MMT | Middle terrace soils | Very dark grey sandy clay loam topsoil, over dark brown – dark yellowish brown sandy clay loam subsoil with discontinuous organic cutans | Pd024 |
| MHS | Variable hill soils | Angular bouldery deposits with variable cover of dark yellowish brown aeolian fine sandy loam | - |

*Table 5.1(b) Summary of soil classes at Sakten*

| SOIL CLASS | | Main Features | Representative profiles and analyses (see App. B) |
|---|---|---|---|
| **Code** | **Name** | | |
| SFP | Flood plain bouldery soils | Rounded boulder beds with interstitial sand. | - |
| SLT | Low terrace soils | Brown – very dark brown sandy loam – sandy clay loam topsoil over dark brown – yellow brown of variable subsoil texture, sandy clay loam – sandy loam – silty loam. | PC030<br>PC032 |
| SHT | High terrace very bouldery soils | Very dark grey – very dark greyish brown loam topsoil, over dark grey fine sandy loam subsoil with boulder beds < than 50 cm. | - |
| SHZ | Silty hill soils | Dark fine sandy loam – sandy clay loam topsoil over yellow brown – brownish yellow silty loam – silty clay deep subsoils. | PC029<br>PC031<br>Pd026<br>Pd027 |
| SHS | Fine sandy hill soils | Dark yellowish brown fine sandy loam + topsoil, over dark brown – brownish yellow fine sandy clay loam subsoil with weak organic cutans. | Pd025 |
| SHG | Granite hill soils | Very dark greyish brown medium sandy loam topsoil, over dark brown – yellowish brown humic loam – sandy loam subsoil over pale, coarse grain weathered granite within 1 m. | PC033 |
| SGL | Gley soils | Dark yellowish brown humic loam topsoil, over greyish brown – greenish grey subsoil over weathered phyllite/ slate > than 1 m. | PC034 |

### *5.2.4 Hill soils (MHS)*

These soils were seen on the northern slope of the valley. The area does not appear to have been heavily over-grazed, probably due to the presence of steep slopes. Bushy juniper and some local scattered grasses occupy the area. There surface deposits are of mainly aeolian and glacial origin. Aeolian deposits are very irregular and tend to appear only on the areas that are covered by juniper. Stony glacial deposits are noticeable on the foot of the slopes. No profiles have been described or analysed for these soils.

However augering showed that these soils have dark brown fine sandy clay loam topsoils. The subsoils are dark greyish brown – dark yellowish brown. Textures vary according to the nature of the slope and the surface parent material (sandy glacial or silty aeolian) from silty clay to sandy clay loam. These soils mostly have boulders within 50 cm of the surface.

## 5.3 Characteristic of soil classes at Sakten

The soils seen at Sakten are divided into seven classes, as summarised in Table 5.1 (b):

### *5.3.1 Flood plain bouldery soils (SFP)*

These soils occupy the wide valley of Gum Ri. The area is not cultivated, due to extensive angular boulder deposits and the frequency of floods. The land is covered by grasses and low shrubs. It is used for sporadic grazing.

The soil consists of rounded bed of boulders with interstitial sand and silt. There are no described or analysed profiles for these soils.

### *5.3.2 Lower terrace soils (SLT)*

These soils occupy the two levels of lower terraces of Gum Ri, at about 3 – 15 m above the current river level. The area is covered by grasses. The land is presently under grazing and the settlement. One profile has been described and analysed in detail (see PC030 in Appendix B). Another has been described but not sampled (PC032).

The topsoils consist of brown – very dark brown fine sandy clay loam to fine sandy loam. Structures are variable, ranging from subangular blocky to fine crumb. It has reasonable porosity. These soils have a bright subsoil colours, ranging from dark brown – yellowish brown. Textures range from silty loam to sandy loam. The structures are mainly subangular blocky. In places these soils are gravely and stony at depth.

The laboratory analysis of the single profile shows that both topsoil and subsoils are acid with very low base saturations. Topsoil organic carbon levels are high. Total nitrogen is moderate with satisfactory C: N ratio (13). Available phosphate contents are low (<15 ppm). Cation exchange capacity is moderate with extremely low TEB and base saturation.

### *5.3.3 High terrace very bouldery soils (SHT)*

These soils occupy the 10 – 15 m high terraces embedded with angular bouldery deposits. They are covered with rhododendron, *Quercus* and grasses, and used for grazing.

No profiles of these soils have been examined in detail or sampled for analysis. However augering shows that the depth of stone–free topsoil nowhere extends below 50 cm. These soils have very dark grey – very dark greyish brown loam topsoils. Subsoils are uniformly dark grey fine sandy loams with abundant angular boulders.

### *5.3.4 Silty hill soils (SHZ)*

These soils occupy hill slopes on both sides of the valley. The vegetation comprises of juniper, *Quercus spp, Daphne* spp and rhododendrons. The ground cover is mainly *Fragaria spp* and grasses. Some of this land is under buckwheat cultivation, and these are the main buckwheat soils. It is also used for intensive grazing. Four profiles have been examined in detail and sampled (see PC029, PC031, Pd026 & Pd027).

These soils have dark greyish brown – dark yellowish brown fine sandy loam to silty loam topsoils, with faint reddish brown, orange and grey mottling. Structures are variable from crumb to subangular blocky. Subsoils are deep, dark brown to yellowish brown. Textures vary from silty loam to silty clay loam. A few profiles have sandy loam texture. Subsoil structures are as in the topsoils. In some of the profiles, the subsoil structure faces have weak clay skins. A feature of these soils is their depth, with few stones, boulders or patches of weathered rock seen in the top metre, even on slopes of 50 % +.

These soils are very acid (pH < 5). In one profile pH increases towards slightly acid (pH < 6) in the subsoil, but base saturations are low in all of the sampled profiles. Topsoil organic carbon and total nitrogen levels are moderate to very high. Available P contents are very low (< 5 ppm), but available K contents are moderate (<100 ppm).

### *5.3.5 Fine sandy hill soils (SHS)*

These soils occupy midslopes. The land is presently cultivated for buckwheat. The natural vegetation is juniper and local grasses. One profile has been described and analysed in detail (see Pd025 in Appendix B).

The topsoil consists of dark yellowish brown sandy loam +. Structures are medium subangular blocky with reasonable porosity. Subsoils are dark brown - yellow brown in colour, like silty hill soils, but textures are mainly fine sandy clay loam. These subsoils have a uniform medium subangular blocky structure with discontinuous organic coatings. The few stones are predominantly granite and slate, but these soils are mainly deep and stone-free.

The single analysed profile shows that these soils are slightly acid, with pH of 5.4 in water, which decreases to 5.2 to become acid in the subsoil. Total N is moderate (< 0.5%) but organic carbon levels are reasonably high (3.1 %). Contents of available P (5ppm) and K (< 40 ppm) are extremely low, as are the base saturations (< 5 %). TEB and CEC are generally low except for the subsoil, in which CEC grades to moderate (about 20 me %).

### *5.3.6 Granite hill soils (SHG)*

These soils occupy the lower slope of the granite hills on the south bank and are mainly occupied by tsenden, *Acer cambelli* and rhododendron. In places they are covered by bamboo. They are mostly used for grazing.

The one detailed examined profile (see PC033 in Appendix B) in these soils has very dark greyish brown medium sandy loam topsoil. Structures are loose crumb. Subsoils ranges from dark brown to yellowish brown, with weathered granite within 40 cm. The texture varies with depth to weathered rock from loam to coarse sandy loam. These soils are mostly underlain by very distinctive deep pale highly weathered granite. The granite has a distinctive “sugary” consistence. However some hard vein quartz also occurs within it. Subsoil structures vary from crumb to single grain.

Laboratory analysis confirmed that these soils have acid topsoils but the subsoils are only slightly acid. Topsoil organic carbon (about 3 %) and total nitrogen (0.78 %) are reasonably high but C: N ratios are generally very low (< 5). Available K, P and TEB are all very low in the sampled profile. The CEC is high (33.5 me %) in the acid topsoil because of the high organic matter and decreases to 15.6 me % in slightly acid mineral subsoil.

### *5.3.7 Gley soils (SGL)*

These soils occupy lower slopes and occur on or close to drainage lines. The vegetation is mixed conifer forest with hemlock, larch, rhododendron and bamboo.

Although these soils are not extensive, one profile has been described and analysed in detail (See PC034 in Appendix B). Topsoils are mostly loose – friable dark yellowish brown humic loam with a crumb structure. These soils have moist – wet, greyish brown – greenish grey subsoils with distinct rust mottling. Texture varies with depth from sandy loam to gravelly loam. Structures are crumb – subangular blocky. Stones are dominantly angular but in places these soils are underlined by platy weathered slate or phyllite.

The soils are very acid, with pH values <5 (in water). Total nitrogen, organic carbon (< 1%) and C: N ratios are relatively low. This is probably due to prolonged saturation. Available P and K contents are also very low. Both TEB and base status are very low but subsoil base saturations are moderate (60%) despite the acidity.

### *5.3.8 Analytical summary*

The chemical characteristics of the soil classes in the two areas are summarised in Table 5.2.

A feature of all of the analyses of the samples from this survey is the acidity of the soils and the generally low contents of available P. Organic carbon levels are generally high, and nitrogen contents are moderate, except for gley soils. Base saturations are all very low.

## 5.4 Soil correlation

### *5.4.1 Correlation with international soil classifications*

The local classifications used in Tables 5.1 (a) and (b) and in sections 5.2 and 5.3 aim to be simple and to clearly indicate the main soil features to those interested specifically in the soils of Bhutan, and Merak and Sakten. 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 Tables 5.3 (a) and (b). There is discussion of the correlations in Appendix C.

*Table 5.2 Chemical analyses, by soil classes, Merak and Sakten*

| 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) |
| MLT (1) | 5.6 | 0.42 | 13 | 14 | 5.5/5.9 | 2.5/0.2 | 14./5 | 0.5/0.1 | 90.6/8 |
| MMT (1) | 6.2 | 0.42 | 15 | 1 | 5.7/5.3 | 0.5/0.3 | 2/2 | 0.3/0.1 | 44.8/0.9 |
| SLT (1) | 4.6 | 0.35 | 13 | 8 | 4.5/4.7 | 0.3/0.5 | 2/3 | 0.1/0.0 | 6.1/2.9 |
| SHZ (4) | 2.6 - 15.0 | 0.21 - 1.75 | 6 – 12 | 1 - 2 | 4.5 - 4.9/ 4.6 - 5.7 | 0.4 - 15.1/ 0.2 - 1.4 | 1 - 38/ 1 - 12 | 0.1 - 0.6/ 0.0 - 0.1 | 7.3 - 95.1/ 1.3 - 49.0 |
| SHS (1) | 3.1 | 0.22 | 14 | 2 | 5.4/5.2 | 0.3/0.3 | 2/1 | 0.1/0.1 | 7.6/2.1 |
| SHG (1) | 3.4 | 0.78 | 4 | 1 | 5.0/5.8 | 0.8/1.1 | 2/7 | 0.3/0.0 | 61.8/3.8 |
| SGL (1) | 0.1 | 0.31 | <1 | 7 | 4.8/5.0 | 0.9/2.0 | 4/60 | 0.2/0.1 | 49.9/14.5 |

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

### *5.4.2 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 Bhutan conditions. Although there is no irrigation in Merak and Sakten, the classification is useful, as it indicates the general stability of the soils and their susceptibility to slumping and other forms of mass movements. Tables 5.4 (a) and (b) correlates the soil of Merak and Sakten with the geotechnical classification.

*Table 5.3(a) International correlation of Soil Classes at Merak*

| **Soil Class** | | **Subunit in World Reference Base (FAO 1998)** | **Great group in USDA Soil Taxonomy (Soil Survey Staff 1998) [Family in italics]** |
|---|---|---|---|
| **Code** | **Name** | | |
| MFP | Flood plain soils | Skeletic Fluvisol | Typic Cryofluvent or Ustifluvent *[cryic or frigid, skeletal, mixed]* |
| MLT | Low terrace soils | Dystric Cambisol | Ustic Dystrocryept or Fluventic Dystrustept *[cryic or frigid, loamy, mixed]* |
| MMT | Middle terrace soils | Dystric Cambisol | Ustic Dystrocryept or Fluventic Dystrustept *[cryic or frigid, loamy, mixed]* |
| MHS | Variable hill soils | Skeletic or dystric Regosol or Cambisol | Lithic or Typic Cryorthent or Dystrocryept *[cryic or frigid, loamy skeletal]* |

*Table 5.3(b) International correlation of Soil Classes at Sakten*

| **Soil Class** | | **Subunit in World Reference Base (FAO 1988)** | **Great group in USDA Soil Taxonomy (Soil Survey Staff 1998) [Family in italics]** |
|---|---|---|---|
| **Code** | **Name** | | |
| SFP | Flood plain bouldery soils | Skeletic Fluvisol | Typic Ustifluvent *[Frigid, sandy skeletal, mixed]* |
| SLT | Low terrace soils | Dystric Cambisol | Fluventic or Typic Dystrustept *[frigid, loamy, mixed]* |
| SHT | High terrace very bouldery soils | Skeletic Fluvisol or Regosol | Typic or Fluventic Dystrustept *[frigid, sandy skeletal, mixed]* |
| *SHZ* | Silty hill soils | Dystric Cambisol | Typic Dystrustept *[frigid, coarse silty, mixed]* |
| SHS | Fine sandy hill soils | Dystric Cambisol | Typic Dystrustept *[frigid, coarse loamy, mixed]* |
| SHG | Granite hill soils | Dystric Cambisol | Typic Dystrustept *[frigid, coarse loamy or sandy, mixed]* |
| SGL | Gley soils | Dystric Gleysol | Typic Endoaquept *[frigid, coarse loamy or sandy, mixed]* |

*Table 5.4(a) Geotechnical correlation of soils of Merak*

| **Merak soil class** | **REID Irrigation Section Geotechnical Soil Classification** | |
|---|---|---|
| | **Land unit** | **Soil class** |
| MFP | 5D | GW (well graded gravel) |
| MLT | 5A | ML (low liquid limit silt) |
| MMT | | |
| MHS | 3A/B | CL (low liquid limit clay) |

*Table 5.4(b) Geotechnical correlation of soils of Sakten*

| **Sakten soil class** | **REID Irrigation Section Geotechnical Soil Classification** | |
|---|---|---|
| | **Land unit** | **Soil class** |
| SFP | 5D | GW (well graded gravel) |
| SLT | 5A | SC (sand with clay fines) |
| SHT | | ML (low liquid limit silt) |
| SHZ | 3A/B | |
| SHS | | |
| SHG | | SM (low liquid limit sand) |
| SGL | 5A, 5D, 3A/B | |

Source for class criteria: CIP (1993)

# 6. SOIL DISTRIBUTION

Because the soil classification has a strong geomorphological basis, the distributions of the soil classes are closely related to topography. Thus the floodplain soils are on the floodplains, and the terrace soils are on the terraces.

The distribution of the hill soils of Merak appears to be mainly controlled by the parent material. Where there are substantial aeolian deposits, we find stone - free loamy topsoils. Where the parent material is glacial, the soils are stony throughout.

At Sakten most of the hill soils have silty or fine sandy textures probably due to aeolian deposits. The main exception is the area of coarse sandy soils derived from granite. The gley soils are localised in depressions and along drainage lines.

# 7. OVERVIEW AND IMPLICATIONS

## 7.1 Overview of soils

The two areas include a wide range of soils. However they do have a number of features in common. These include:

> Acidity and poor base saturations. All the topsoils have high organic carbon levels and good cation exchange capacities. Total nitrogen is moderate. However available P and K are very low.

Features which vary considerably include:

> Textures range from stony sands in some floodplain deposits to soils high in silt and clay on the hills at Sakten. The moisture status is moderately good on the lower terraces. However it tends to droughtiness in the higher terraces and hill soils, and at the other extreme the Sakten gley soil has excess moisture.

## 7.2 Implications of results

Low temperatures limit the range of cropping. Merak is climatically very marginal. The only possibilities are buckwheat and a few types of house garden vegetables. Sakten is also cold but has slightly wider range of possible crops, such as buckwheat, temperate cereals and house garden vegetables.

In Merak the middle and upper terraces form the only possible area for arable cropping. Most of the steep hill and floodplain soils at Merak are unsuitable because of their high contents of boulders. Table 7.1 summarises the analytical data for the four composite topsoil samples taken from house gardens at Merak and Ganggyu. The results show the effects of the heavy manuring of these gardens, with high contents of organic carbon, total nitrogen and available P. The soils are also less acid and base-depleted than those of the surrounding open land.

*Table 7.1 Summary of the composite topsoil samples from house gardens at Merak*

**SPAL analytical results for SSU Composite auger topsoil samples Survey area: Sakten**

| SSU No. | Depth cm | SPAL Lab No | pH | | | EC (mS/cm) | Avail. P (ppm) | Organic C (%) | Total N (%) | C:N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $H_2O$ | KCl | Diff | | | | | |
| AC0028 | Topsoil | 5591 | 6.2 | 5.1 | 1.1 | 0.00 | 35 | 4.0 | 0.80 | 5 |
| AC0029 | Topsoil | 5592 | 5.6 | 4.5 | 1.1 | 0.03 | 35 | 6.6 | 0.30 | 22 |
| AC0030 | Topsoil | 5593 | 5.8 | 4.6 | 1.2 | 0.01 | 35 | 6.5 | 0.30 | 22 |
| AC0031 | Topsoil | 5594 | 6.3 | 4.2 | 2.1 | 0.01 | 35 | 6.6 | 0.91 | 7 |

Exchangeable bases

| SSU No. | Exchangeable | | | | TEB | Extr Al | Extr H | CEC | | BS% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | | | | AmOAc | ECEC | AmOAC | EBS % |
| AC0028 | 12.6 | 1.8 | 1.1 | 0.1 | 15.7 | Nd | Nd | 28 | Nd | 56 | Nd |
| AC0029 | 8.2 | 1.5 | 1.0 | 0.1 | 10.8 | Nd | Nd | 23 | Nd | 46 | Nd |
| AC0030 | 12.2 | 1.9 | 1.4 | 0.1 | 15.6 | Nd | Nd | 29 | Nd | 53 | Nd |
| AC0031 | 20.1 | 2.7 | 1.4 | 0.1 | 24.4 | Nd | Nd | 33 | Nd | 74 | Nd |

Fine earth granulometric

| SSU 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 | | |
| AC0028 | Nd | Nd | Nd | Nd | Nd | 22.0 | 19.0 | 37.9 | 56.9 | 21.1 | ZL |
| AC0029 | Nd | Nd | Nd | Nd | Nd | 25.5 | 23.6 | 31.1 | 54.7 | 19.8 | ZL |
| AC0030 | Nd | Nd | Nd | Nd | Nd | 29.2 | 25.3 | 28.6 | 53.9 | 16.9 | ZL |
| AC0031 | Nd | Nd | Nd | Nd | Nd | 35.7 | 23.8 | 24.0 | 47.8 | 16.4 | L - ZL |

Most of the hill soils at Sakten are deep, well watered and well aerated and are physically suitable for arable crops, although needing good conservation measures because of the steep slopes. Table 7.2 summarises the analyses of the two composite topsoil samples taken in the area intended for temperate cereal trials on the spur north of Sakten village. They generally confirm the analytical results from the profiles of the Sakten hill soils, including the high silt and moderately high clay contents. Chemically the soils have moderate contents of organic carbon and total N, and good C: N ratios. However they very acid and have very low contents of exchangeable bases, with one of them containing only traces of exchangeable Ca. Available P contents are low – very low in both of them. The acidity, very low base status and very low Available P make these soils only marginally suitable for arable cropping.

*Table 7.2 Summary of analyses of two composite topsoil samples from proposed temperate cereal trial area, Sakten*

**SPAL analytical results for SSU Composite auger topsoil samples Survey area: Sakten**

| SSU No. | Depth cm | SPAL Lab No | pH | | | EC (mS/cm) | Avail. P (ppm) | Organic C (%) | Total N (%) | C:N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | H2O | KCl | Diff | | | | | |
| Ad0211 | Topsoil | 5595 | 4.7 | 4.0 | 0.7 | 0.01 | 6 | 3.3 | 0.40 | 8 |
| Ad0212 | Topsoil | 5596 | 5.3 | 4.3 | 1 | 0.01 | 2 | 3.2 | 0.34 | 9 |

Exchangeable bases

| SSU No. | Exchangeable | | | | TEB | Extr Al | Extr H | CEC | | BS% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | | | | AmOAc | ECEC | AmOAC | EBS% |
| Ad0211 | 0.3 | 0.2 | 0.3 | 0.1 | 0.9 | 3.3 | 0.8 | 20 | 5 | 4 | 18 |
| Ad0212 | 0.01 | 0.1 | 0.3 | 0.1 | 0.5 | 2.2 | 0.7 | 21 | 3.4 | 2 | 15 |

Fine earth granulometric

| SSU 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 | | |
| Ad0211 | Nd | Nd | Nd | Nd | Nd | 13.5 | 13.9 | 37.5 | 51.4 | 35.1 | ZCL |
| Ad0212 | Nd | Nd | Nd | Nd | Nd | 19.0 | 13.6 | 33.5 | 47.1 | 33.9 | ZCL |

The general conclusions are that:

- Temperature constraints mean that only a limited range of crops can be grown at Merak and Sakten.
- The only soils with arable potential at Merak are those on the middle and upper river terraces. Radish, some leafy vegetables, and possibly buckwheat are the only feasible crops.
- The hill soils at Sakten can be used for buckwheat, some vegetables, and possibly cold - tolerant wheat and barley, but they may be too acid for some crops.

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# APPENDIX A: METHODS OF SOIL ANALYSIS 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) < 7, as these apply to all of the samples from Merak and Sakten.

## 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 $H_2SO_4$ and a Se-based catalyst

Ammonium – N and nitrate – N are extracted by shaking with 0.01 M $CaCl_2$ 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 $NH_4F$ for 1 minute.

Available K is extracted by shaking 5 g of fine earth with 50 ml of 0.01 M $CaCl_2$ 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 ($NH_4OAc$).

The ammonium is extracted by leaching the soil with excess 1 M KCl, and measured to give the Cation Exchange Capacity.

Extractable Al and H are extracted from 5 g fine earth with 100 ml of 1 M acidified KCl.

## Assays of extracts

The $NH_4$ from the Total N digestion, and from the KCl leaching for CEC determination, the $NH_4$ – N, $NO_3$ – 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 $NH_4$, $NO_3$ and available P, and a flame spectrophotometer for available K, and for exchangeable K and Na.

Exchangeable Ca and Mg in the $NH_4OAc$ leachate are measured with a Unicam Atomic Adsorption Spectrophotometer.

Extractable acidity (Al + H) in the KCl leachate are measured by titration with 0.05 M NaOH, and extractable Al alone is measured by a second titration with 0.05 M HCl, after the addition of NaF.

**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 pre-treatment of the fine earth with $H_2O_2$ to remove organic binding effects, and with HCl to remove aggregation effects by carbonates, Fe and Al oxides, and other mineral cementing agents. They are dispersed with sodium hexametaphosphate.

**TEB, ECEC, BS and C:N**

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

TEB = Exchangeable Ca + Mg + K + Na.

ECEC = TEB + Extractable Al + H

BS% ($NH_4OAc$) = TEB / CEC ($NH_4OAc$) x 100

EBS% = TEB / ECEC x 100

C:N = Organic C / Total N.

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

*Table APPA.1 Summary of current 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 ($NH_4OAc$) (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 % ($NH_4OAc$) | > 80 | 65 - 79 | 50 - 64 | 35 - 49 | < 35 |
| EBS (%) | > 80 | 50 - 79 | 35 - 49 | 20 - 34 | < 20 |
| AvK (ppm) | > 300 | 200 - 299 | 100 - 199 | 40 - 99 | < 40 |
| AvP 9ppm) | > 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 11 soil profiles. The profiles are in the sequence in Table APPB.I.

*Table APPB.1 Summary of soil profiles*

| Profile no. | Merak (M) or Sakten (S) soil class | No. of horizons analysed |
|---|---|---|
| PC028 | MLT | 4 |
| Pd024 | MMT | 3 |
| PC029 | SHZ | 4 |
| PC030 | SLT | 4 |
| PC031 | SHZ | 4 |
| PC032 | SLT | Not sampled |
| PC033 | SHG | 2 |
| PC034 | SGL | 2 |
| Pd025 | SHS | 3 |
| Pd026 | SHZ | 3 |
| Pd027 | SHZ | 3 |
| **Total** | **11** | **32** |

| | | |
|---|---|---|
| Profile: | PC028 | |
| Soil Classification: | Merak soil class: | MLT |
| | Soil Taxonomy: | Ustic Dystrocryept *(cryic, coarse loamy, mixed)* |
| | WRB: | Dystric Cambisol |
| Survey area: | Merak | |
| Location: | 400 m E of Merak village | |
| GPS: | Not available | |
| Altitude: | 3550 m a.s.l | |
| Described & sampled: | 26.10.1998, IC Baillie | |
| Climate: | General: Cool temperate, P = ca 1100 m p.a | |
| Recent weather: | Cloudy & cool | |
| Regional topography: | Wide valley | |
| Site position: | Front edge of low river terrace | |
| Slope: | 12%, ca 150m long, rectilinear-convex, aspect SSE ($150^0$) | |
| Site drainage: | Good | |
| Parent material: | Solid: Metamorphics | |
| | Drift: Old alluvium, some aeolian | |
| Land use: | Natural pasture | |
| Vegetation: | Low grass, sward with rare *Juniperus recurva* & *Berberis,* bushes & moss | |
| Surface: | Litter: | Very thin discontinuous grass litter |
| | Outcrops: None | |
| | Stones: | Rare angular quartzitic sandstone |
| | Cracks: | None |
| | Roots: | None |
| | Microrelief: | Slight hummocks behind bushes |
| | Faunal activity: | None |
| | Other features: | None |

**Profile description: (Colours are moist unless indicated)**

cm

0- 18 10YR 3/3 (dark brown) with no mottles; fine sandy loam; moderate fine subangular blocky breaking to moderate fine crumb; common fine pores; moist & friable; abundant fine & common medium roots; common medium hard round & angular quartz & metamorphic stones; HCl negative; gradual regular boundary to: [Sample PC028/1 @ 0-10]

18- 32 2.5Y 5/2 (greyish brown) with common fine faint & distinct reddish brown mottles; silty loam; moderate medium subangular blocky; common fine pores; moist & friable; common medium & many fine roots; many medium hard round & angular quartz & metamorphic stones; HCl negative; diffuse boundary to: [Not sampled]

32 – 48 2.5Y 6/2 (light greyish brown) with no mottles; silty loam - silt; weak medium platy breaking to weak fine subangular blocky; many fine pores; moist & friable; few fine roots; few medium hard round & angular quartz & metamorphic stones; HCl negative; abrupt regular boundary to: [Sample PC028/2 @ 35-45]

48 - 50 Thin orange & yellow iron pan across face [Not sampled]

50 - 73 2.5Y 6/2 (light greyish brown) with few fine faint yellow mottles; (loamy) fine sand; single grain; many fine & medium pores; moist & very friable; no roots; rare hard round quartz & metamorphic gravel; HCl negative; clear regular boundary to: [Sample PC028/3 @ 55-65]

73 - 93 Greyish brown; sandy gravel; stony & interstitial single grain; many fine & medium pores; moist & loose; no roots; abundant hard round & platy quartz & metamorphic gravel; HCl negative; clear regular boundary to: [Not sampled]

93 - 110 2.5Y 6/32 (light yellowish-greyish brown) with no mottles; loamy fine sand; single grain; many fine & medium pores; moist & loose; no roots; few medium hard round quartz & metamorphic gravel; HCl negative; clear regular boundary to: [Sample PC028/4 @ 100-110]

110+ Densely packed hard subangular & round quartz & metamorphic gravel

Comment: Thin iron pan at 48 – 50 appears to be incipient podzolisation. High available Phosphate levels throughout subsoil are questionable in view of low organic matter and clay content.

**SPAL analytical results for SSU** **Profile PC028** **Survey area: Merak**

Reaction, P & organic matter

| SSU No. | Depth cm | SPAL Lab No | pH | | | EC | Avail. | Organic | Total N | C:N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $H_2O$ | KCl | Diff | mS/cm | P ppm | C% | % | |
| PC028 /1 | 0 – 10 | 5547 | 5.5 | 4.4 | 1.1 | 0.01 | 14 | 5.6 | 0.42 | 13 |
| PC028 /2 | 35 – 45 | 5548 | 5.9 | 4.5 | 1.4 | 0.00 | 35 | 0.1 | 0.01 | 10 |
| PC028 /3 | 55 - 65 | 5549 | 5.3 | 4.3 | 1.0 | 0.01 | 35 | 0.3 | 0.02 | 15 |
| PC028 /4 | 100 - 110 | 5550 | 4.9 | 3.8 | 1.1 | 0.05 | 35 | 0.1 | 0.01 | 10 |

Exchangeable base status

| SSU No. | Exchangeable | | | | TEB | Extr Al | Extr H | CEC | | BS% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | | | | AmOAc | ECEC | AmOAC | EBS% |
| PC028 /1 | 1.6 | 0.3 | 0.5 | 0.1 | 2.5 | nd | nd | 17.0 | nd | 14 | Nd |
| PC028 /2 | Tr | Tr | 0.1 | 0.1 | 0.2 | nd | nd | 4.1 | nd | 5 | Nd |
| PC028 /3 | 0.2 | 0.1 | 0.0 | 0.1 | 0.5 | 0.5 | 0.4 | 5.0 | 1.4 | 9 | 36 |
| PC028 /4 | Tr | 0.1 | 0.1 | 0.1 | 0.3 | 0.3 | 0.1 | 4.0 | 0.7 | 8 | 43 |

Fine earth granulometric

| SSU 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** | | |
| PC028 /1 | nd | nd | nd | nd | nd | 46.4 | 20.9 | 20.8 | 41.7 | 12.0 | L |
| PC028 /2 | nd | nd | nd | nd | nd | 69.6 | 17.9 | 9.2 | 27.1 | 3.3 | SL |
| PC028 /3 | nd | nd | nd | nd | nd | 48.2 | 23.4 | 22.0 | 45.4 | 6.4 | SL |
| PC028 /4 | nd | nd | nd | nd | nd | 75.1 | 14.3 | 7.7 | 22.0 | 2.9 | LS |

| | |
|---|---|
| Profile: | Pd024 |
| Soil Classification: | Provisional Merak soil class: MMT |
| Soil Taxonomy: | Ustic Dystrocryept *(cryic, fine loamy, mixed)* |
| WRB: | Dystric Cambisol |
| Survey area: | Merak |
| Location: | Ca 1 km W of Merak village |
| GPS: | $27^0$ 18.01 N', $91^0$ 51.19 E. |
| Altitude: | 3440 m asl |
| Described & sampled: | 26.10.1998, Tsheten Dorji |
| Climate: | General: Cool temperate |
| Recent weather: | Light shower |
| Regional topography: | High mountain |
| Site position: | Middle terrace |
| Slope: | 8%, Ca .5 Km +, rectilinear, aspect south ($178^0$) |
| Site drainage: | Good |
| Parent material: | Solid: Schist |
| Drift: | Tethyan Aeolian + Colluvium |
| Land use: | Grazing land |
| Vegetation: | Common grasses |
| Surface: | Litter: None<br>Outcrops: None<br>Stones: Few boulders<br>Cracks: None<br>Roots: None<br>Microrelief: None<br>Faunal activity: None<br>Other features: None |

**Profile description: (Colours are moist unless indicated)**

cm

0 - 26 7.5YR 3/1 (very dark grey) with no mottles; fine sandy clay loam; moderate coarse breaking to medium subangular blocky; weak discontinuous organic cutans; abundant fine & medium pores; moist & friable; common fine & medium roots; HCl negative; few earthworms; few charcoal; gradual regular boundary to: [Sample Pd024/1 @ 0 – 10 cm]

26 - 39 7.5YR 3/2 (dark brown) with abundant coarse prominent yellowish brown & reddish brown mottles; fine sandy clay loam; weak medium subangular blocky; weak discontinuous organic cutans; abundant fine, medium & few coarse pores; moist & friable; few fine roots; few medium schist stones; HCl negative; few earthworms; few charcoal; gradual regular boundary to: [Sample Pd024/2 @ 30 – 35 cm]

39 - 52 10YR 4/6 (dark yellowish brown) with no mottles; fine sandy clay loam; moderate coarse breaking to medium subangular blocky; many fine pores; moist & very friable; rare fine & few medium & coarse schist stones; HCl negative; few charcoal; clear regular boundary to: [Sample Pd024/3 @ 40 – 50 cm]

52 - 84 10YR 5/4 (yellowish brown) with few coarse distinct reddish brown & orange mottles; medium sandy clay loam; moderate coarse subangular blocky; many fine pores; moist & slightly friable; common medium, coarse & few bouldery schist stones; HCl negative; some decayed roots; clear regular boundary to: [Not sampled]

84 - 140 + 2.5Y 4/2 (dark greyish brown) with no mottles; very strong & gravelly sandy loam; interstitial single grain; common inter pores; moist & stony consistence; abundant schist boulders; HCl negative: [Not sampled]

**SPAL analytical results for SSU** **Profile Pd024** **Survey area: Merak**

Reaction, P & organic matter

| SSU No. | Depth cm | SPAL Lab No | pH | | | EC mS/cm | Avail. P ppm | Organic C% | Total N % | C:N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | H2O | KCl | Diff | | | | | |
| Pd024 /1 | 0-10 | 5579 | 5.7 | 4.4 | 1.3 | 0.01 | 1 | 6.2 | 0.42 | 15 |
| Pd024 /2 | 30-35 | 5580 | 5.3 | 4.5 | 0.8 | 0.01 | 4 | 2.6 | 0.17 | 15 |
| Pd024 /3 | 40-50 | 5581 | 5.3 | 4.6 | 0.7 | 0.00 | 2 | 1.4 | 0.09 | 16 |

Exchangeable base status

| SSU No. | Exchangeable | | | | TEB | Extr Al | Extr H | CEC | | BS% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | | | | AmOAc | ECEC | AmOAC | EBS% |
| Pd024 /1 | 0.01 | 0.1 | 0.3 | 0.1 | 0.5 | nd | nd | 23.7 | nd | 2 | nd |
| Pd024 /2 | 0.01 | 0.1 | 0.1 | 0.1 | 0.3 | nd | nd | 17.9 | nd | 2 | nd |
| Pd024 /3 | 0.01 | 0.1 | 0.1 | 0.1 | 0.3 | nd | nd | 13.6 | nd | 2 | nd |

Fine earth granulometric

| SSU No. | Sand | | | | | | Siit | | | **Clay** | **Texture class** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | >1000 micron | 425-1000 | 212-425 | 106-212 | 50-106 | **Total sand** | 20-50 micron | 2-20 | **Total silt** | | |
| Pd024 /1 | nd | nd | nd | nd | nd | 27.5 | 22.9 | 27.7 | 50.6 | 21.8 | CL |
| Pd024 /2 | nd | nd | nd | nd | nd | 32.0 | 18.4 | 33.1 | 51.5 | 16.5 | ZL |
| Pd024 /3 | nd | nd | nd | nd | nd | 34.5 | 21.2 | 29.8 | 51.0 | 14.4 | ZL |

Profile: PC029

Soil Classification: Sakten soil class: SHZ
Soil Taxonomy: Typic Dystrustept (f*rigid, fine loamy, mixed)*
WRB: Dystric Cambisol

Survey area: Sakten
Location: Middle of eastern traverse on north bank
GPS: Not available
Altitude*:* 3000 m a.s.l

Described & sampled: 28.10.1998, IC Baillie & Tshering Dorji

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

Regional topography: Wide valley
Site position: Midslope

Slope: 47%, ca 0.5 km long, rectilinear, aspect SSE ($155^0$)
Site drainage: Good

Parent material: Solid: Mixed
Drift: Colluvium

Land use: Natural pasture
Vegetation: Grasses, bracken, berries & moss

Surface: Litter: Thin discontinuous grass & forb litter
Outcrops: None
Stones: None
Cracks: None
Roots: None
Microrelief: Livestock hummocks & terraces up to 1 m high
Faunal activity: None
Other features: None

Profile description: **(Colours are moist unless indicated)**
cm

0- 8 10YR 3/4 (dark yellowish brown) with common fine distinct reddish brown & medium faint brownish grey mottles; very fine sandy loam; moderate fine subangular blocky; few medium pores; moist & slightly firm; common fine & few medium roots; ants seen; few fine charcoal; HCl negative; gradual regular boundary to: [Sample PC029/1 @ 0-8]

8 - 37 10YR 4/4 (dark yellowish brown) with no mottles; very fine sandy loam; weak moderate subangular blocky breaking to moderate fine crumb; common fine pores; moist & slightly friable; common medium & fine roots; rare fine angular quartz gravel; HCl negative; clear slightly wavy boundary to: [Sample PC029/2 @ 20 - 30]

37 – 47 10YR 3/4 (dark brown) with many fine faint grey, & brown yellow mottles; very fine sandy loam; moderate fine subangular blocky; few medium pores; moist & slightly firm; common medium & fine roots; HCl negative; clear slightly wavy boundary to: [Sample PC029/3 @ 40-45]

47 - 56 10YR 4/4 (dark yellowish brown*);* very fine sandy loam; moderate fine crumb; many fine pores; moist & friable; common medium & fine roots; HCl negative; clear slightly wavy boundary to: [Not sampled]

56 - 70 10YR 3/4 (dark yellowish brown*)* with common medium distinct yellowish brown mottles*;* fine sandy loam; weak medium subangular blocky breaking to moderate fine crumb; many fine pores; moist & friable; common medium & fine roots; common fine charcoal; HCl negative; diffuse boundary to: [Not sampled]

70 - 95 10YR 4/6 (dark yellowish brown*);* very fine sandy clay loam; weak medium subangular blocky breaking to moderate fine crumb; common medium & fine pores; moist & friable firm; few medium & fine roots; HCl negative; clear slightly wavy boundary to: [Not sampled]

95 - 122 10YR 5/6 (yellowish brown); silty clay loam; weak medium subangular blocky breaking to moderate fine crumb; many medium & fine pores; moist & friable; few medium & fine roots; rare medium hard angular stones; HCl negative; diffuse boundary to: [Sample PC029/4 @ 100-110]

122 - 170+ 10YR 5/8 (yellowish brown); silty clay loam; moderate medium subangular blocky; many medium & fine pores; moist & brittle - slightly friable; rare medium & fine roots; common medium hard angular stones; few fine charcoal; HCl negative: [Not sampled]

Comment: At least two buried topsoils (37-47 & 56-70) and charcoal below 1.5 m indicates active colluviation. Organic carbon and total nitrogen levels moderate at depth, but available phosphate very low throughout.

**SPAL analytical results for SSU** **Profile PC029** **Survey area: Sakten**

Reaction, P & organic matter

| SSU No. | Depth cm | SPAL Lab No | pH | | | EC mS/cm | Avail. P ppm | Organic C% | Total N % | C:N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | H2O | KCl | Diff | | | | | |
| PC029 /1 | 0-8 | 5551 | 4.9 | 3.5 | 1.4 | 0.02 | 1 | 2.6 | 0.21 | 12 |
| PC029 /2 | 20-30 | 5552 | 5.8 | 4.3 | 1.5 | 0.00 | 2 | 5.7 | 0.27 | 21 |
| PC029 /3 | 40-45 | 5553 | 4.8 | 3.6 | 1.2 | 0.01 | 1 | 1.7 | 0.11 | 15 |
| PC029 /4 | 100-110 | 5554 | 4.8 | 3.8 | 1.0 | 0.00 | 1 | 0.9 | 0.05 | 18 |

Exchangeable base status

| SSU No. | Exchangeable | | | | TEB | Extr Al | Extr H | CEC | | BS% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | | | | AmOAc | ECEC | AmOAC | EBS% |
| PC029 /1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.5 | 0.8 | 0.1 | 10.8 | 1.4 | 4 | 36 |
| PC029 /2 | 0.5 | 0.2 | 0.3 | 0.1 | 1.1 | nd | nd | 19.0 | nd | 6 | nd |
| PC029 /3 | Tr | 0.1 | 0.1 | 0.1 | 0.3 | 0.7 | 0.2 | 9.0 | 1.2 | 3 | 25 |
| PC029 /4 | Tr | 0.1 | 0.1 | 0.1 | 0.3 | 0.4 | 0.3 | 9.8 | 1.0 | 3 | 30 |

Fine earth granulometric

| SSU 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** | | |
| PC029 /1 | nd | nd | nd | nd | nd | 38.4 | 21.8 | 20.8 | 42.6 | 19.1 | L |
| PC029 /2 | nd | nd | nd | nd | nd | 36.5 | 25.4 | 21.3 | 46.7 | 16.8 | L |
| PC029 /3 | nd | nd | nd | nd | nd | 34.8 | 24.4 | 25.7 | 50.1 | 15.0 | L-ZiL |
| PC029 /4 | nd | nd | nd | nd | nd | 30.1 | 27.3 | 24.8 | 52.1 | 17.8 | ZiL |

| | | |
|---|---|---|
| Profile: | PC030 | |
| Soil Classification: | Sakten soil class: | SLT |
| | Soil Taxonomy | Fluventic or Typic Dystrustept *(frigid, coarse loamy, mixed)* |
| | WRB: | Dystric Cambisol |
| Survey area: | Sakten | |
| Location: | Southern end of eastern traverse on north bank | |
| GPS: | Not available | |
| Altitude*:* | 2920 m a.s.l | |
| Described & sampled: | 28.10.1998, IC Baillie & Tshering Dorji | |
| Climate: | General: | Cool temperate, P = ca 1100 mm p.a |
| | Recent weather: | Sunny |
| Regional topography: | Wide valley | |
| Site position: | Front edge of low (5m) river terrace | |
| Slope: | Flat (0%), ca 150 m long, irregular rectilinear | |
| Site drainage: | Good | |
| Parent material: | Solid: | Mixed |
| | Drift: | River alluvium |
| Land use: | Natural pasture | |
| Vegetation: | Short grass & forb sward | |
| Surface: | Litter: | None |
| | Outcrops: | None |
| | Stones: | None |
| | Cracks: | None |
| | Roots: | None |
| | Microrelief: | Moderate relief, ca 50 cm, due to minor erosion channels |
| | Faunal activity: | None |
| | Other features: | None |

**Profile description: (Colours are moist unless indicated)**

cm

0- 16 10YR 4/3 (brown - dark brown) with rare fine faint reddish brown & dark grey mottles; very fine sandy clay loam; strong medium subangular blocky; few fine & medium pores; moist & slightly firm; common fine roots; ants seen; few fine charcoal; HCl negative; gradual regular boundary to: [Sample PC030/1 @ 0-10]

16 - 44 10YR 3/3 (dark brown) with few fine faint brown mottles; very fine sandy clay loam; strong fine subangular blocky; common fine & medium pores; moist & slightly firm; few fine roots; HCl negative; gradual regular boundary to: [Sample PC030/2 @ 25-35]

44 – 72 10YR 3/2 (very dark greyish brown); silty loam; moderate medium subangular blocky*;* few fine pores; moist & slightly friable; few fine roots; HCl negative; clear regular boundary to: [Sample PC030/3 @ 50-60]

72 - 100 10YR 5/6 (yellowish brown); silty loam+; moderate medium breaking to moderate fine subangular blocky; many fine & medium pores; moist & brittle - friable*;* no roots; HCl negative; clear wavy boundary to: [Sample PC030/4 @ 80 - 90]

100 - 130+ 10YR 5/6 (yellowish brown); bouldery silty loam+; stony structure; many fine & medium pores; moist & stony*;* no roots; abundant hard coarse rounded boulders; HCl negative: [Not sampled]

Comment: The top 3 horizons seem be in an inverted colour sequence, presumably due to an earlier stillstand and subsequent rapid deposition. However organic carbon contents decrease from surface downwards, although still moderate at 60 cm. Very low exchangeable base status.

**SPAL analytical results for SSU** **Profile PC030** **Survey area: Sakten**

Reaction, P & organic matter

| SSU No. | Depth cm | SPAL Lab No | pH | | | EC MS/cm | Avail. P ppm | Organic C% | Total N % | C:N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | H2O | KCl | Diff | | | | | |
| PC030 /1 | 0-10 | 5555 | 4.5 | 3.7 | 0.8 | 0.03 | 8 | 4.6 | 0.35 | 13 |
| PC030 /2 | 25-35 | 5556 | 5.2 | 4.1 | 1.1 | 0.01 | 9 | 3.6 | 0.23 | 16 |
| PC030 /3 | 50-60 | 5557 | 4.7 | 3.3 | 1.4 | 0.06 | 11 | 3.4 | 0.30 | 11 |
| PC030 /4 | 80-90 | 5558 | 4.6 | 3.4 | 1.2 | 0.03 | 9 | 1.0 | 0.11 | 9 |

Exchangeable base status

| SSU No. | Exchangeable | | | | TEB | Extr Al | Extr H | CEC | | BS% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | | | | AmOAc | ECEC | AmOAC | EBS% |
| PC030 /1 | Tr | 0.1 | 0.1 | 0.1 | 0.3 | 2.1 | 1.1 | 13.7 | 3.5 | 2 | 9 |
| PC030 /2 | Tr | 0.1 | 0.0 | 0.1 | 0.3 | 2.0 | 0.9 | 16.1 | 3.2 | 2 | 10 |
| PC030 /3 | 0.2 | 0.1 | 0.0 | 0.1 | 0.5 | 2.1 | 0.8 | 16.3 | 3.4 | 3 | 15 |
| PC030 /4 | Tr | 0.1 | 0.0 | 0.1 | 0.3 | 1.0 | 0.2 | 10.2 | 1.5 | 2 | 20 |

Fine earth granulometric

| SSU 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** | | |
| PC030 /1 | nd | nd | nd | nd | nd | 25.8 | 23.1 | 31.8 | 54.9 | 19.4 | Zil |
| PC030 /2 | nd | nd | nd | nd | nd | 21.8 | 22.4 | 32.8 | 55.2 | 23.1 | Zil |
| PC030 /3 | nd | nd | nd | nd | nd | 20.3 | 25.8 | 31.4 | 57.2 | 22.4 | Zil |
| PC030 /4 | nd | nd | nd | nd | nd | 31.1 | 29.2 | 23.6 | 52.8 | 16.1 | Zil |

| | |
|---|---|
| Profile: | PC031 |
| Soil Classification: | Sakten soil class: SHZ |
| Soil Taxonomy: | Typic Dystrustept *(frigid, coarse loamy, mixed)* |
| WRB: | Dystric Cambisol |
| Survey area: | Sakten |
| Location: | Western of 2 traverses on south bank, +/- across river from BHU |
| GPS: | Not available |
| Altitude*:* | 3005 m a.s.l |
| Described & sampled: | 29.10.1998, IC Baillie |
| Climate: | General: Cool Temperate, P = ca 1100 mm p.a<br>Recent weather: Sunny & cool |
| Regional topography: | Wide valley |
| Site position: | Midslope |
| Slope: | 46%, ca 1 km long, irregular rectilinear, aspect ENE ($65^0$) |
| Site drainage: | Good |
| Parent material: | Solid: Mixed |
| Drift: | Mixed fan & river alluvium |
| Land use: | Natural pasture |
| Vegetation: | Short grass & forb sward with many *Plantago* |
| Surface: | Litter: Very thin discontinuous grass & forb litter<br>Outcrops: None<br>Stones: None<br>Cracks; None<br>Roots: None<br>Micro relief: Livestock terracettes up to 70 cm high<br>Faunal activity: None<br>Other features: None |

**Profile description: (Colours are moist unless indicated)**

Cm

0- 18 10YR 3/2 (very dark greyish brown) with many fine faint reddish brown & orange mottles; silty loam; weak fine subangular blocky breaking to moderate medium crumb; few fine pores; moist & slightly friable; common fine & few medium roots; HCl negative; gradual regular boundary to: [Sample PC031/1 @ 0-10]

18 - 47 10YR 3/2 (very dark greyish brown) with no mottles; silty loam; moderate fine subangular blocky breaking to moderate medium crumb; weak moisture films; common fine pores; moist & slightly friable; common fine roots; HCl negative; clear wavy boundary to: [Sample PC031/2 @ 30-40]

47 - 92 10YR 5/6 (yellowish brown); silty clay loam; moderate medium subangular breaking to moderate fine angular blocky*;* weak clayskins & many moisture films; common fine pores & few coarse krotovinas with dark infill; moist & slightly friable; rare fine roots; few medium hard bluish grey platy gravel; HCl negative; diffuse boundary to: [Sample PC031/3 @ 60-70]

92 - 145+ 10YR 5/6 (yellowish brown); silty clay; moderate medium breaking to moderate fine angular blocky*;* moderate clayskins & many moisture films common fine & medium pores; moist & firm*;* no roots; common medium hard bluish grey platy gravel; HCl negative; [Sample PC031/4 @110-120]

Comment: Typical of fine textured hill soils

**SPAL analytical results for SSU** **Profile PC031** **Survey area: Sakten**

Reaction, P & organic matter

| SSU No. | Depth cm | SPAL Lab No | pH | | | EC mS/cm | Avail. P ppm | Organic C% | Total N % | C:N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | H2O | KCl | Diff | | | | | |
| PC031/1 | 0-10 | 5559 | 4.5 | 3.5 | 1.0 | 0.03 | 1 | 6.6 | 0.64 | 10.3 |
| PC031/2 | 30-40 | 5560 | 5.6 | 4.3 | 1.3 | Nd | 1 | 5.0 | 0.35 | 14.2 |
| PC031/3 | 60-70 | 5561 | 4.6 | 3.7 | 0.9 | 0.05 | 1 | 2.5 | 0.22 | 11.3 |
| PC031/4 | 110-120 | 5562 | 4.5 | 3.5 | 1.0 | 0.01 | 1 | 0.8 | 0.09 | 8.8 |

Exchangeable base status

| SSU No. | Exchangeable | | | | TEB | Extr Al | CEC | | BS% | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | | | AmOAc | ECEC | AmOAC | EBS% |
| PC031/1 | 0.2 | 0.2 | 0.3 | 0.1 | 0.8 | nd | nd | 24.9 | nd | 3.0 |
| PC031/2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.5 | nd | nd | 25.5 | nd | 1.8 |
| PC031/3 | 0.2 | 0.1 | 0.0 | 0.1 | 0.5 | nd | nd | 22.0 | nd | 2.0 |
| PC031/4 | 0.1 | 0.0 | 0.1 | 0.1 | 0.4 | nd | nd | 12.7 | nd | 2.8 |

Fine earth granulometric

| SSU 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** | | |
| PC031/1 | nd | nd | nd | nd | nd | 21.8 | 14.8 | 37.2 | 52.0 | 26.3 | Zi |
| PC031/2 | nd | nd | nd | nd | nd | 21.7 | 19.0 | 31.8 | 50.8 | 27.5 | Zil |
| PC031/3 | nd | nd | nd | nd | nd | 42.9 | 16.2 | 25.7 | 41.9 | 15.1 | L |
| PC031/4 | nd | nd | nd | nd | nd | 32.5 | 26.6 | 24.5 | 51.1 | 16.4 | Zil |

| | | |
|---|---|---|
| Profile: | PC033 | |
| Soil Classification: | Sakten soil class: | SHG |
| | Soil Taxonomy: | Typic Dystrustept *(frigid, coarse loamy, mixed)* |
| | WRB: | Dystric Cambisol |
| Survey area: | Sakten | |
| Location: | Ca 30 minutes from Sakten on Merak path, close to 'welcome' area | |
| GPS: | Not available | |
| Altitude*:* | 2990 m a.s.l | |
| Described & sampled: | 29.10.1998, IC Baillie | |
| Climate: | General: | Cool temperate, P = ca 1100 mm p.a |
| | Recent weather: | Sunny & cool |
| Regional topography: | Medium mountains | |
| Site position: | Low pass on interfluve | |
| Slope: | 15%, ca 200 m long, convex, aspect (N-NNE15$^0$) | |
| Site drainage: | Good | |
| Parent material: | Solid: Granite | |
| Drift: | Deeply weathered residual | |
| Land use: | Secondary regrowth | |
| Vegetation: | Mixed conifer with hemlock, larch, *Rhododendron*, tsenden (*Cupressus* sp) & much moss | |
| Surface: | Litter: | 12 cm rooted L/H layer |
| | Outcrops: | None |
| | Stones: | None |
| | Cracks: | None |
| | Roots: | None |
| | Microrelief: | 2 m eroded path @ 10 m distance |
| | Faunal activity: | None |
| | Other features: | None |

**Profile description: (Colours are moist unless indicated)**
cm

12 - 0 10YR 3/2 (very dark greyish brown) moss & root litter; root-bound crumb; moist & very loose – friable; abundant fine & medium roots; HCl negative; gradual regular boundary to: [Not sampled]

0 - 24 10YR 3/2 (dark brown) with no mottles; humic loam; root bound medium crumb; many fine pores; moist & root bound friable; abundant fine & medium roots; HCl negative; clear slightly wavy boundary to: [Sample PC033/1 @ 0-10cm]

24 – 38 10YR 5/6 (yellowish brown) with many medium distinct orange, yellow, white & brown mottles; coarse sandy loam; very weak medium subangular blocky breaking to single grain; many medium & fine pores; moist & extremely friable; common fine & medium roots; common angular crumbly weathered granite stones; HCl negative; diffuse boundary to: [Sample PC033/2 @ 25-35 cm]

38 – 120+ White, pale yellow, yellow & orange slightly hard weathered granite with patches of reddish brown & black; some hard quartz grit but some is sugary: [Not sampled]

Comment: Not as deep as first appears and the striking pale colours are in the saprolite, not solum. Organic C surprisingly low in humic loam Al. Very high C: N & CEC suggest lab under-estimate of OC. Very low available P and exchangeable bases.

**SPAL analytical results for SSU** **Profile PC033** **Survey area: Sakten**

Reaction, P & organic matter

| SSU No. | Depth cm | SPAL Lab No | pH | | | EC mS/cm | Avail. P ppm | Organic C% | Total N % | C:N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | H2O | KCl | Diff | | | | | |
| PC033 /1 | 0-10 | 5563 | 5.0 | 3.7 | 1.3 | Tr | 1 | 3.4 | 0.78 | 4 |
| PC033 /2 | 25-35 | 5564 | 5.8 | 4.5 | 1.3 | 0.01 | 1 | 1.8 | 0.11 | 16 |

Exchangeable base status

| SSU No. | Exchangeable | | | | TEB | Extr Al | Extr H | CEC | | BS% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | | | | AmOAc | ECEC | AmOAC | EBS% |
| PC033 /1 | 0.2 | 0.2 | 0.3 | 0.1 | 0.8 | 5.4 | 0.8 | 33.5 | 7.0 | 2 | 11 |
| PC033 /2 | 0.9 | 0.1 | 0.0 | 0.1 | 1.1 | 3.1 | 1.2 | 15.6 | 5.4 | 7 | 20 |

Fine earth granulometric

| SSU 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** | | |
| PC033 /1 | nd | nd | nd | nd | nd | 25.0 | 13.7 | 34.3 | 48.0 | 27.0 | L-CL |
| PC033 /2 | nd | nd | nd | nd | nd | 64.6 | 13.6 | 117 | 25.3 | 10.1 | SL |

| | | |
|---|---|---|
| Profile: | PC034 | |
| Soil Classification: | Sakten soil class: | SGL |
| | Soil Taxonomy: | Typic Endoaquept *(frigid, loamy skeletal, mixed)* |
| | WRB: | Dystric Gleysol |
| Survey area: | Sakten | |
| Location: | Ca 45 minutes from Sakten on Merak path | |
| GPS: | Not available | |
| Altitude*:* | 2900 m a.s.l | |
| Described & sampled: | 29.10.1998, IC Baillie | |
| Climate: | General: Cool temperate, P = ca 1100 mm p.a | |
| Recent weather: | Sunny & cool | |
| Regional topography: | Middle mountains | |
| Site position: | Declivity in lower slope | |
| Slope: | 105%, ca 100 m long, irregular rectilinear, aspect NW ($325^0$) | |
| Site drainage: | Imperfect | |
| Parent material: | Solid: | Slate & phyllite |
| | Drift: | Colluvium |
| Land use: | Forest | |
| Vegetation: | Mixed conifer with hemlock, larch, *Rhododendron*, bamboo & much moss | |
| Surface: | Litter: | 12 cm moss & bamboo sheaths |
| | Outcrops: | None |
| | Stones: | Common subangular mixed metamorphic boulders & stones & gneiss boulders |
| | Cracks: | None |
| | Roots: | None |
| | Microrelief: | Stepping up to 25 cm high behind clumps & roots |
| | Faunal activity: | None |
| | Other features: | None |

**Profile description: (Colours are moist unless indicated)**
Cm

12 - 0 10YR 3/4 (dark yellowish brown); moss & bamboo litter – humic loam; root-bound fine crumb; moist & very loose – friable; HCl negative; gradual regular boundary to: [ Not sampled]

0 - 52 10YR 3/2 (very dark greyish brown) with no mottles; humic medium sandy loam; moderate fine crumb; many fine pores; moist & very friable; abundant fine & medium roots; few hard angular stones; HCl negative; clear regular boundary to: [Sample PC034/1 @ 0-10cm]

52 – 175 2.5Y 5/2 (greyish brown) with common medium distinct orange, yellow & brown mottles; stony loam; stony structure with interstitial moderate medium subangular blocky; common medium & fine pores; stony consistence with interstitial moist & friable; few medium roots; many hard angular stones & boulders; HCl negative; clear slightly wavy boundary to: [SamplePC034/2 @ 90-100 cm]

175 – 185 2.5Y 4/4 (olive brown) with many medium distinct orange, reddish yellow pale yellow & grey mottles; medium sandy clay; stony structure with interstitial strong medium subangular & angular blocky; few fine & medium pores; moist – wet; stony with interstitial firm, plastic & slightly sticky; rare fine roots; common platy weathered grey phyllite; HCl negative; clear slightly wavy boundary to: Not sampled]

185 – 220+ 5G/1 (greenish grey) silvery, platy, slightly hard, weathered phyllite, with few orange streaks & bands. [Not sampled]

Comment: The striking blue colours seen initially in this soil are mainly in the weathered rock, not the solum. Organic carbon of 0.1% in 0-10 cm sample highly improbable, and probably lab error. Confirmed by impossible C: N ratio and oderately high CEC.

**SPAL analytical results for SSU** **Profile PC034** **Survey area: Sakten**

Reaction, P & organic matter

| SSU No. | Depth cm | SPAL Lab No | pH | | | EC mS/cm | Avail. P ppm | Organic C% | Total N % | C:N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | H2O | KCl | Diff | | | | | |
| PC034 /1 | 0-10 | 5565 | 4.8 | 3.8 | 1.0 | 0.06 | 7 | 0.1 | 0.31 | 32 |
| PC034 /2 | 90-100 | 5566 | 5.0 | 4.3 | 0.7 | 0.01 | 35 | 0.1 | 0.01 | 10 |

Exchangeable base status

| SSU No. | Exchangeable | | | | TEB | Extr Al | ExtrH | CEC | | BS% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | | | | AmOAc | ECEC | AmOAC | EBS% |
| PC034 /1 | 0.3 | 0.2 | 0.2 | 0.1 | 0.8 | 2.5 | 0.2 | 20.7 | 3.6 | 4 | 25 |
| PC034 /2 | 1.7 | 0.1 | 0.1 | 0.1 | 2.0 | nd | nd | 3.3 | nd | 60 | nd |

Fine earth granulometric

| SSU 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** | | |
| PC034 /1 | nd | nd | nd | nd | nd | 33.9 | 23.3 | 26.7 | 50.0 | 16.0 | ZiL |
| PC034 /2 | nd | nd | nd | nd | nd | 53.2 | 28.5 | 15.7 | 44.2 | 2.6 | SL |

Profile: Pd025

Soil Classification: Provisional Sakten soil class: SHS
Soil Taxonomy: Typic Dystrustept *(frigid, fine loamy, mixed)*
WRB: Dystric Cambisol

Survey area: Sakten
Location: North bank ca 150 m north of Dungpa's quarter
GPS: $27^0$ 24.35 N', $91^0$ 55. 21 E
Altitude: Not available

Described & sampled: 28.10.1998, Tsheten Dorji

Climate: General: Cool temperate
Recent weather: Sunny

Regional topography: High mountain
Site position: Lower slope

Slope: 46%, ca 400 m +, rectilinear, aspect south ($192^0$)
Site drainage: Good

Parent material: Solid: Tethyan Schist & granite
Drift: Aeolian over colluvium

Land use: Buckwheat field
Vegetation: *Juniperus recurva* & local grasses

Surface: Litter: None
Outcrops: None
Stones: Few medium – coarse subangular schist & granite stones
Cracks: None
Roots: None
Microrelief: 1 – 5 cm irregular cattle poaching of 10 – 15 cm apart
Faunal activity: None
Other features: None

**Profile description: (Colours are moist unless indicated)**
cm

0 - 20 10YR 4/4 (dark yellowish brown) with no mottles; fine sandy loam +; moderate medium subangular blocky; abundant fine & medium pores; moist & slightly friable; many fine, medium & few coarse roots; few medium quartz stones; HCl negative; few grubs seen; gradual regular boundary to: [Sample Pd025/1 @ 0 – 10 cm]

20 - 34 7.5YR 3/2 (dark brown) with no mottles; fine sandy loam +; weak medium subangular blocky; weak discontinuous organic cutans; abundant fine & medium pores; moist & friable; few fine roots; HCl negative; clear wavy boundary to: [Sample Pd025/2 @ 20 – 30 cm]

34 - 50 10YR 3/3 (dark brown) with no mottles; fine sandy clay loam; moderate coarse breaking to medium subangular blocky; weak discontinuous organic cutans; many fine & medium pores; moist & slightly friable; rare fine; few schist & granite stones & boulders; HCl negative; clear regular boundary to: [Sample Pd025/3 @ 40 – 50 cm]

50 - 79 10YR 4/6 (dark yellowish brown) with no mottles; fine sandy clay loam; moderate medium subangular blocky; weak discontinuous organic cutans; many fine, medium & few coarse pores; moist & slightly friable; common medium, coarse & schist & granite stones & boulders; HCl negative; coarse pores filled by organic matter; diffuse boundary to: [Not sampled]

79 - 140 + 10YR 6/6 (brownish yellow) with no mottles; fine sandy clay loam; moderate medium subangular blocky; few fine & medium pores; moist & slightly friable; abundant schist & granite stones & boulders; HCl negative: [Not sampled]

Comment: Typical sandy hillsoil, although subsoil stony. Organic Carbon confirms 20-34 cm as probable buried topsoil. Very low available Phosphate, exchangeable Ca and other bases, but organic Carbon and total Nitrogen contents moderate.

**SPAL analytical results for SSU** **Profile Pd025** **Survey area: Sakten**

Reaction, P & organic matter

| SSU No. | Depth cm | SPAL Lab No | pH | | | EC mS/cm | Avail. P ppm | Organic C% | Total N % | C:N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | H2O | KCl | Diff | | | | | |
| Pd025 /1 | 0-10 | 5582 | 5.4 | 4.6 | 0.8 | 0.01 | 2 | 3.1 | 0.22 | 14 |
| Pd025 /2 | 20-30 | 5583 | 4.9 | 3.7 | 1.2 | 0.03 | 1 | 4.3 | 0.25 | 17 |
| Pd025 /3 | 40-50 | 5584 | 5.2 | 4.0 | 1.2 | 0.01 | 1 | 2.9 | 0.22 | 13 |

Exchangeable base status

| SSU No. | Exchangeable | | | | TEB | Extr Al | Extr H | CEC | | BS% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | | | | AmOAc | ECEC | AmOAC | EBS% |
| Pd025 /1 | Tr | 0.1 | 0.1 | 0.1 | 0.3 | 1.2 | 0.6 | 14.5 | 2.1 | 2 | 14 |
| Pd025 /2 | Tr | 0.1 | 0.1 | 0.1 | 0.3 | 2.3 | 0.3 | 18.4 | 2.9 | 2 | 10 |
| Pd025 /3 | Tr | 0.1 | 0.1 | 0.1 | 0.3 | 1.2 | 0.6 | 19.7 | 2.1 | 1 | 14 |

Fine earth granulometric

| SSU 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** | | |
| Pd025 /1 | nd | nd | nd | nd | nd | 21.6 | 15.2 | 35.5 | 50.7 | 27.8 | ZL |
| Pd025 /2 | nd | nd | nd | nd | nd | 21.4 | 20.1 | 31.4 | 51.5 | 27.1 | ZL-CL |
| Pd025 /3 | nd | nd | nd | nd | nd | 23.9 | 17.4 | 36.1 | 53.5 | 22.7 | ZL |

| | | |
|---|---|---|
| Profile: | Pd026 | |
| Soil Classification: | Provisional Sakten soil class: | SHZ |
| Soil Taxonomy: | Typic Dystrustept *(frigid, coarse silty, mixed)* | |
| WRB: | Dystric Cambisol | |
| Survey area: | Sakten | |
| Location: | South bank, ca 500 m + south east of Gum Ri, near Pusa | |
| GPS: | $27^0$ 24.13 N', $91^0$ 56. 42 E. | |
| Altitude: | Not available | |
| Described & sampled: | 29.10.1998, Tsheten Dorji & Tshering Dorji | |
| Climate: | General: | Cool temperate |
| | Recent weather: | Sunny |
| Regional topography: | High mountain | |
| Site position: | Lower slope | |
| Slope: | 52%, ca 500 m +, rectilinear, aspect SE ($143^0$) | |
| Site drainage: | Good | |
| Parent material: | Solid: | Schist & granite |
| | Drift: | Tethyan Aeolian over colluvium |
| Land use: | Grazing/ fallow land | |
| Vegetation: | Rhododendron, *Daphne* spp, *Rosa* spp & some grasses | |
| Surface: | Litter: | None |
| | Outcrops: | None |
| | Stones: | None |
| | Cracks: | None |
| | Roots: | None |
| | Microrelief: | 1 – 10 cm deep irregular cattle poaching, 5 – 10 cm apart |
| | Faunal activity: | None |
| | Other features: | None |

Profile description: (Colours are moist unless indicated)
Cm

0 - 30 10YR 3/2 (very dark greyish brown) with abundant fine, medium & coarse prominent dark brown & patches of coarse brown & reddish brown mottles; fine sandy loam +; moderate medium subangular blocky; abundant fine & medium pores; moist & friable; abundant fine & few medium roots; HCl negative; gradual regular boundary to: [Sample Pd026/1 @ 0 – 10 cm]

30 - 51 10YR 4/1 (dark grey) with fine & medium faint grey mottles; fine sandy clay loam; weak medium subangular blocky; weak discontinuous clayskins; abundant fine & many medium pores; moist & friable; few fine roots; HCl negative; clear regular boundary to: [Sample Pd026/2 @ 40 – 50 cm]

51 - 81 10YR 4/6 (dark yellowish brown) with no mottles; silty clay loam; moderate medium subangular blocky; strong discontinuous clayskins; many fine, medium & few coarse pores; slightly wet slightly firm & sticky; rare fine roots; HCl negative; few manganese stains; diffuse boundary to: [Sample Pd026/3 @ 60 – 70 cm]

81 - 100 10YR 5/6 (yellowish brown) with no mottles; silty clay loam; strong medium subangular blocky; strong discontinuous clayskins; common fine & medium pores; slightly wet slightly firm & sticky; HCl negative; few manganese stains; diffuse boundary to: [Not sampled]

100 - 131+ 10YR 5/8 (yellowish brown) with no mottles; silty clay loam; strong medium subangular blocky; strong discontinuous clayskins; common fine & medium pores; slightly wet slightly firm & sticky; HCl negative: [Not sampled]

Comment: Good example of silty hill soil. Very low available phosphate and exchangeable bases (especially calcium) but organic carbon and total nitrogen are moderate to 60 + cm. High CEC probably due to high o.m. Hence extremely low base saturation.

SPAL analytical results for SSU Profile Pd026 Survey area: Sakten

**Reaction, P & organic matter**

| SSU No. | Depth cm | SPAL Lab No | pH | | | EC mS/cm | Avail. P ppm | Organic C% | Total N % | C:N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | H2O | KCl | Diff | | | | | |
| Pd026 /1 | 0 - 10 | 5585 | 4.9 | 4.1 | 0.8 | 0.00 | 1 | 5.1 | 0.84 | 6 |
| Pd026 /2 | 40 - 50 | 5586 | 5.3 | 4.1 | 1.2 | 0.01 | 1 | 4.1 | 0.34 | 12 |
| Pd026 /3 | 60 - 70 | 5587 | 5.7 | 4.8 | 0.9 | 0.01 | 1 | 2.3 | 0.26 | 9 |

**Exchangeable base status**

| SSU No. | Exchangeable | | | | TEB | Extr Al | Extr H | CEC | BS% | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | | | | AmOAc | ECEC | AmOAC | EBS% |
| Pd026 /1 | Tr | 0.1 | 0.2 | 0.1 | 0.4 | nd | nd | 29.3 | nd | 1 | nd |
| Pd026 /2 | Tr | 0.1 | 0.1 | 0.1 | 0.2 | 3.9 | 0.6 | 26.3 | 4.7 | 1 | 4 |
| Pd026 /3 | Tr | 0.1 | 0.1 | 0.1 | 0.2 | nd | nd | 24.1 | nd | 1 | nd |

***Fine earth granulometric.***

| SSU 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** | | |
| Pd026 /1 | nd | nd | nd | nd | nd | 8.5 | 15.8 | 39.8 | 55.6 | 35.8 | ZCL |
| Pd026 /2 | nd | nd | nd | nd | nd | 10.2 | 9.8 | 44.3 | 54.1 | 35.7 | ZCL |
| Pd026 /3 | nd | nd | nd | nd | nd | 60.0 | 7.9 | 22.1 | 30.0 | 10.0 | SL |

Profile: Pd027

Soil Classification: Provisional Sakten soil class: SHZ
Soil Taxonomy: Typic Dystrustept *(frigid, coarse silty, mixed)*
FAO: Dystric Cambisol

Survey area: Sakten
Location: Lower spur above mouth of Yalachung Ri
GPS: $27^0$ 24.76 N', $91^0$ 56. 90 E.
Altitude: 3090 m asl

Described & sampled: 30.10.1998, Tsheten Dorji

Climate: General: Cool temperate
Recent weather: Sunny

Regional topography: High mountain
Site position: Lower slope/ footslope

Slope: 65%, ca 300 m +, rectilinear, aspect SW ($235^0$)
Site drainage: Good

Parent material: Solid: Sandstone
Drift: Tethyan Colluvium

Land use: Forest grazing land
Vegetation: Q*uercus semecarpifolia, Rhododendron* spp, *Fragaria* spp & *Pteridium aquilinium*

Surface: Litter: None
Outcrops: None
Stones: None
Cracks: None
Roots: None
Microrelief: 5 – 10 cm very deep irregular cattle poaching 10 – 15 cm apart
Faunal activity: None
Other features: None

Profile description: (Colours are moist unless indicated)
Cm

0 - 10 7.5YR 2.5/1 (black) with common medium & coarse faint reddish brown mottles; humic loam; moderate fine crumb; few medium pores; moist & very friable; many fine & few medium roots; HCl negative; worm & few grubs seen; clear slightly wavy boundary to:
[Sample Pd027/1 @ 0 – 10 cm]

10 - 24 7.5YR 2.5/2 (very dark brown) with few medium very faint dark brown; medium sandy loam; moderate fine crumb; few medium pores; moist & very friable (slightly brittle); many fine & few medium roots; HCl negative; few charcoal; gradual slightly wavy boundary to:
[Sample Pd027/2 @ 10 – 20 cm]

24 - 38 Mixed colours of brown, brownish yellow & dark brown; silty loam; moderate medium breaking to fine subangular blocky; few fine pores; moist, slightly brittle & friable; common fine & few medium & coarse roots; few fine soft weathering rock; common black manganese stains & soft concretions; HCl negative; few earthworms seen; gradual wavy boundary to: [Not sampled]

38 - 73 10YR 5/6 (yellowish brown) with many fine very faint yellow mottles; silty clay loam; moderate medium subangular blocky; strong discontinuous clayskins on pore walls; many fine & few medium & coarse pores; moist & friable; few medium & coarse roots; common slightly hard – soft weathered grey green rocks & few medium hard quartz stones; HCl negative; clear slightly wavy boundary to:
[SamplePd027/3 @ 50 - 60 cm]

73 - 102 + Slightly hard *in situ* greenish grey weathered sandstone with no cracks & no roots, hand textures as loamy fine sand in softer portions.
[Not sampled]

Comments: Humic loam and colour of topsoil confirmed by high organic carbon. Good nitrogen status but available phosphate is very low. The high exchangeable calcium and TEB in this soil does not accord with pH level.

SPAL analytical results for SSU Profile Pd027 Survey area: Sakten

**Reaction, P & organic matter**

| SSU No. | Depth cm | SPAL Lab No | pH | | | EC MS/cm | Avail. P ppm | Organic C% | Total N % | C:N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | H2O | KCl | Diff | | | | | |
| Pd027 /1 | 0 – 10 | 5588 | 4.9 | 3.8 | 1.1 | 0.00 | 2 | 15.0 | 1.75 | 8 |
| Pd027 /2 | 10 – 20 | 5589 | 5.2 | 4.1 | 1.1 | 0.01 | 1 | 4.6 | 0.39 | 12 |
| Pd027 /3 | 50 - 60 | 5590 | 5.2 | 4.2 | 1.0 | 0.00 | 1 | 0.7 | 0.04 | 18 |

**Exchangeable base status**

| SSU No. | Exchangeable | | | | TEB | Extr Al | Extr H | CEC | | BS% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | | | | AmOAc | ECEC | AmOAC | EBS% |
| Pd027 /1 | 12.2 | 2.2 | 0.6 | 0.1 | 15.1 | 1.2 | 0.8 | 39.8 | 17.1 | 38 | 88 |
| Pd027 /2 | 0.6 | 0.4 | 0.2 | 0.1 | 1.3 | 4.8 | 0.4 | 39.9 | 6.5 | 3 | 20 |
| Pd027 /3 | 0.2 | 0.6 | 0.5 | 0.1 | 1.4 | nd | nd | 11.2 | nd | 12 | nd |

**Fine earth granulometric**

| SSU No. | Sand | | | | | | Siit | | | **Clay** | **Texture class** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | >1000 micron | 425-1000 | 212-425 | 106-212 | 50-106 | **Total sand** | 20-50 micron | 2-20 | **Total silt** | | |
| Pd027 /1 | nd | nd | nd | nd | nd | 24.8 | 23.8 | 33.3 | 57.1 | 18.1 | ZL |
| Pd027 /2 | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| Pd027 /3 | nd | nd | nd | nd | nd | 28.3 | 28.4 | 23.9 | 52.3 | 19.4 | ZL |

| | | |
|---|---|---|
| Profile: | PC032 | |
| Map unit: | | |
| Soil Classification: | Sakten soil class: | SLT |
| | Soil Taxonomy: | Fluventic Dystrustept *(frigid, loamy skeletal, mixed)* |
| | WRB: | Skeletic Fluvial |
| Survey area: | Sakten | |
| Location: | South bank of Gum Ri, across river from radio building | |
| GPS: | Not available | |
| Altitude*:* | 2915 m a.s.l | |
| Described & sampled: | 29.10.1998, IC Baillie | |
| Climate: | General: | Cool temperate |
| | Recent weather: | Sunny & cool |
| Regional topography: | Wide valley | |
| Site position: | Truncated lower edge of alluvial fan/terrace | |
| Slope: | 5%, ca 100 m long, convex, aspect E ($100^0$) | |
| Site drainage: | Good | |
| Parent material: | Solid: | Mixed |
| | Drift: | Mixed fan & river alluvium |
| Land use: | Natural pasture | |
| Vegetation: | Short grass & forb sward with many *Rumex* | |
| Surface: | Litter: | Thin discontinuous grass & forb litter |
| | Outcrops: | None |
| | Stones: | Common angular & subangular boulders with dark lichen crust |
| | Cracks: | None |
| | Roots: | None |
| | Microrelief: | Hummocks up to 10 cm high |
| | Faunal activity: | None |
| | Other features: | None |

Profile description: **(Colours are moist unless indicated)**
cm

0- 12 10YR 2/2 (very dark brown), slightly stony fine sandy loam; moderate fine crumb; many fine pores; moist & very friable (stony); many fine & common medium roots; many angular & subrounded & platy hard mixed cobbles up to 15 cm diameter; few ants seen; HCl negative; gradual regular boundary to: [Not sampled]

12 - 120 10YR 3/4 (dark yellowish brown) with no mottles; sandy gravel; stony structure; few fine pores; moist & loose; few fine roots; abundant angular & rounded rouded mixed gravel; HCl negative; clear wavy boundary to: [Not sampled]

120 – 140+ 10YR 4/4 (dark yellowish brown); fine sandy loam; weak fine subangular blocky; few fine pores; moist & friable; no roots; rare fine rounded gravel; HCl negative; diffuse boundary to: [Not sampled]

Comment: Mixed angularity of gravels not decisive as to whether origin is from side valley fan or main river terrace, as main river is less than 10 km long upstream to source, and transport distances are short

# APPENDIX C: SOIL CORRELATION

## APPC.1 Soil classification and correlation in Bhutan

Tables 5.3 (a) and (b) in the main report summarise the correlations of the Merak and Sakten soil classes with the international soil classifications. This appendix discusses the reasoning behind the correlations assigned. This is necessary because SSU is still at an early stage of its operations and the soil correlations need to be worked out. Some of them will undoubtedly be revised in the future, when we learn more about Bhutan's soils.

The international systems suffer from several problems. The worst is that there are two of them– the USDA Soil Taxonomy and FAO World Reference Base for Soils. Either system would be improved more quickly if it was accepted by all and was the sole focus of attention.

The Soil Taxonomy (Soil Survey Staff 1975) was originally developed to meet the needs of soil survey in the continental United States. It has been extended (Soil Survey Staff 1998) since then, but it is still stronger on temperate than on tropical soils. It is detailed and comprehensive. The FAO system is more globally oriented, and is less detailed, but still quite comprehensive. It has been improved in the recent World Reference Base for Soil Resources (FAO 1998). It has an advantage that it uses more traditional and comprehensible soil names.

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, SSU will use local soil classes and names within Bhutan, and will correlate them against both of the international systems.

## APPC. 2 General criteria

Before considering individual soils, there are some general environmental considerations for the Merak and Sakten as a whole that need to be determined for the application of Soil Taxonomy.

### *APPC 2.1 Soil moisture regimes*

This is necessary for the definition of ST suborders or great groups. In the absence of soil moisture data, soil moisture regimes are normally approximated from rainfall totals and distribution. Even this is not possible for Merak and Sakten. It is assumed that they have an ustic climate, which is defined as having more 90 consecutive dry days per year and a summer rainfall distribution. All of the soil classes are assigned to ustic soil moisture regimes except for the poorly drained soils at Sakten (SGL). These have an aquic moisture regime, which refers to soils that are permanently wet due to their topographic position.

### *APPC 2.2 Soil temperature regimes*

This is a criterion for classification in Soil Taxonomy. Climatic data from Ura and Lame Gompa were extrapolated and these indicate that Merak has a cryic or frigid STR, but Sakten is almost certainly warm enough to be only frigid.

### *APPC 2.3 Mineralogy classes*

This is a family criterion in Soil Taxonomy. Although muscovite is a visible component in some soils, 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.

## APPC. 3 Correlation of Merak and Sakten soils

*APPC 3.1 Floodplain soils (MFP and SFP)*

The flooding regime and high boulder contents qualify these clearly as Skeletic Fluvisols (WRB) and Fluvents in Soil Taxonomy. In Soil Taxonomy these may be Cryofluvents at Merak but not at Sakten.

*APPC 3.2 Terrace soils (MLT, MMT, SLT and SHT)*

Nearly all of these soils appear to be sufficiently weathered and developed to be classed as Cambisols (WRB) or Inceptisols in Soil Taxonomy. As in the floodplain soils, the STR may be sufficiently cold for them to be in the coldest suboder – the Cryepts - at Merak but not at Sakten. The high terrace remnant seen upstream of Sakten is so bouldery that it is best designated as Skeletic Fluvisol or Regosol (WRB) but has been left as an Inceptisol in Soil Taxonomy.

*APPC 3.3 Merak hill soils (MHS)*

Many of these variable hill soils are so stony that they are classed as Skeletic Regosols (WRB) or Lithic Cryorthents in Soil Taxonomy. The soils with significant stone - free aeolian material are Cambisols (WRB) or Dystrustept or Dystrocryepts in Soil Taxonomy.

*APPC 3.4 Sakten hill soils (SHZ, SHS, and SHG)*

These are sufficiently weathered and developed to be Cambisols in WRB or Dystrustept in Soil Taxonomy.

*APPC 3.5 Gley soils (SGL)*

These soils are probably wet all year round, and qualify as Aquept in Soil Taxonomy and Gleysol in WRB. They do not appear to be organic enough to qualify as Histosols. As these soils are wet throughout the profile, they qualify for the Endo – rather than Epi – groups in the Aquept suborder of Soil Taxonomy.

## APPENDIX D: SOIL SURVEY UNIT

The Soil Survey Unit 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 Soils Services Centre of the Council for RNR Research of Bhutan (CoRRB) of the Ministry of Agriculture (MoA). It began field activities in June 1997.

The emphasis in the initial stages of the Project has been on training 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 at Merak - Sakten is the first reconnaissance survey ever done by SSU as a training exercise.

Table App D.I shows the main soil survey reports done by SSU.

*Table APPD.1 SSU main soil survey reports*

| | | |
|---|---|---|
| 1 & 1(a) | General & Technical reports of detailed soil survey of Yusipang RNR-RC | Final, distributed 7/98 |
| 2 & 2(a) | General & Technical reports of detailed soil survey of Bathpalathang site, Jakar RNR-RC | Final, distributed, 9/98 |
| SS 3 & SS 3(a) | General & Technical reports of detailed soil survey of Bajo RNR-RC | Final, distributed, 12/98 |
| SS 4 & SS4(a) | General & Technical reports of detailed soil survey of Khangma RNR-RC | Final, distributed, 3/99 |
| SS 5 & SS 5(a) | General & Technical reports of semi-detailed soil survey of Lingmutey Chhu watershed | Technical final distributed 4/99. General final distributed 11/99 |
| SS 6 & SS 6(a) | General & Technical reports of semi-detailed soil survey of Radhi geog | Draft technical distributed for feedback, 7/99 |
| SS 7 & SS 7(a) | General & Technical reports of semi-detailed soil survey of Lame Gompa Research Forest | Draft technical distributed for feedback, 4/99 |
| **SS 8** | **Report on the soils of Merak and Sakten** | **This report.** Final distributed 11/99 |
| *SS 9 & SS 9(a)* | *General & Technical reports of semi-detailed soil survey of arable lands of middle Tsang Chhu valley* | Fieldwork in progress |
| SS 10 & 10(a) | General and Technical reports of semi-detailed soil survey of arable lands of middle Nyakalumphu valley, Punakha | Final, distributed 10/99 |