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

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

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CONTENT

SUMMARY

A detailed soil survey of the Bajo Renewable Natural Resources Research Centre, Wangduehodrang was carried out during December 1997. The survey was the third done by the Bhutan Soil Survey Project.

The Centre occupies 26 ha (about 64 acres) on the true left (= east) bank in the main valley of Tsang Chhu about 2 km north of Wangdi town. The survey also included the adjacent seed production area of the Druk Seed Corporation, covering about of 5 ha (12 acres). Most of the Centre's land is located on the lower (ca 10 m above the river) and middle (ca 25 m) level alluvial terraces, which were deposited by river and then left on the side of the valley. There are also small areas of hillslope, the lower part of the connecting slope up from the middle to the high river terrace, and of the discontinuous floodplain deposits along the river. Apart from the small area of hillslope, all of the soils are derived from alluvial parent materials. These originate from the upper catchment of the main river, and are of mixed lithological origin.

The Centre is the longest established of the RNR-RC's, and its research programme has expanded to use nearly all of the land available, and there is little scope for further expansion.

The most extensive soils of the Centre are located on the flat and gently sloping tops of the middle and lower river terraces. The soils of the middle terrace consist of a hard, greyish brown silty upper part overlying a reddish, weathered, more sandy and more friable lower section. The depth of the upper part is variable, and tends to decrease upslope as the gradient of the slope slightly steepens. Three depth subdivisions have been mapped. The soils of the lower terrace also have a hard, grey and greyish brown, silty upper part. This tends to be finer textured and even harder than the equivalent layer in the middle terrace soils. The lower section of the low terrace soils is loose, pale fine sand, similar to the white sand currently being deposited by the river. The depth of the hard silty upper layer varies and, in contrast the middle terrace soils, tends to get deeper on the higher sites, away from the river. The soils of the small areas of steep riser slopes connecting the middle terrace up to the high terrace and down to the lower terrace are deep, brown – reddish brown loams, with beds of rounded alluvial boulders in their subsoils. The floodplain soil is predominantly pale, loose, fine sand, but there are subordinate layers of brown silty loam at the surface and sporadically down through the subsoil. The small area of hillslope, soils has been much disturbed by terracing and other constructions. The soils are deep, brown to reddish yellow in colour, and of sandy loam - sandy clay loam textures.

The Bajo soils are correlated with the classes of the international systems of soil classification. The hill soils are mostly Ustochrepts in the American Soil Taxonomy and Eutric Cambisols in the FAO system. The middle terrace soils have similar correlations but the less weathered and more contrasting layered soils of the lower terrace are Entisols (Orthents and Fluvents) in Soil Taxonomy and Fluvisols in the FAO system.

The results of the soil survey indicate that the Centre is well situated for resaerch on the wetland rice/wheat/mustard cropping system on alluvial soils in the Wangdi–Punakha region. The Centre has already produced valuable results for this important food-producing area. Proposals to relocate the Centre to make way for urban expansion will disrupt on–going trials and negate much previous good work. The Centre has no significant areas of alluvial fans, lower hill slopes, or remnants of the higher river terraces. These are also used for wetland cultivation in the region. The possibility of a small out-station for on–station trials on such types of land, to complement on-farm research, could be considered.

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The analyses of the soil samples were done by the Soil and Plant Analytical Laboratory (SPAL) at Semtokha. SPAL also provided the records of the previous analyses of soil samples from Bajo RNR-RC.

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We are grateful to Chencho Norbu, and the staff of the RNR-RC for helpful comments on the draft text and map. Feedback is important, because BSSP is still trying to establish formats that make its reports useful to researchers, planners, extension workers and other soil managers.

1. INTRODUCTION

1.1 Bhutan Soil Survey Project

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

The emphasis in the initial stages of the Project is on the training of Bhutanese nationals as soil surveyors, and the establishment of a functioning Soil Survey unit. The main method of training is by 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 the soil pattern to be worked out by direct observation, with the minimum of extrapolation and assumptions. This survey of the Bajo Renewable Natural Resources (RNR) Research Centre (RNR-RC) is the third of the detailed surveys/training exercises undertaken by the Project.

1.2 Bajo RNR-RC

Bajo is one of the four main RNR Research Centres in REID. Its national mandate is for research in wetland production systems. The main field crops investigated are summer rice, and winter wheat, mustard and other grains. It also investigates vegetables and subtopical fruit trees, such as mandarins, guavas, pomelos and others. It has a regional mandate for the coordination of all RNR research and extension activities in the West Central region, which cover the dzongkhags of Gasa, Punakha, Wangduephodrang, Tsirang and Dagana.

1.3 Aims of the Bajo soil survey

The detailed soil survey was undertaken with objectives of:

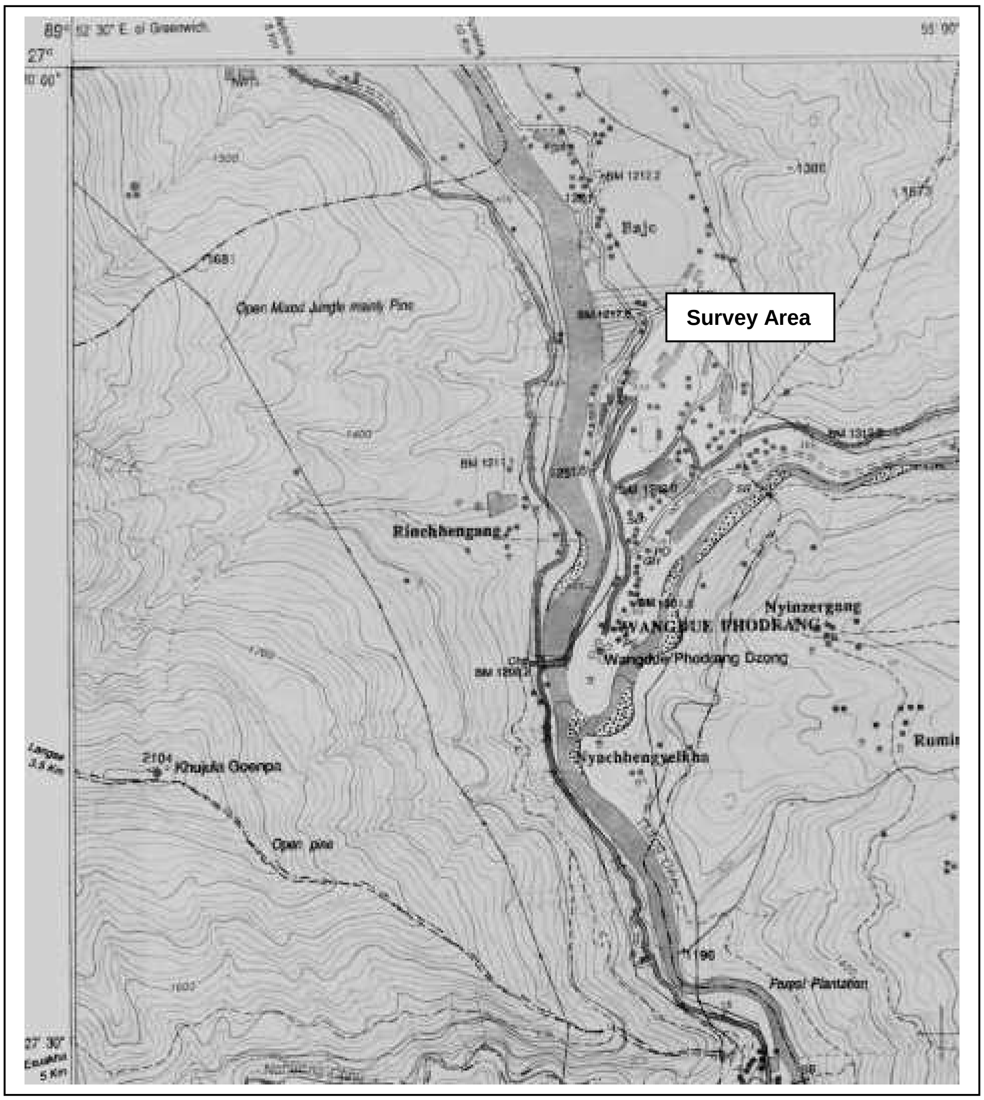
- Further training in soil survey techniques for BSSP staff.
- Further adjustment of standard soil survey practice to suit Bhutan conditions.
- Providing Bajo RNR-RC with detailed information on the nature and distribution of their soils.
- Indicating the extent of the applicability of research results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

2. THE SURVEY AREA

2.1 Location and extent

The Centre is located in Wangduephodrang dzongkhag, on the Wangdi-Shengana feeder road along the true left (i.e. eastern) bank of the Tsang Chhu. It is about 2 km north of Wangdi town centre. The road is black-topped from Wangdi town to the RNR-RC, but is gravel from there northwards. The Research Centre proper covers 26 hectares (64 acres), mostly on the eastern (i.e. upper) side of the road. The land between the road and the river is also part of the Centre. Immediately adjacent to the research area, the government-run Druk Seed Corporation has a seed replication and production center, covering about 5 ha (12 acres). This was also included in the soil survey area. The soil survey area totals 31 ha (76 acres). It is located at latitude 89^0 54.15' N and longitude 27^0 29.70 'E. Figure 2.1 depicts the detail location of the survey area.

Figure 2.1 Location map of the Survey area



Most of the survey area has been under wetland cultivation for many years. The land was acquired by the Ministry of Agriculture in 1965. Initially it was used for extension demonstrations and for vegetable seed production. Research work began in 1982, and has been in progress ever since.

2.2 Climate

The Centre lies at an altitude of 1200-1300 m a.s.l., and has a warm temperate – subtropical climate (Eguchi 1997). It lies in the chir pine eco-climatic zone. The Centre lies in a wide valley and is fairly flat, so that aspect is less important than in many parts of Bhutan. However the site has a slightly westerly aspect, and lies close to the eastern wall of the valley, so that it is slightly shaded in the early mornings.

Table 2.1 summarises the main features of the climate of the Centre, as reported in the Wangdi Groundwater study (PCI 1996). There are also data for the same station held at the Meteorological Unit of the Ministry of Trade and Industry (MUMTI). These are more or less in agreement. The mean annual rainfall is about 700 mm, about 75% of which falls during the southwest monsoon in June-September. However showers can occur at other times of the year. Temperatures rise from mean minima of about 5^0 C and mean maxima of about 18 -19^0 C in December – January to flatten out at about 19 - 20^0C mean minima and 28 – 29^0C mean maxima in May, and continue at about these levels right through the monsoon. They begin to decline again in October.

There are data for other climatic parameters from the Hesithanka Hydel station, which lies about 2 km south of Wangdi Bridge and therefore about 4 km south of the survey area. These data for 1990 – 1996 are summarised in Table 2.2. The temperature data are similar to those for the RNR-RC. The mean annual temperature is 17.9^0C, with 28.6^0C as the highest mean monthly maximum and 5.3^0C as the lowest monthly minimum; the mean annual total precipitation at the Hydel is 649.5 mm, with a range from about 550 mm to about 800 m over a seven year period. The differences in precipitation estimates between Tables 2.1 and 2.2 may be partly due to different locations and partly to different time periods covered. Mean monthly evaporation exceeds mean monthly rainfall for every month of the year, even in the monsoon months, due to the high summer temperatures. This gives the area a moderately xeric moisture regime (Ohsawa 1991). However the measured evaporation is probably greater than potential evapotranspiration, and there are probably short and irregular periods of moisture surplus during the monsoon (Wohrer 1992). A major factor in the high evaporation rates are the high runs of wind. These are not apparent in Table 2.2, which only summarises the spot wind speeds at 9 a.m. A feature of the area is the strong and prolonged upstream winds that blow on many afternoons (Eguchi 1997), earning the valley the name of 'Windy Wangdi'.

2.3 Geology and soil parent materials

The Centre is located almost entirely on the alluvial deposits of the Tsang Chhu river, and there are no outcrops of bedrock. The alluvium is derived from the rocks of the upstream catchment. This has a varied geology, with large outcrops of plutonic leucogranites in the High Himalaya near the Tibet border, Paro Formation schists, phyllites, quartzite and limestones, and Thimphu Formation gneisses further downstream. The metamorphic rocks of the Paro and Thimphu Formations are intruded with quartz veins, amphibolite dikes, anatectic granitic bodies, and skarn rocks, in which limestones have been metamorphosed by suffusion with magmatic fluids. Although of varied provenance, the bulk of the alluvial clasts appears to be derived from quartzites, vein quartz, gneisses and granites (Gansser 1983, ESCAP 1991, Bhargava 1995). The chemical characteristics of the soils suggest that there may be a calcitic component in the alluvial fines.

The alluvial history of the section of the Tsang Chhu valley is complex. The general, rapid but irregular movement downwards of the erosional base level has resulted in the deposition and subsequent dissection of successive levels of alluvium. The dissected older alluvia are now left as relict river terraces along the sides of the valley. These have been divided into three groups at different heights (Bhargava 1995; PCI 1996), but there are distinct subterraces within each group. Takada (1991) gives different height designations and numbering to the terraces, but the correlations with PCI (1996) are generally clear.

The terraces of the highest and oldest group in the vicinity of the survey area are at about 100-130 m above the current river level. The largest remnant of these forms the shelf on which Wangdi town and RBA Camp are located. The full depth of these deposits is exposed in the road cuttings along the Thimphu Highway down from the town to Wangdi Bridge. This section shows that this alluvium is very heterogeneous, with beds of rounded boulders, interlayered with beds of sand and pebbles. There are also massive boulders (of up to 100 m^3) which have been hardly rounded. These may be colluvial/landslip clasts that have rolled down local slopes and been incorporated into the more traveled alluvium. Alternatively they may be truly alluvial and have been moved long distances by extremely turbulent floods generated by glacial lake outbursts (GLO) in the High Himalayas upstream (Gansser 1983, Takada 1991).

The middle group of terraces in the survey area is at about 25 – 40 m above the current river. The upper part of the Centre is located on these deposits. The cutoff bluff at their lower edge reveals rounded boulders at depths of 2-3 m. In the Centre's borehole on this terrace, the clast – free alluvium is much deeper. The drilling data indicated that up to 40 m of sand, silt and clay alluvium overlies a dense bed of rounded boulders. This may mark an earlier course of the main river (PCI 1996).

Table 2.1 Climatic summary for Bajo RNR-RC, 1985-1995

	J	F	M	A	M	J	J	A	S	O	N	D	Year mean or total
Mean minimum temperature ^{0}C	5	8	11	13	17	20	20	20	19	15	9	5	13
Mean maximum temperature ^{0}C	18	18	22	25	28	29	28	28	28	26	22	19	24
Mean rainfall (mm)	12	16	20	44	35	139	154	126	91	36	11	10	693

Source: PCI (1996)

The lowest group of terraces in the survey area is at 5 - 15 m above the current river level. The different subterraces within this group are more distinct than in the middle group, as they are younger and have been less exposed to natural smoothing. They have also been less favoured for wetland terracing, which tends to obscure minor natural differences in level. The alluvium of these terraces tends to be silty at the surface, will fine sand at depths of 0.5 – 1.5. m. Profiles in this group of terraces located about 3 km upstream show boulder beds at depths of 1.5 m+ (see forthcoming BSSP Report SS 5(a) on the Lingmutey Chhu watershed), but none were seen in the survey area.

The downcutting of the river base level was mainly controlled by tectonic uplift. This appears to have been rapid, with the surface metre or so of the middle terrace alluvium tentatively dated at only 350 years BP (Takada 1991). However it has not been smooth, with the terraces deposited during prolonged stillstands, and the dissections occurring during major uplifts. The drillings on the 25-40 m terrace show that alluvium there now extends to below the current river level (PCI 1996). This implies that, at one time, the river level was lower than it is now, and that there has since there has been a period with a rise in the local erosional base level and alluvial infilling of the valley floor. Current dissection is only now cutting back down towards an earlier level. Episodes of base level rise and infilling like this are probably locally controlled, and are unlikely to be due to regional tectonic downwarping. In the case of the survey area, a major landslip damming of the river downstream could have led to a localised rise in base level and increased deposition. The narrow section of the Tsang Chhu valley at Wangdi Bridge is a possible location for such a major landslip dam. As noted above, the highway sections there expose massive boulders, which could be of local origin, emplaced by mass movement. PCI (1996) mapped the slopes around and above the village of Rinchengang on the west bank above Wangdi Bridge as being mantled with landslip deposits.

Table 2.2 Climatic summary for Hesitanka Hydel, 1990 – 1996

	J	F	M	A	M	J	J	A	S	O	N	D	Year mean or total
Temperature mean minimum ^{0}C	5.9	7.9	10.8	13.3	17.5	19.8	20.1	20.0	19.3	14.5	8.7	5.3	13.6
Temperature mean maximum ^{0}C	17.1	18.6	22.8	26.0	27.9	28.6	28.2	28.4	27.4	25.7	21.9	19.1	24.3
Mean rainfall (mm/mo)	19.5	13.5	13.5	44.7	38.6	108.9	138.8	144.0	90.9	18.1	14.1	4.9	649.5 mm/yr
Mean 0900am wind speed (m/s)	1.6	1.9	2.1	2.2	2.3	2.1	1.9	1.6	1.4	1.5	1.3	3.1	1.9
Mean evaporation (mm/mo)	85.0	111.8	151.5	179.1	196.2	168.9	187.8	165.2	147.0	148.8	105.9	88.1	1735.3 mm/yr
Mean sunshine (hrs/mo)	147.4	138.9	175.5	187.8	154.2	119.6	136.1	148.0	133.0	200.3	168.9	186.0	157.9

Source: Data supplied by MUMTI, 1998.

2.4 Topography and drainage

As noted above, most of the Centre is located on the lower and middle groups of terraces of the main valley of Tsang Chhu. The two groups are separated by a distinct bluff about 10 – 15 m high, that runs below the RNR-RC main building and above the Druk Seed Corporation buildings. The Wangdi - Shengana feeder road is cut into this slope. Several distinct levels can be distinguished within the lower group of terraces. These range from about 3-5 up to 10 – 15 m above the current river. The tops of these are flat – gently sloping (1 – 4%). The breaks of slope between the levels are visible in places, but the bluffs are very short (> 10 m long). The lower subterraces form embayments and re – entrants cut into the upper levels. The embayments form the natural drainage lines in this part of the Centre.

Above the main bluff the middle terrace slopes gently uphill (about 2 – 4% natural slope) to the concave lower slope of the foothills which come down to the eastern boundary of the survey area. There appear be two levels within the middle group of terraces, separated by a minor bluff 2 – 4 m high, running across just below the level of the Borehole. However the land surface has been much modified by the construction of agricultural irrigation terraces, and these obscure the natural break of slope. There do not appear be any significant natural drainage lines on the main expanse of the middle terrace, but there may have been one along the base of the riser slope up to high terraces.

There is a small area in the southeast of the survey area that is located on the lower section of steep riser slope up to the higher group of terraces, from which the RBA Camp looks down on the Centre from a relative height of about 60 m. The riser slope is slightly indented by minor gullies and intervening spurs. The steep (up to 80%) slopes are naturally concave – rectilinear, but they have been modified by agricultural terrace construction in a few places.

The northeastern corner of the survey area includes a very small area of the footslope of the main hills to the east. The natural surface morphology of this small area is steep, concave – rectilinear and somewhat gullied, but it has been much disturbed by construction of buildings and agricultural terraces.

2.5 Land use and vegetation

Virtually the whole of the survey area is under irrigated agriculture. The bulk of it is used for trials by the RNR-RC. The main cropping systems investigated are summer rice; winter wheat and mustard; summer and winter vegetable; and warm temperate and subtropical fruit tree crops, including peaches and mandarins.

The Centre was established in 1965. The land had been under wetland cultivation for some years before that. The previous farming system differed from current practice in that the land was fallowed for cattle grazing in winter following the summer wetland rice crop. The introduction and widespread adoption of irrigated winter wheat and mustard in the area is largely due to the successful adaptive research by the Centre and extension activities of MoA (Kuensel 21/3/1998).

The northwestern 5 ha (12 acres) of the survey area has been developed by Druk Seed Corporation for seed production. The main seeds produced are for winter brassicas (mainly cabbage and cauliflower). During summer the land is used for the production of grass seed.

There are small uncultivated areas along the riverbanks, the lowest parts of the floodplain and on the steep sections of the terrace riser slopes and the footslope of the eastern mountain. All of these have been much disturbed and none of them retain their natural climax vegetation. On the steepland slopes there is a scrub of tall local grasses, Artemisia vulgaris and some chir pine seedings. Uncultivated areas near the river bank carry tall grasses, sedges and Artemisia.

3. PREVIOUS SOILS INFORMATION

3.1 Introduction

As far as is known, the Centre has not been covered by any previous soil surveys. However there are three previous data sets and/or studies which are relevant to the survey area.

3.2 Agronomic soil analyses

Soil samples have been collected on the Centre for analysis for agronomic research work. The data available are summarised in Table 3.1. The results show that many of the soils are of nearly neutral pH, as a result of their prolonged use for wet rice, and possibly also because of limestone components in the alluvium. Organic matter levels are low, another result of prolonged wet rice cultivation. However C:N ratios are satisfactory. Available P levels are variable, as a result of natural heterogeneity and because of different fertilizer treatments. P is thought to be a major constraint in the summer rice – winter wheat/mustard cropping system. It is treated as a major effect and interaction in former and ongoing fertiliser trials.

3.3 Wangdi groundwater study (PCI 1996).

PCI (1996) have described and mapped (at 1:10,000) the topography and terrace alluvium of the Wangdi area, including the Centre. Their maps are very useful for general environmental and geomorphological background, but the report is generalised in its description of the alluvia and cannot be used for the detailed discrimination and characterisation of soils. The study contains no actual soils data.

3.4 Land resources of Thedtsho and Baap blocks (Drukpa 1996)

The land resources of an area on both banks of Tsang Chhu just to the north of Bajo were mapped (at scale ca 1:70 000) and analysed by D. Drukpa (1996). As well as Drukpa, the soils fieldwork was done by the LUPP soils team (R. Allen and D. Kumar). They described and sampled 22 profiles, seven of which are located on the middle and lower river terraces near Wanjgokha and Bajothango, about 2 km north of our survey area

The descriptions and analyses of their terrace profile are similar the findings of our survey, in that they also found hard silty loam – silty upper horizons overlying more sandy lower sections, with mainly neutral pH and high base saturations. However they found some features that are different to those in the Bajo soils, i.e.

a) They report quite reddish subsoil colours (Munsell hue 2.5 YR). None of the terrace soils seen on the Centre are of hue redder than 5 YR.

b) Their topsoil consistences are not quite as hard as those at Bajo.

c) The subsoil horizons in their lower terrace soils are not as pale, coarse textured and loose as most of those at Bajo.

Table 3.1 Soil analyses for agronomic trials at Bajo RNR-RC, 1995-1998.

Year	No. of samples	Depths (cm)	SPAL Sample Nos.	Analyses completed
1995	41	Topsoil	622 – 662	pH, EC, AvP, exchangeable cations, texture.
1995	26	Topsoil	1504 – 1529	pH, EC, AvP, OrgC, Total N, texture
1997	15	Topsoil	4234 – 4248	Full chemical and texture.
1998	52	Topsoil	4661 – 4712	Full chemical and texture.
1998	36	Topsoil	4860 – 4895	Full chemical, no textures.

Source: SPAL records 1998.

4. METHODS

4.1 Field

This was the third survey undertaken by BSSP, and it was partly done as a field training exercise. As the soil surveyors had by then several months of field experience, they did much of the routine fieldwork independently. The time taken for this survey was much shorter (two team weeks) than for the Yusipang RNR-RC soil survey (BSSP Report 1(a) 1998).

The soils were examined on a routine basis at 71 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. At the few sites, where the first attempt to auger was stopped by stones at less than 50 cm, a second attempt was made within a few metres. A few examinations were done in road cuttings, cut back at least 15 cm to expose fresh soil. All of the sites were located on a free survey basis, because it was simple to locate observation sites accurately, using field and plot boundaries, all of which are shown on the base map supplied by the RNR-RC.

For routine soil observations the following site data were collected:

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

The soil profiles were described according to their natural layering (horizons) in the upper one metre, and not at fixed depths. The following data were 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. One of the detailed descriptions was done in freshly cleaned-back road cutting, and the remainder in purpose – dug profile pits. The site data were the same as for the routine sites, with the addition of a detailed description of surface features, including:

> Microrelief, rock outcrops; litter, cracks, faunal activity, sand wash, and capping.

The soil profiles were described by horizons. The data collected for each horizon were the same 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); moisture state and 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.

4.2 Mapping

The Survey of Bhutan (SoB) topographic mapping of the area is sheet # 78E-15 at scale 1:50 000. The current edition was produced by the Survey of India in 1964. The scale of 1:50 000, is too small for the topographic map to be used as a base for 1:2500 soil mapping. The recent SoB 1:25 000 topographic remapping of the Wandi and Punakha sheets is not yet available.

However the RNR-RC has been mapped at larger scale, although when and by whom is not indicated. The scale of the map is not given, but measurements on the ground indicate that is about 1:1500. The map appears to be accurate as to the older infrastructure (it does not show the new RNR-RC building) and especially with respect to the boundaries of the trial and seed production fields plots. The map does not show contours, but the Centre is covered by the 10 m contour mapping of the Wandgi groundwater study (PCI 1996).

A problem with the large scale map is that it was not tied into a national spatial frame, and no control points are shown. This means that, although it can be used as the basis of a free – floating drawing, it is difficult to place it in the national x – y frame of the LUSS GIS. This may slightly restrict its potential uses and value. In an attempt to overcome this problem and to relate the soil map to the national geo-referencing frame in the GIS, GPS readings (averages of 20) were taken on the ground at 8 easily identified stations around the Centre. Some of these had poor satellite geometry and undesirably high PDOP (= error) values. When all of the GPS reading were entered in the GIS and compared with the initial digitisation of the base map, the RMS error was unacceptably high, by several orders of magnitude, and the map is seriously distorted. For the present, the GPS reading have been ignored. The Cadastral Section of SoB have recently supplied x – y coordinates for some cadastral stations, which will allow the map to be located in the national frame.

The infrastructure, soil boundaries, and the sites of augerings and the profile pits were plotted on photo – reduced hard copies of the base map. The data were then digitised into the GIS as three separate covers: infrastructure; soil inspection sites; and soil boundaries.

4.3 Laboratory

The 61 soil samples collected from the main horizons of the 11 detailed profiles were analysed by the Soil and Plant Analytical Laboratory (SPAL) of the National Soil Service Centre, (NSSC) of the Research, Extension and Irrigation Division (REID) of the Ministry of Agriculture at Semtokha. The methods of analysis used by SPAL are summarised in Appendix A.

The only 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 quantity required. This is referred to as CEC (NH_4OAC). An alternative is to estimate CEC by summing the exchangeable bases (Ca + Mg + K + Na = (TEB), and the extractable aluminium. This is known as the 'effective cation exchange capacity (ECEC). SPAL does not measure extractable Al in soils with pH (water) greater than 4.5. As none of our Bajo samples are sufficiently acid, there are no determinations for extractable Al. In such cases the ECEC is identical with the TEB, is not informative, and has not been given in this report. Base saturation is the quotient TEB/CEC. If the TEB and the ECEC are identical (as is the case where there is no extractable aluminium), the 'effective base saturation' (EBS % = TEB/ECEC) is automatically 100 %. Such values add no information, and have not been given in this report. The base saturations in the soil class descriptions in Section 5.2 and in the soil profile data in Appendix B therefore refer to TEB/CEC (NH_4OAC).

5. SOIL CLASSIFICATION, CHARACTERISTICS AND CORRELATION.

5.1 Soil classification

The soils of the survey area are divided into five groups based on geomorphological position. These are further subdivided on the basis of topography and soil textural profiles to give a total of 10 soil classes, as summarized in Table 5.1. Further details of representative profiles of the soil classes are given in Appendix B.

Table 5.2 summarises the main chemical characteristics of the soil classes, as determined from the profiles sampled during this survey. The detailed analyses for the representative profiles are given in Appendix B.

5.2 Characteristics of soil classes at Bajo RNRRC

5.2.1 Hill slope soils (HS)

These soils occupy the small area of foothill toeslope in the northeastern corner of the Centre. They have been considerably disturbed by terrace construction and other human activities. These soils were described in detail in one profile (see PK030 in Appendix B). This is on a relatively undisturbed site, but is still thought to have been somewhat modified by overburden from excavations and terrace construction upslope.

The profile is deep, with weathered gneiss not encountered until almost two meters. The matrix colour is brown throughout, including the topsoil. There are reddish yellow and orange mottles that increase with depth. Structures are subangular blocky, and the solum is friable throughout, although the underlying weathered rock, which hand textures as a sandy clay loam, is very hard.

The single analysed profile is slightly alkaline (pH 7-8) throughout. The moderately low cation exchange capacity (8-14 me%) is 100% base saturated, with Ca as the dominant exchangeable cation, and Ca:Mg ratios vary between 5 and 7. Organic carbon levels are low throughout the profile, as are total nitrogen contents. Available P is very low throughout the subsoil but is moderately low in the topsoil. Exchangeable and available K levels are moderate – high, presumably as a result of the weathering of micaceous minerals from the gneiss.

5.2.2 High terrace riser soil (THr)

This soil occurs as a strip along the southeastern boundary of the survey area, where the Centre's land includes the lower section of the steep connecting slope between the middle and high terraces. These soils were described in detail and samples analysed for only one profile (see PH014 in Appendix B)

Although boulder beds outcrop in places on the riser slope, the described profile has few stones in the top 1.5 m. The fine earth textures show the alluvial origin of the soil with a preponderance of fine sand and clear, inherited depositional layering. Textures vary from loamy fine sand to fine sandy loam +, becoming coarser with depth. The top 50 cm has pale brown and brown matrix colours and is increasingly mottled with depth. Below 50 cm the

Table 5.1 Summary of soil classes at Bajo RNR-RC

Soil class		***Brief description***	***Profiles & analyses (Appendix B)***
Code	***Name***		
HS	Hillslope soil	Brown sandy loam; over mixed reddish and yellowish brown sandy clay loam; over weathered rock at 1 m +. Slopes up to 60%	PK030
THr	High terrace riser soil	Hard brown sandy loam; over friable reddish brown sandy loam, +/- rounded boulders. Slopes up to 80%.	PH014
TM	Middle terrace soils	Hard grey – greyish brown silty or fine sandy loam, 30 to 100+ cm deep; over friable reddish brown medium sandy loam – sandy clay loam. (3 subdivisions)	PK023 PK026 PK028 PK029
TMr	Middle terrace riser soils	Grey, brown and reddish brown loam – clay, +/- rounded subsoil boulders, +/- buried charcoal layer	PK025
TL	Lower terrace soils	Hard grey and brown silty clay – fine sandy clay loam 50 to 100+ cm deep; over loose, pale, sandy loam - fine sand. (3 subdivision).	PK022 PK024 PK027
FP	Floodplain soils	Loose pale fine sand - loamy fine sand; +/- thin brown silty surface layer; +/- buried lenses/layers of silty loam.	PK031

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

Soil class (number of profiles analysed)	TOPSOIL ONLY				TOPSOIL AND SUBSOIL (T/S)				
	Organic C (%)	Total N (%)	C:N	AvP (ppm)	pH	TEB me %	BS (%)	ExchK (me %)	AvK (ppm)
HS (1)	1.0	0.08	12	9	6.2/7.3	8.2/10.0	98/100	0.5/1.3	240/193
THr (1)	1.5	0.16	9	14	7.4/7.7	15.0/7.8	100/100	0.6/0.2	30/18
TM (4)	0.9-1.2	0.15-0.27	8-11	3-5	6.3-7.0 /7.6-7.9	5.4-10.1 /9.3-11.0	60-100 /75-100	0.0-0.4 /0.0-0.4	27-38 /25-48
TMr (1)	4.2	nd*	nd*	35	6.6/8.2	21.4/15.1	96/100	1.0/0.9	140/1100
TL (3)	0.6-1.2	0.09-0.17	4-13	7-35	6.2-7.3 /7.0-79	6.9-9.9 /5.0-13.9	79-81 /81-94	0.3-0.9 /0.0-0.1	65-260 /16-42
FP (1)	2.1	0.14	15	8	7.9/8.2	20.6/8.4	100/100	1.5/0.4	100/91

*nd = no data

See Table APPA.1 in Appendix A for interpretative criteria.
soil becomes reddish brown. Mottling decreases in the lower subsoil, but there are some manganese stains at 50-68 cm. The subangular blocky structures become weaker and the consistence more friable as the texture lightens with depth.

The only analysed profile is of neutral to slightly alkaline pH, and base saturation is 80-100%, with Ca as the dominant cation. The topsoil has low-moderate contents of organic carbon and total nitrogen, but subsoil levels are low. Available P is moderate in the upper two horizons (down to 30 cm), but is low beneath that. Exchangeable and available K levels are low – very low throughout.

5.2.3 Middle terrace soil (TM)

These are the most extensive soils on the Research Centre and the DSC seed production area. They stretch from the Wangdi-Shengana road upslope to the foot of the hill. They were described in detail and sampled in four profile pits (see PK023, PK026, PK028 and PK 029 in Appendix B).

The profile varies somewhat with topographic position, but basically consists of a grey-greyish brown, hard-firm silty or fine sandy clay – clay loam upper part, overlying a redder (usually reddish brown), and more friable lower section. This lower subsoil is usually of coarser texture (often sandy loam) than the surface layers, but some sandy clay lower subsoils were seen. The sand in the subsoil is often coarser grained, usually medium or coarse, than the silt, fine and very fine sands of the upper horizons. There are few stones in the upper part, but stone contents of the lower subsoil are variable, ranging from none to many. The stones are mostly rounded quartz gravels and cobbles. Exposures along the edge of the terrace and the evidence of borehole drilling show that there are massive boulder beds at depths of more than 2-3 metres in this deposit, but these do not affect the agricultural soil. Both the upper and lower sections have orange and reddish brown mottles, but these are usually more distinct in the greyish matrix upper horizons. Black manganiferous stains and a few fine soft concretions are found in the horizons close to the boundary between the upper and lower sections, but also occur elsewhere. The depth of the grey, finer textured upper section is greatest (often > 100 cm) on the gentler slopes on the lower section of the terrace, and decreases to about 30-70 cm on the slightly steeper concave gradients towards the upper part of the terrace. However, the auger data show that there are considerable local deviations from this trend.

The distinctive upper and lower sections are attributed to different phases of alluvial deposition. The greyish and finer grained materials forming the upper horizons are thought to have been deposited by less turbulent flow than those that deposited the lower layers. The difference may be due to local changes in the juxtaposition of the turbulent main channel and relatively placid floodplain backwaters. Alternatively, it may be a more regional difference and due to changes in the general nature of the river from turbulent glacio-fluvial in the late Holocene to more gentle and fluvial conditions that have prevailed in the apst millenium or so. The prolonged use of these soils for irrigated rice has affected the colour and consistence of the surface horizons.

The topsoils are slightly acid or neutral (pH 6-7), but the subsoils are all slightly alkaline (pH 7-8). The moderate cation exchange capacities (10-20 me %) are highly base – saturated (70-100%), with Ca as the dominant cation. Organic carbon levels are low in all horizons, as are total nitrogen contents. Available P levels are low – very low, despite the fact that all four profiles are located in research areas, some of which have probably received inorganic fertilizer applications. The exchangeable and available K levels are very low in all samples. This does not appear to accord with the presence of many fine visible muscovite flakes in the profile descriptions. The consistently low P and K levels distinguish these soils from those of the lower terrace. The high pH and low organic matter contents probably relate to the prolonged cultivation of these soils for paddy rice.

These soils have been divided into three soil mapping units (see Chapter 6), according to the depth of the greyish upper section, general slope gradient and topographic position. The SMU are:

i. The soils of the upper part of the terrace (TMu), with profile upper section of 30-70 cm depth, and slope gradients of 4-9 %.
ii. The soils of the middle part of the terrace (TMm), with profile upper section of 40-100+ cm depth, and slope gradients of 2-6%
iii. The soils of the lower part of the terrace, (TMl) with profile upper section mostly >100cm deep, and slope gradients of 1-4 %

These definitions intentionally overlap, so as to allow for local variation within the mapping units.

5.2.4 Middle terrace riser soil (TMr)

These soils occur on the steep slope separating the middle and lower terraces. This is a convex - concave bluff, about 10 m high and with gradients of up to 100%. Some of this land has been incorporated into roads, buildings and has been mapped as disturbed ground (DG). However there is a strip of less disturbed land running North – South through the survey area. These less disturbed soils have been described in detail and sampled for analysis in one profile (see PK025 in Appendix B).

This soil is derived from the same deposits as those of the flat top of the middle terrace, and the profile shows some similar features. The upper part of the profile has pale matrix colours, but these are brownish rather than grey. The textures are fine and have high silt contents, and are mostly in the range silty clay loam – silty clay. These upper horizons are hard when dry and tend to be firm when moist. Below 50cm the colours become more reddish, and textures are coarser, with fine sand replacing silt as the dominant size fraction. The consistence becomes more friable with depth. These soils are only slightly or moderately mottled, and no manganese stains or concretions were seen. A feature of this profile that has also been seen elsewhere in these soils is a thin layer of charcoal and ash at 148-150 cm. The origin of this material is unknown. However the fragments of charcoal are sufficiently large for C^{14} dating, and a sample has been dated at 350 BP (Takada 1991). This implies either very rapid river downcutting or that aeolian deposition has recently been very active

The chemical properties of the sampled profile show considerable variation with depth. The topsoil is of nearly neutral (pH 6.6) but the subjacent horizon at 16-36 cm is slightly acid (pH 5.8). Below that the pH values are slightly alkaline (pH 7.6 – 8.3). Base saturations vary in parallel with pH, with the neutral and alkaline horizons fully saturated but the more acid second horizon is less than 50% saturated. Ca is the dominant exchangeable cation but three horizons have exchangeable Mg contents of >2 me%. The organic carbon content is moderate in the topsoil (> 4%), and decreases erratically with depth, with more than 2% in the horizon 102 – 148 cm just above the ash and charcoal layer. The topsoil available P is high, presumably due to a recent fire or heavy fertiliser spillage in the vicinity (the actual site is uncultivated, and would not itself have been fertilised). K levels are high, with exceptionally high available K levels (> 1000 ppm) in the subsoil. This is thought to be due to the mobilisation of K associated with the layer of buried ash and charcoal.

5.2.5 Lower terrace soils (TL)

These soils occupy most of the research and seed production land downslope from, i.e. to the west of, the Wangdi–Shengana feeder road. They lie below the distinct bluff separating the middle and lower terraces, and are between about 5 and 15 metres above the current river level. There are three subterraces within this unit, but these differ in elevation by only a few metres. Breaks of slope between them can be distinguished easily in places, but are indistinct elsewhere. Three profiles were described in detail and sampled for analysis in these soils (see PK022, PK024 and PK027 in Appendix B).

As in the middle terrace soils, there are some common basic profile features in all of these soils, but there are also variations according to topographic position. The basic profile form has an upper section of grey – brown fine sandy clay loam – silty clay. This material is very hard when dry, and almost massive in structure. It overlies a strongly contrasting material of pale brown – light grey – white, loose, fine sand – loamy fine sand. These soils differ from those of the middle terrace in a number of ways. The fine textured upper horizons are considerably harder when dry, and firmer when moist. It is not known how much this difference is inherent and how much is due to prolonged use for wetland rice. The underlying material is much paler, looser and has higher contents of sand than the lower sections of the middle terrace soils. These differences result in a greater contrast between the upper and lower parts of the lower terrace profiles than in the middle terrace soils.

In contrast to the middle terrace soils, the finer textured upper section tends to be deeper and harder on the older and higher subterraces away from the river. This trend is consistent enough to be permit subdivision of these soils into different mapping units with overlapping definitions (see section 6.2)

The three analysed profiles indicate that these soils have near neutral topsoils (pH 6-7) and slightly alkaline subsoils (pH 7-8), and are more or less fully base saturated throughout. Organic carbon levels are low – very low, even in the topsoils but they vary erratically with depth. Two of the topsoils have high levels of available P, presumably due to recent applications of phosphatic fertilizers. Exchangeable K levels are moderate – low, but higher than in the middle terrace soils. Available K levels are all very low.

5.2.6 Floodplain soils (FP)

These soils occupy small areas of low-lying land along the river, and in the bottoms of drainage lines cut into the lower terrace. They were examined in detail and sampled in only one profile (see PK031 in Appendix B).

These soils consist mainly of the same pale loose fine sand or loamy fine sand that forms the lower parts of the profiles of the lower terrace soils. Some profiles have the thin surface layer of brown silty or very fine sandy loam, but this is patchy and, even where present, is nowhere more than about 30 cm thick. In profile PK031 the layer is only 10cm thick. There may also be thin brown silty layers and lenses in the subsoil.

The sampled profile in this soil is slightly alkaline (pH 7.3 - 8.2) and the moderate low cation exchange capacities are fully base saturated throughout. Ca is the dominant exchangeable cation, and the topsoil has moderately high contents of this cation. Organic carbon contents are low in the topsoil, very low in the loamy sand, and vary erratically below that. This pattern is inherited from the deposition process, and makes these soils unequivocal Fluvents in the USDA Soil Taxonomy system of classification. Total nitrogen and available P contents are generally low, but vary erratically with depth. Exchangeable K levels are high but available K is only moderate.

5.3 Soil correlation

5.3.1 Correlation with international soil classifications.

The local classification used in Table 5.1 and Section 5.2 aims to be simple and to clearly indicate the main soil features to those specifically interested in the soils of Bhutan and Bajo. The classes and their names are too generally defined to convey much to people outside Bhutan. To facilitate international communication, the classes are correlated with the two main international system of soil classification in Table 5.3. There are further details of the correlations in Appendix C.

5.3.2 Correlation with CIP geotechnical classification of soils.

The stability of soil terraces and water conveyance systems are critical features of soils for agriculture 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. Table 5.4 correlates the soil classes of Bajo with their classification. The rock classifications have been omitted because nearly all of the Bajo soil parent materials appear to be alluvial and derived from mixed lithologies. The hillslope soils are derived from rocks of CIP (1993) gneiss group.

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

Soil class		Subunit in FAO Soil Map of the World Legend of (FAO 1974 & 1988)	Great group in USDA Soil Taxonomy (Soil Survey Staff 1975 & 1992) [Family in italics]
Code	Name		
HS	Hillslope soil	Eutric Cambisol	Typic Ustochrept [mesic, fine loamy, mixed]
THr	High terrace riser soil	Eutric Cambisol	Typic Ustochrept [mesic, loamy over loamy skeletal, mixed]
TM	Middle terrace soils	Eutric Cambisol	Typic Ustochrept [mesic, fine loamy, mixed]
TMr	Middle terrace riser soil	Eutric Cambisol	Fluventic Ustochrept [mesic, loamy skeletal – fine loamy, mixed]
TL	Lower terrace soils	Eutric Fluvisol	Typic Ustifluvent & Ustorthent [mesic, loamy – sandy, mixed]
FP	Floodplain soils	Eutric Fluvisol	Typic Ustifluvent [mesic, sandy, mixed]

Table 5.4 Geotechnical correlation of soils of Bajo RNR-RC

Bajo soil class	REID Irrigation Section Geotechnical Soil Classification	
	Land unit	Soil class
HS	3A/B	ML
THr	5B	
TM	5A	CL
TMr	5B	
TL	5A	ML
FP	5C	

Source for class criteria: CIP (1993)

6. SOIL DISTRIBUTION AND MAPPING

6.1 Soil distribution

The geomorpohological basis of the soil classification means that distribution of the soil classes is closely related to landform. Thus the hillslope, high terrace riser, middle terrace riser and floodplain soils are located on their namesake landforms. The same is true for the extensive lower and middle terrace soils. Within the soil classes on the terrace tops there are topographical trends. In both groups, the thickness of the overlying hard, grey, silty and fine sandy layers varies systematically with distance and height from the river. In the case of the lower terrace soils, the deepest upper profile sections are found in the higher soils, furthest from the river and just under the riser bluff up to the middle terrace. In the middle terrace soils, the trend is reversed, with the deepest upper layers on the lowest and flattest part, and the thickness decreases upslope on the slightly steeper concave higher part.

6.2 Soil mapping units.

All but one of the soil mapping units are simple consociations (i.e. with one soil class dominant) and there has been no need to map complexes, with coequal soil classes. However none of consociations are wholly pure and all contain minor components of other soil classes.

The middle and lower terrace soil classes have each been subdivided into three mapping units, according to the depth of the hard grey silty and fine sandy upper layers, and have been mapped according to topographic position and the auger data. There is one non-soil Miscellaneous Land Type mapping unit (disturbed ground – DG) for the land occupied by the Centre's main building, the Seed Production Centre's buildings; the old RNR-RC building, staff housing, roads, and other infrastructure.

The compositions of the mapping units are summarised in Table 6.1 and their areas in Table 6.2. The soils of the terrace tops are the most extensive, with the middle terrace units accounting for 44% and the lower terrace units for 23% of the survey area.

Table 6.1 Soil mapping units at Bajo RNR- RC

Mapping unit	Type	Main soil classes	Minor soil classes
HS	Consociation	Hs	None
THr	"	THr	[Tmu]
TMu	"	TM (upper)	TM (medium)
TMm	"	TM (medium)	TM (upper & lower)
TMl	"	TM (lower)	TM (medium)
TMr	"	TMr	TM (lower)
TLu	"	TL (upper)	TL (medium)
TLm	"	TL (medium)	TL (upper & lower)
TLl	"	TL (lower)	TL (medium)
FP	"	FP	[TM (lower)]
DG	MLT	Disturbed ground	

Table 6.2 Area of soil mapping units at Bajo RNR- RC

Soil mapping Unit	Area		
	Ha	acres	% survey area.
HS	0.9	2.1	2.8
THr	2.6	6.4	8.4
TMu	7.2	17.8	23.4
TMm	4.0	10.0	13.1
TMl	2.3	5.7	7.5
TMr	1.7	4.3	5.6
TLu	1.5	3.6	4.7
TLm	3.7	9.2	12.1
TLl	2.0	4.9	6.5
FP	0.6	1.4	1.9
DG	4.3	10.6	14.0
TOTAL	30.8	76.0	100.0

7. OVERVIEW AND IMPLICATIONS

7.1 Overview of soils.

The soils of the Centre are morphologically varied, ranging in texture from fine sand to clay loam, and in slope gradient from 1 to 100+%. Stone contents and colours also vary. However all of the soils have similar chemical properties, with neutral – slightly alkaline pH values, near total base saturations, and low organic carbon, total N and available P contents. The low levels of organic matter are thought to be mostly due to the long use of the soils for wetland rice.

The most extensive cultivated soils in the Centre are those of the flat upper surfaces of the middle and lower alluvial river terraces. These are morphologically and chemically fairly uniform, with hard, grey, silty upper layers overlying coarse textured and more friable deep subsoils. The middle terrace soils appear to be slightly easier to manage, as their upper layers are not quite as hard as those of the lower terrace soils, and their subsoils are less sandy and droughty.

7.2 Implications of results

In addition to supplying general information on an important aspect of the production environment, the results of the soil survey can be applied to specific aspects of a Research Centre's operations and effectiveness.

In particular the results are relevant to the following questions:

- Are the soils of the Centre found elsewhere, and to what extent can research findings on the soils of the Centre be applied to other parts of the region?
- Are the current trials at the Centre located on appropriate soils?

The Bhutan Soil Survey is still in its early stages of operations and this is its first systematic survey in the West Central region. It cannot therefore pronounce in detail on the first point listed above, i.e. the regional relevance of Bajo's soils. However it is clear that the lower and river middle terraces are important agricultural areas in the Wangdi – Punakha region. The Centre's soils therefore probably make the extrapolation of its findings to the surrounding area generally appropriate.

Bajo is the longest established of the RNR-RC's and its investigative programme has expanded to use all of its cultivable soils. Unlike the other RNR-RC's, the soil survey is unlikely to be used for physical and structural planning in the near future. However it can contribute to a major planning issue that is currently affecting the Centre. There are proposals that the urban area of Wangdi should be transferred to, or expanded on to, the flat alluvial land in the Bajo area, possibly incorporating the Centre. MoA do not favour these suggestions, on the grounds that large amounts of time, effort and material/financial resources have been invested in building the Centre up to its present effective level.

The results of this soil survey confirm that the Centre should remain where it is, as the Centre's alluvial wetland soils appear to be typical of important agricultural production areas in the Wangdi – Punakha region. Results from the Centre's trials are therefore necessary for the further improvement of agriculture in this region, one of the main rice producing areas in the country. The practical value of the Centre's previous experimental work has already been shown by the large scale adoption of winter wheat and mustard after initial development work on the Centre.

Although the Centre's cultivable and experimental areas appear to be typical of the lower and middle terrace alluvial soils in Wangdi – Punakha area, there are areas of wetland production in the region on some of high alluvial terrace remnants, and also on colluvial deposits of the gentler lower slopes of hills. These kinds of soils are not found on the Centre, so that there are, as yet, no on–station experimental data from this kind of land. To some extent this deficiency can be made good by off – station trials on farmer's fields. However some kinds of experimental work are best done under the more controlled conditions on–station. The possibility of establishing an outlying experimental substation or block on high terrace and lower slope hill soils might be considered.

ABBREVIATIONS AND GLOSSARY

(Simple metric units and chemical element symbols not included)

AAS	Atomic absorption spectrophotometery
AHT	Agrar - und HydrotechniK, GmbH, (Germany).
AIT	Asian Institute of Technology, Bangkok
Alluvial fan	Poorly stratified and sorted material deposited in side valley
AmOAc	Ammonium acetate (extractant for exchangeable cations and for measuring CEC)
AvP	Available Phosphate
AWC	Available water capacity
amsl	Above mean sea level
asl	Above sea level
BP	Before present
BS%	Base saturation percentage
BSSP	Bhutan Soil Survey Project
C	Clay
ca	Approximately
CEC	Cation exchange capacity
Chhu	Stream or river
Chhuzing	Irrigated agricultural land
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.
Creep	Slow gravitational mass movement of colluvium downslope.
Danida	Danish International Development Assistance.
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
fe	fine earth (particle size < 2mm)
FYM	Farmyard manure
Geog	Block or subdistrict, administrative subdivision of Dzongkhag.
GIS	Geographical information system
Gley	Sol that is permanently wet, poorly aerated and has predominately greyish colours, due to reduction of free iron to ferrous valency state. May have local oxidising conditions giving rust - coloured mottles, especially around root channels.
GLO	Glacial lake outburst
GSI	Geological Survey of India
GPS	Global positioning system
Gup	Head of the geog
ha	Hectare
HCl	Hydrochloric acid
IRRI	International Rice Research Institute, Los Banos, Philippines
ISRIC	International Soils Reference & Information Centre, Wageningen, Netherlands
JICA	Japanese International Cooperation Agency
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

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.
MUMTI	Meteorological Unit of MTI
NH_4OAC	Ammonium acetate
NSSC	National Soils Services Centre, REID, Semtokha
OC	Organic carbon
OM	Organic matter
P	Precipitation, rainfall
P	Phosphate
PCI	Pacific Consultants International (Japan)
PDOP	Position dilution of precision (measure of GPS performance)
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.
Shogshing	Forest from which needles or leaves are collected for livestock bedding and FYM.
Si	Silt
Sk	Skeletal (high stone content)
SMU	Soil mapping unit
SoB	Survey of Bhutan
Solum	True soil, in which soil processes have removed many traces of parent materials structure.
SPAL	Soils and Plant Analysis Laboratory, NSSC, REID, Semtokha.
SSF&PNMP	Sustainable Soil Fertility & Plant Nutrition Management Project, NSSC, REID.
SSU	Soil Survey Unit
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)
TOR	Terms of Reference
TRB	True right bank (facing downstream)
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organsiation
USDA	United States Department of Agriculture
v/v	% by volume
WR	Weathered rock
WRB	World Reference Base (ISRIC development of FAO system of soil classification)
w/w	% by weight
X	Exchangeable (for cation)
Z,Zi	Silt

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APPENDIX A: SOIL ANALYSES METHOD USED IN 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) both > 7 and < 7, as samples of both types were collected during this survey. However there are no samples of pH (water) < 4.5.

<u>Sample preparation.</u>

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

<u>pH.</u>

Soil pH is measured in suspensions of the soil in distilled water and 1 M KCL (both 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.
- For soils with pH (water) < 7, 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. For soils with pH > 7, available P is extracted by shaking 5 g of fine earth with 35 ml of the Olsen extractant of 0.5 M Na HCO_3 and 1 M NaOH 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).
- For the soils with pH (water) < 7.5, the ammonium is extracted by leaching the soil with excess 1 M KCl, and measured to give the Cation Exchange Capacity. For the soil with pH (water) > 7.5, the ammonium is extracted by leaching with excess 1 M sodium acetate.
- For the soils with pH (water) < 4.5, extractable Al and H are extracted from 5 g fine earth with 100 ml of 1 M acidified KCl.

<u>Assays of extracts.</u>

The NH_4 in the extracts from the Total N digestion, the KCl leaching for CEC determination, and from NH_4 – N; NO_3 – N; available P; available K; and exchangeable K and Na in the different extracts are measured with the Skalar Segmented Flow Analyser system, which includes colorimeters for NH_4, NO_3 and P, and a flame spectrophotometer for K and Na.

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

For acid soils, 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 of carbonates, Fe and Al oxides, and other mineral cementing agents, and dispersion of the clay 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 computation, i.e.;

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

The analytical results from SPAL are interpreted according to the criteria summarised in Table AppA.1.

APPENDIX B: SOIL PROFILE DESCRIPTION & ANALYSES

This appendix includes the detailed descriptions and analyses of all of the soil profiles. The profiles appear in the order summarised in Table AppB.I.

Table APPB.1 Summary of soil profiles

Profile Number	Bajo soil class	Number of horizons analysed.
PH014	THr	6
PK022	TL	4
PK023	TM	5
PK027	TL	5
PK025	TMr	5
PK026	TM	6
PK028	TM	5
PK024	TL	6
PK029	TM	6
PK030	Hs	5
PK031	Fp	6
TOTAL	11	59

Profile:	PH014	
Map unit:	THr	
Soil classification:	Provisional Bajo soil class: Soil Taxonomy: FAO:	High terrace riser soil (THr) Typic Ustochrept; *thermic, fine loamy over sandy, Mixed* Eutric Cambisol
Survey area: Location: GPS: Altitude:	Bajo RNR-RC. At the edge of the grape trial. 27^0 29.42 N, 89^0, 54. 00 E 1260 m a.s.l.	
Described & sampled:	1.12.97, HB Tamang.	
Climate:	General: Warm temperate, P = ca 700 mm pa Recent weather: Sunny	
Regional topography: Site position:	River valley Toe of riser slope up to high terrace.	
Slope: Site drainage:	18%, straight, 400m, aspect 250^0. Good.	
Parent material:	Solid: Mixed Drift: Old alluvium.	
Land use: Vegetation:	Grass margin of grape trial. Native grasses, weeds and grape.	
Surface:	Litter: None. Outcrops: None Stones: None Cracks: None. Roots: None Microrelief: None. Faunal activity: None Other features: None	

Profile description: (Colours are moist unless indicated)
cm

0 – 14	10YR 6/3 (pale brown) dry; very fine sandy loam +; strong medium & coarse subangular blocky; many medium & fine pores; dry & firm; common medium & fine roots; few fine hard quartz; HCl negative; few earthworm casts; gradual slightly wavy boundary to: [Sample PH014/1 @ 0 -10]
14 - 32	10YR 5/3 (brown) dry, with common fine faint dark brown & orange mottles; fine sandy loam; strong medium & coarse subangular blocky; many fine pores; dry & very firm; few fine roots; few fine hard quartz stones; HCl negative; few charcoal; clear slightly wavy boundary to: [Sample PH014/2 @ 20 - 30]
32 – 50	10YR 6/3 (pale brown) dry, with abundant medium & fine distinct yellow brown & dark mottles; very fine sandy loam +; strong medium & coarse subangular blocky; weak discontinuous clayskins; dry, very firm & slightly sticky when wetted; many fine pores; few fine roots; few fine hard quartz & gneiss stones; HCl negative; clear slightly wavy boundary to: [Sample PH014/3 @ 35 - 45]
50 - 68	7.5YR 7/4 (very pale brown) dry, with dark manganese stains; loamy fine sand; moderate medium subangular blocky; many fine pores; dry & firm; few fine roots; few medium & fine angular gneiss stones; HCl negative; clear slightly wavy boundary to: [Sample PH014/4 @ 55 - 65]
68 – 110	5YR 4/4 (reddish brown) with few fine faint yellow mottles; fine sandy loam; weak medium subangular blocky breaking to medium fine crumb in hand; few fine pores; moist & friable; few fine roots; few round cobbles; HCl negative; diffuse boundary to: [Sample PH014/5 @ 80-90]
110 – 150+	7.5YR 4/4 (brown) with few fine faint yellow & orange mottles; loamy fine sand; weak coarse breaking to medium subangular blocky & fine crumb; few fine pores; moist & very friable; few round cobbles; HCl negative; [Sample PH014/6 @ 130-140]

Comment: Laboratory analyses confirm textural layering inherited from alluvial deposition. Two upper horizons have high Ca status.

SPAL analytical results for BSS Profile PH014 Survey area: Bajo RNR-RC

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C %	Total N %	C:N
			H_2O	KCl	Diff					
PH014 /1	0-10	4471	7.4	6.1	1.3	0.02	14	1.5	0.16	9.3
/2	20-30	4472	7.7	6.0	1.7	0.02	11	0.8	0.09	8.8
/3	35-45	4473	7.7	6.2	1.5	0.01	5	0.5	4.00	0.1
/4	55-65	4474	7.7	6.2	1.5	0.01	1	0.1	0.02	5.0
/5	80-90	4475	7.9	6.2	1.7	0.01	1	0.3	0.01	30
/6	130-140	4476	8.0	6.2	1.8	0.01	2	0.3	0.01	30

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PH014 /1	11.8	2.5	0.6	0.1	15.0	-	10.2	-	100	-
/2	13.8	2.1	2.0	0.2	18.0	-	15.5	-	100	-
/3	5.9	1.9	0.2	0.1	8.1	-	10.4	-	78	-
/4	5.9	1.6	0.2	0.1	7.8	-	7.8	-	100	-
/5	4.2	0.1	0.2	0.1	4.5	-	6.8	-	66	-
/6	3.8	0.9	0.1	0.0	4.8	-	5.6	-	85	-

Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	**Total sand**	20-50 micron	2-20	**Total silt**		
PH014 /1						50.8	8.1	40.1	48.2	1.0	SL
/2						50.4	9.0	16.6	25.6	24.1	SCL
/3						52.8	7.8	17.1	24.9	22.3	SL
/4						81.4	3.7	4.8	8.5	10.1	LS
/5						64.2	11.4	7.4	18.5	17.3	SL
/6						78.9	4.3	7.2	11.5	9.5	LS

Profile:	PK022	
Map unit:	TLm	
Soil classification:	Provisional Bhutan soil series:	Lower terrace soil (TL)
	Soil Taxonomy:	Typic Ustrothent; *thermic, fine loamy over sandy, mixed*
	FAO:	Eutric Fluvisol
Survey area:	RNR-RC Bajo.	
Location:	50 m E of pumping station.	
GPS:	27^0 29.39 N, 89^0 53.84' E.	
Altitude:	1310 m a. s. l.	
Described & sampled:	25/11/97, K Tshering	
Climate:	General:	Warm temperate, P = ca 700 mm pa
	Recent weather:	Cloudy.
Regional topography:	Lower river terrace in major valley.	
Site position:	Middle terrace	
Slope:	5 % rectilinear, ca 0.2 km long, aspect 250^0	
Site drainage:	Good	
Parent material:	Solid:	Mixed
	Drift:	Alluvium.
Land use:	Fallow wetland research plot.	
Vegetation:	*Artimesia & Amaranthus spp.*	
Surface:	Litter:	None.
	Outcrops:	None
	Stones:	Few coarse hard subangular mixed stones.
	Cracks:	None
	Roots:	None
	Microrelief:	None
	Faunal activity:	None
	Other features:	None

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

0 - 16	10YR 5/3 (brown) dry, 10YR 4/2 (dark greyish brown) moist, with few fine faint yellow, orange, brown & grey mottles; fine sandy clay loam +; coarse moderate angular blocky; many fine pores; slightly dry & very hard, firm when moist, slightly sticky when wet; many medium & fine roots; ants nest & earthworm burrow; gradual regular boundary to: [Sample PK022/1 @ 0 – 10]
16 – 39	10YR 6/4 (light yellowish brown) dry, 10YR 4/2 (dark greyish brown) moist, with abundant medium prominent red, orange & black mottles; very fine sandy loam +; moderate coarse angular blocky; many fine pores; very hard when dry, very firm when moist, sticky when wet; common fine roots; gradual slightly wavy boundary to: [Sample PK022/2 @ 20 – 30]
39 – 66	10YR 6/4 (light yellowish brown) dry, 10 YR 4/2 (dark greyish brown) moist, with abundant medium prominent black mottles; very fine sandy loam +; moderate coarse angular blocky; very weak cutans; slightly moist & very firm, sticky when wet; common fine pores; common medium & fine roots; common medium black manganese stains; clear regular boundary to: [Sample PK022/3 @ 40 - 50]
66 –178 +	10YR 6/3 (pale brown) with few coarse faint greyish brown mottles; very fine sand; very weak angular blocky breaking to single grain; many medium pores; moist & very friable; many medium & fine roots. [Sample PK022/4 @ 90 - 100]
Comment:	This profile is typical of the lower subterrace within the lower terrace. The contrast between the fine loamy textures to 66 cm depth, and the pale loose, fine sand beneath is very clear. The textural contrast is also clear in the laboratory results, with clay content dropping 6-fold. Silt contents are moderately high throughout. The prominent manganese mottling just above the textural change is striking.

SPAL analytical results for BSS Profile PK022 Survey area: Bajo RNR-RC

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK022/1	0-10	4477	6.2	5.8	0.4	0.01	7	0.9	0.07	12.8
/2	20-30	4478	7.5	6.1	1.4	0.01	6	0.5	0.03	16.6
/3	40-50	4479	7.0	6.0	1.0	0.02	3	0.4	0.03	13.3
/4	90-100	4480	7.0	5.1	1.9	nd	4	0.2	0.02	10.0

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAC	EBS%
PK022 /1	5.3	1.3	0.3	nd	6.9	nd	8.7	nd	79	nd
/2	8.7	1.3	0.1	nd	10.1	nd	11.9	nd	85	nd
/3	3.9	1.0	0.0	nd	5.0	nd	6.1	nd	81	nd
/4	0.3	0.3	0.1	nd	0.8	nd	2.8	nd	27	nd

Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	**Total sand**	20-50 micron	2-20	**Total silt**		
PK022 /1	nd	nd	nd	nd	nd	46.2	14.1	15.7	29.8	24.0	L
/2	nd	nd	Nd	nd	nd	52.6	15.4	13.2	28.6	18.9	SL
/3	nd	nd	nd	nd	nd	52.2	20.9	9.7	30.6	17.1	SL
/4	nd	nd	nd	nd	nd	67.8	22.0	7.0	2.0	3.2	SL

Profile:	PK023	
Map unit:	TMm	
Soil classification:	Provisional Bhutan soil series:	Middle terrace soil (TM)
	Soil Taxonomy:	Typic Ustochrept; *thermic, fine loamy, mixed*
	FAO:	Eutric Cambisol

Survey area: RNR-RC, Bajo
Location: 100 m NE of RNR-RC offices
GPS: 27^0 29.46 N, 89^0 53.96 E
Altitude: 1320 m a. s. l.

Described & sampled: 25/11/97, K Tshering

Climate: General: Warm temperate, P = ca 700 mm pa
Recent weather: Cloudy

Regional topography: Major river valley
Site position: Central section of middle terrace

Slope: 9%, rectilinear, ca 1 km long, aspect 278^0
Site drainage: Good

Parent material: Solid: Mixed rocks
Drift: Old alluvium.

Land use: Groundnut trial
Vegetation: Groundnuts and local weeds

Surface:

Litter:	None.
Outcrops:	None
Stones:	None.
Cracks:	None
Roots:	None
Microrelief:	None
Faunal activity:	None
Other features:	None

Profile description: (Colours are moist unless indicated)
cm

0 - 16: 2.5Y 5/2 (greyish brown), with abundant coarse prominent dark reddish, orange & yellow mottles; fine sandy loam +; medium coarse moderate subangular blocky; few very weak cutans; many medium & fine pores; moist & very firm; many medium & fine roots: HCl negative; insect burrows; gradual regular boundary to:
[Sample PK023/1 @ 0 - 10]

16 – 60: 2.5Y 4/1 (dark grey), with abundant fine orange & yellow mottles; fine sandy loam +; moderate coarse angular blocky; few very weak cutans; moist & very firm; common medium & fine roots; common medium & fine hard quartz gravel; HCl negative; few black manganese stains; clear wavy boundary to:
[Sample PK023/2 @ 30 – 40]

60 – 70: 2.5Y 4/1 (dark grey), with abundant reddish brown & black mottles; medium sandy loam +; moderate coarse angular blocky; few weak cutans; abundant coarse medium & fine pores; moist & very firm; common fine roots; many medium hard quartz & gneiss stones; HCl negative; clear regular boundary to:
[Sample PK023/3 @ 60 - 70]

70 - 104: 7.5YR 4/3 (brown), with abundant prominent dark brown mottles; medium sandy clay; weak angular blocky breaking to fine crumb; few very weak cutans; abundant coarse, medium & fine pores; moist & slightly firm; common medium & fine hard quartz & gneiss stones; HCl negative; gradual wavy boundary to:
[Sample PK023/4 @ 80 - 90]

104 - 165 +: 7.5YR 4/4 (brown), with many fine dark brown mottles; fine sandy loam +, medium weak angular blocky breaking to fine crumb; many coarse, medium & fine pores, moist & slightly firm; HCl negative:
[Sample PK023/5 @ 130 - 140]

Comments: The laboratory results do not confirm the coarse textures below 1 m. This may be partly due to the very high silt content in the laboratory granulometric data for the 70 – 104 cm horizon. The textural and consistence contrast is much less than in the lower terrace soils (compare with profiles PK022 & PK027).

SPAL analytical results for BSS **Profile PK023** **Survey area: Bajo RNR-RC**

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK023/1	0-10	4481	6.4	5.2	1.2	nd	3	0.9	0.27	10.9
/2	30-40	4482	7.5	6.0	1.5	nd	2	0.6	0.06	10.0
/3	60-70	4483	7.7	6.0	1.7	nd	4	0.4	0.03	10.0
/4	80-90	4484	7.8	5.1	2.7	nd	1	0.3	0.04	10.0
/5	130-140	4485	7.9	5.3	2.6	nd	8	0.3	0.02	13.3

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAC	EBS%
PK023 /1	8.6	1.4	0.0	0.0	10.1	-	11.1	-	91.0	-
/2	13.9	1.8	0.1	0.1	15.9	-	18.8	-	85.0	-
/3	7.7	1.5	0.1	0.0	9.3	-	12.4	-	75.0	-
/4	11.5	1.1	0.3	0.1	13.0	-	18.9	-	69.0	-
/5	4.5	1.6	0.2	0.1	6.4	-	7.4	-	87.0	-

Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	**Total sand**	20-50 micron	2-20	**Total silt**		
PK023 /1						36.5	4.0	32.6	36.6	26.8	L
/2						39.3	16.2	11.5	27.7	32.9	CL
/3						54.9	5.5	16.9	22.4	22.7	SCL
/4						41.3	12.1	51.3	63.4	4.7	ZL
/5						48.3	9.4	12.6	22.0	29.7	SCL

Profile:	PK027	
Map unit:	TLm	
Soil classification:	Provisional Bhutan soil series:	Lower terrace soil (TL)
	Soil Taxonomy:	Typic Ustifluvent; *thermic, fine loamy over sandy, mixed*
	FAO:	Eutric Fluvisol
Survey area:	Bajo RNRRC	
Location:	50 m south of Druk Seed Corporation Offices.	
GPS:	27^0 29.51' N, 89^0 53.84 E	
Altitude:	1284 m a. s. l.	
Described & sampled:	2.12.97, K Tshering	
Climate:	General:	Warm temperate, P = ca 700 mm pa
	Recent weather:	Shower previous night.
Regional topography:	Major valley	
Site position:	Middle section of lower river terrace	
Slope:	4%, terraced, ca 100 m long, W facing (aspect 260^0)	
Site drainage:	Good	
Parent material:	Solid:	Mixed rocks
	Drift:	Old alluvium.
Land use:	Soya bean seed production	
Vegetation	Soya beans	
Surface:	Litter:	None
	Outcrops:	None.
	Stones:	None
	Cracks:	None
	Roots:	None
	Microrelief:	None
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)
cm

0 – 26	10YR 7/2 (light grey) dry, 10YR 5/1 (grey) moist, with few fine yellow & orange mottles; silty clay; moderate medium subangular blocky; many fine pores; slightly dry & very hard; many medium & fine roots; few quartz & gneiss subangular stones; HCl negative; regular gradual boundary to: [Sample PK027/1 @ 0 - 10]
26 –36	10YR 4/2 (dark greyish brown), with abundant red, orange, reddish brown & black mottles; medium sandy loam +; moderate medium angular blocky; continuous dark organic & clay cutans; many fine pores; dry & very hard; common fine roots; few fine rounded quartz & gneiss gravel; common black manganese stains; insects seen; clear slightly wavy boundary to: [Not sampled]
36 – 60	10YR 4/2 (dark greyish brown), with many coarse, yellow orange & dark brown mottles; medium sandy loam +; medium angular blocky; very weak clayskins; many fine pores; slightly dry & very hard; common fine roots; few fine hard quartz & gneiss stones; HCl negative; clear regular boundary to: [Sample PK027/2 @ 40 - 50]
60 – 95	10YR 4/2 (dark greyish brown) dry, 10YR 3/2 (brown) moist; silty loam +; moderate medium angular blocky breaking to fine subangular blocky; very weak cutans; abundant medium & fine pores; slightly dry & firm; few course & many fine roots; HCl negative; clear regular boundary to: [Sample PK027/3 @ 70 - 80]
95 – 120	10YR 7/3 (pale brown) dry, 10YR 5/3 (brown) moist; loamy fine sand; single grain; moist & friable; common medium & fine roots; HCl negative; clear regular boundary to: [Sample PK027/4 @ 100 - 110]
120 – 160+	10 YR 5/3 (brown); silty loam; massive; moist & friable; rare medium roots; HCl negative; [Sample PK027/5 @ 130 - 150]
Comments:	Example of lower terrace soil in which subsoil includes silty layers as well as pale and loose, fine sand. High available P in topsoil may be due to fertilizer application to Soya.

SPAL analytical results for BSS **Profile PK027** **Survey area: Bajo RNR-RC**

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK027 /1	0-10	4504	7.0	6.0	1.0	-	35	0.6	0.17	3.5
/2	40-50	4505	7.7	6.2	1.5	-	5	0.4	0.60	6.6
/3	70-80	4506	7.9	6.4	1.5	-	5	0.4	0.04	10.0
/4	100-110	4507	7.9	6.5	1.4	-	2	2.0	0.02	-
/5	130-150	4508	7.9	6.5	1.4	-	2	0.6	0.03	20.0

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAC	EBS%
PK027 /1	7.7	1.8	0.4	0.1	9.9	-	12.3	-	81	-
/2	8.7	1.6	0.0	0.1	10.5	-	10.1	-	100	-
/3	7.6	1.0	0.1	0.1	8.8	-	9.5	-	93	-
/4	7.2	0.5	0.2	0.0	8.0	-	8.4	-	95	-
/5	7.1	0.7	0.2	0.3	8.2	-	8.3	-	99	-

Fine earth granulometric

BSS No.	Sand						Silt			Clay	**Texture class**
	>1000 micron	425-1000	212-425	106-212	50-106	**Total sand**	20-50 micron	2-20	**Total Silt**		
PK027 /1						35.4	14.1	21.2	35.3	29.3	CL
/2						53.2	3.1	24.0	27.1	19.7	SL
/3						59.5	16.6	10.3	26.4	13.5	SL
/4						65.4	15.3	16.3	31.6	3.0	SL
/5						69.6	17.8	5.0	22.8	7.7	SL

Profile:	PK029	
Map unit:	TMm	
Soil classification:	Provisional Bhutan soil series:	Middle terrace soils (TM)
	Soil Taxonomy:	Typic Ustochrept; *thermicl loamy, mixed*
	FAO:	Eutric Cambisol
Survey area:	Bajo RNRRC	
Location:	Near north eastern angle of northern boundary fence	
GPS:	27° 29.65' N, 89° 54.03' E	
Altitude:	1250 m. asl.	
Described & sampled:	2.12.1997, I C Baillie	
Climate:	General:	Warm temperate, P = ca 700 mm pa
	Recent weather:	Overnight shower
Regional topography:	Major river valley	
Site position:	Upper section of middle terrace	
Slope:	2%, terraced, 400 m length, aspect W (285°)	
Drainage:	Good	
Parent material:	Solid:	Mixed
	Drift:	Alluvium
Land use:	Former rice trial.	
Vegetation	Rice stubble	
Surface:	Litter:	Discontinuous paddy straw
	Outcrops:	None.
	Stones:	Rare round quartzite boulder
	Cracks:	None
	Roots:	None
	Microrelief:	Slight (0-3 cm), due to poaching
	Faunal activity:	None.
	Other features:	None

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

cm

0 – 13	2.5YR 5/2 (greyish brown) with many fine distinct brownish yellow & reddish brown mottles; very fine sandy clay loam; moderate-weak medium subangular breaking to fine subangular blocky; few medium pores; moist & slightly friable; common fine & medium rice roots; common fine muscovite flakes; gradual regular boundary to: [Sample PK029/1 @ 0-10]
13 –42	10YR 5/2 (greyish brown) with many fine faint reddish yellow & reddish brown mottles; medium sandy clay loam; massive breaking to weak medium subangular blocky; rare fine pores; moist-dry & slightly firm – slightly hard; common medium & fine rice roots; common quartz grit; many very fine muscovite flakes; gradual slightly wavy boundary to: [Sample PK029/2 @ 20 - 30]
42 – 50	10YR 5/2 (greyish brown) with abundant medium & fine prominent red, pale brown, dark brown & black mottles; medium sandy loam; weak medium subangular blocky; common fine pores; moist & firm; rare fine roots; few medium & fine slightly hard angular quartz gravel; common fine soft black ferrimanganiferous stains; many fine muscovite flakes; gradual regular boundary to: [Not sampled]
50-67	10YR 5/3 (brown) with abundant medium & fine prominent red, pale brown, dark brown, reddish yellow, reddish brown & black mottles; gravelly medium sandy loam; weak - moderate medium subangular blocky; weak discontinuous organic cutans; common fine pores; moist & slightly firm; rare fine roots; common rounded quartz & weathered gneiss gravel; rare soft black ferrimanganiferous stains; many fine muscovite flakes; gradual slightly wavy boundary to: [Sample PK029/3 @ 55-65]
67 – 98	10YR 4/2 (dark greyish brown), with abundant medium distinct-prominent brownish red, reddish brown & yellowish red mottles; fine sandy clay loam; moderate medium-fine subangular blocky; few medium pores; moist & friable; rare fine white dead roots; few rounded quartz & weathered gneiss gravel; common soft black ferrimanganiferous stains; many fine muscovite flakes; diffuse boundary to: [Sample PK029/4 @ 75-85]
98 - 140	7.5YR 5/4 (brown) with many coarse faint brown, dark brown & reddish brown mottles; coarse sandy loam; weak coarse subangular breaking to fine subangular blocky; many medium pores; moist & very friable; rare fine

roots; few rounded quartz & weathered gneiss; many very fine muscovite flakes; diffuse boundary to: [Sample PK029/5 @ 115-125]

140 – 182+ 7.5YR 5/4 (brown) with few medium faint brown mottles; medium sandy loam; weak medium subangular breaking to fine subangular blocky; common medium pores; moist & friable; no roots; few rounded quartz & weathered gneiss; many very fine muscovite flakes: [Sample PK029/6 @ 155-165]

SPAL analytical results for BSS **Profile PK029** **Survey area: Bajo RNR-RC**

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK029 /1	0-10	4515	6.3	5.4	0.9	-	5	1.1	0.14	7.9
/2	20-30	4516	7.4	6.4	1.0	-	5	1.1	0.07	16
/3	55-65	4517	7.6	6.2	1.4	-	1	1.5	0.03	50
/4	75-85	4518	7.7	6.0	1.7	-	3	1.1	0.03	37
/5	115-125	4519	7.2	6.3	0.9	-	3	1.7	0.02	85
/6	155-165	4520	7.2	6.4	0.8	-	1	0.4	0.02	20

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAC	EBS%
PK029 /1	6.8	1.2	0.4	0.1	8.2	-	8.1	-	100	-
/2	6.1	0.5	0.3	0.1	7.0	-	7.7	-	90	-
/3	8.8	1.2	0.4	0.2	10.6	-	11.1	-	95	-
/4	7.9	1.3	0.5	0.3	10.0	-	10.0	-	99	-
/5	4.0	0.8	0.6	0.3	5.7	-	5.5	-	100	-
/6	5.0	1.2	1.3	0.1	7.6	-	7.6	-	100	-

Fine earth granulometric

BSS No.	Sand						Silt			Clay	**Texture class**
	>1000 micron	425-1000	212-425	106-212	50-106	**Total sand**	20-50 micron	2-20	**Total silt**		
PK029 /1						48.1	11.6	19.7	31.3	20.6	L
/2						49.3	11.6	18.0	29.6	21.1	SCL
/3						66.5	5.5	14.8	20.3	13.2	SL
/4						69.9	7.0	10.5	17.5	12.5	SL
/5						64.5	0.6	21.4	22.0	14.1	SL
/6						53.3	10.0	18.8	28.8	17.9	L

Profile:	**PK030**	
Map unit:	HS	
Soil classification:	Provisional Bhutan soil series: Soil Taxonomy: FAO:	Hill soil (HS) Typic Ustochrept; *thermic, fine loamy, mixed* Eutric Cambisol
Survey area: Location: GPS: Altitude:	Bajo RNRRC Northeastern corner of survey area 27° 29.57'N, 89° 54.19' E 1330 m asl.	
Described & sampled:	2.12.97, K Tshering	
Climate:	General: Recent weather:	Warm temperate, P = ca 700 mm pa Shower overnight
Regional topography: Site position:	Major river valley Toeslope, close to break of slope to top end of middle terrace	
Slope: Site drainage:	50 %, convex, ca 1 km long, NW facing (300 °) Good	
Parent material:	Solid: Drift:	Mixed gneiss & quartzite Colluvium
Land use: Vegetation:	Fallow after irrigation. Fallow scrub of *Artemisia spp, Opuntia* & Marigolds	
Surface:	Litter: Outcrops: Stones: Cracks: Roots: Microrelief: Faunal activity: Other features:	1 – 2 cm continuous *Artemisia* litter & twigs None Large angular & subangular boulders None. None Terraced, with risers up to 3 m high Common ants. None

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

0 - 40	10YR 4/3 (brown), with common medium faint yellow & orange mottles; coarse sandy loam +; moderate fine subangular blocky; common medium & coarse pores; slightly wet & friable; abundant medium & fine roots; many fine hard quartz & gneiss subangular gravel; HCl negative; many ants; gradual regular boundary to: [Sample PK030/1 @ 0-10]
40 –60	10YR 4/3 (brown) with abundant coarse distinct yellow, red & orange mottles; sandy clay loam; moderate medium angular blocky breaking to fine crumb; many medium & fine pores; slightly wet & friable; common medium & fine roots; common medium hard subangular quartz & gneiss stones; HCl negative; insect burrows; gradual regular boundary to: [Sample PK030/2 @ 45 - 55]
60 –130	10YR 4/3 (brown) with abundant coarse yellow, orange & red mottles; coarse sandy clay loam; moderate medium angular blocky breaking to fine crumb; many moisture films; many medium & fine pores; slightly wet & friable; abundant coarse & medium hard quartz & gneiss angular stones; HCl negative; gradual regular boundary to: [Sample PK030/3 @ 90-100]
130 – 190	10YR 4/3 (brown) with abundant yellowish orange & reddish mottles; coarse sandy loam; medium angular blocky breaking to fine crumb; many fine pores; slightly wet & friable; few medium & fine roots; abundant coarse & medium hard quartz & gneiss stones; HCl negative; gradual regular boundary to; [Sample PK030/4 @ 150 - 160]
190 – 254+	10YR 4/3 (brown), with mixed colours of weathered rock; fine sandy clay loam; medium angular blocky breaking into fine crumb; many medium pores; slightly wet & very hard, & plastic when wetted; few coarse & fine roots; common soft pieces of reddish yellow & brown weathered gneiss; abundant subangular hard quartz & gneiss stones; HCl negative; soft manganese stains: [Sample PK030/5 @ 200 - 210]

SPAL analytical results for BSS **Profile PK030** **Survey area: Bajo RNR-RC**

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK030 /1	0-10	4521	7.3	6.2	1.1	-	9	1.0	0.08	12.5
/2	45-55	4522	7.8	6.8	1.0	-	1	0.4	0.03	13.5
/3	90-100	4523	7.5	6.5	1.0	-	1	0.5	0.03	16.6
/4	150-160	4524	7.5	6.6	0.9	-	1	0.3	0.03	10.0
/5	200-210	4525	7.6	6.5	1.1	-	1	0.4	0.02	20.0

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAC	EBS%
PK030 /1	6.2	1.3	0.5	0.2	8.2	-	8.4	-	98	-
/2	7.3	1.2	1.3	0.63	10.1	-	10.0	-	100	-
/3	8.3	1.4	2.8	0.3	12.8	-	13.9	-	92	-
/4	11.8	1.8	0.6	0.3	14.5	-	14.2	-	100	-
/5	8.7	1.2	0.5	0.3	10.7	-	10.9	-	98	-

Fine earth granulometric.

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	**Total sand**	20-50 micron	2-20	**Total silt**		
PK030 /1						56.0	8.8	17.0	25.8	18.2	SL
/2						57.3	9.5	12.9	22.4	20.3	SCL
/3						53.5	6.6	13.6	20.2	26.3	SCL
/4						57.0	9.2	22.8	32.0	11.0	SL
/5						50.7	9.8	15.9	25.7	23.6	SCL

Profile:	**PK031**	
Map unit:	TL	
Soil classification:	Provisional Bhutan soil series:	Floodplain soil (FP)
	Soil Taxonomy:	Typic Ustifluvent, *thermic, coarse loamy, mixed*
	FAO:	Eutric Fluvisol
Survey area:	RNR-RC Bajo.	
Location:	SW of Druk Seed Corporation production area, below Shengana road.	
GPS:	27° 29.21' N, 89° 53.87' E	
Altitude:	1310 m a. s. l.	
Described & sampled:	3.12.1997, K Tshering	
Climate:	General:	Warm temperate, P = ca 700 mm pa
	Recent weather:	Cloudy.
Regional topography:	Major river valley.	
Site position:	Floor of embayment in lower terrace	
Slope:	ca 5 %, concave, ca 200m long, aspect NE (50 °)	
Site drainage:	Good	
Parent material:	Solid:	Mixed
	Drift:	Young alluvium.
Land use:	Edge of bamboo plantation	
Vegetation:	Bamboo, *Artemisia*, eucalypts, marijuana & sedges.	
Surface:	Litter:	None.
	Outcrops:	None
	Stones:	None
	Cracks:	None
	Roots:	None
	Microrelief:	None
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)
cm

0 - 10	10YR 4/1 (dark grey); silty loam; very weak fine angular blocky; few fine pores; slightly wet & very friable; many medium & fine roots; HCl negative; earthworms seen; common charcoal; clear regular boundary to: [Sample PK031/1 @ 0-10]
10 – 45	10YR 7/1 (light grey), with few medium distinct dark brown mottles; loamy fine sand; very weak fine angular blocky breaking to single grain; few fine pores; slightly wet & very friable - loose; many medium & fine roots; HCl positive; gradual slightly wavy boundary to: [Sample PK031/2 @ 20 – 30]
45 – 65	10YR 4/2 (dark greyish brown) with abundant fine prominent dark brown & dark red mottles; very fine sandy loam +; very weak fine angular blocky breaking to single grain; many medium & fine pores; slightly wet & very friable; many medium & fine roots; HCl negative; clear regular boundary to: [Sample PK031/3 @ 50 - 60]
65 –105	10YR 4/2 (dark greyish brown) with abundant fine distinct dark brown & red mottles; very fine sandy loam +; very weak fine angular blocky; abundant medium & fine pores; moist & very friable; common fine roots: HCl negative; gradual regular boundary to: [Sample PK031/4 @ 80-90]
105 – 135	10YR 4/2 (dark greyish brown) with abundant coarse distinct dark brown, orange & red mottles; silty loam; very weak medium angular blocky; abundant medium & fine pores; moist & very friable; few fine roots: HCl negative; gradual regular boundary to: [Sampled PK031/5 @ 110-120]
135 – 170+	10 YR 4/2 (dark greyish brown) with abundant medium prominent dark brown & red mottles; fine sandy clay loam; very weak medium angular blocky breaking to weak fine crumb; abundant medium & fine pores; moist & very friable; many fine roots: few subanguar hard quartz gravel; HCl negative: [Sampled PK031/6 @ 140-150]

SPAL analytical results for BSS **Profile PK031** **Survey area: Bajo RNR-RC**

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC	Avail.	Organic C%	Total N %	C:N
			H2O	KCl	Diff	mS/cm	P ppm			
PK031 /1	0-10	4526	7.9	6.4	1.5	-	8	2.1	0.14	15.0
/2	20-30	4527	8.2	7.5	0.7	-	2	0.6	0.02	30.0
/3	50-60	4528	7.7	6.4	1.3	-	10	1.3	0.10	13.0
/4	80-90	4529	7.5	6.2	1.3	-	5	1.2	0.10	12.0
/5	110-120	4530	7.4	6.2	1.2	-	7	1.5	0.15	10.0
/6	140-150	4531	7.3	6.8	0.5	-	8	2.0	0.25	8.0

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAC	EBS%
PK031 /1	16.8	1.8	1.5	0.5	20.6	-	18.1	-	100	-
/2	6.6	1.3	0.4	0.1	8.4	-	8.3	-	100	-
/3	12.8	1.4	0.5	0.1	14.9	-	14.6	-	100	-
/4	11.2	1.1	0.4	0.1	12.8	-	15.3	-	84	-
/5	9.9	1.3	0.3	0.1	11.5	-	11.4	-	100	-
/6	13.8	0.9	0.8	0.1	15.6	-	15.4	-	100	-

Fine earth granulometric.

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	**Total sand**	20-50 micron	2-20	**Total silt**		
PK031 /1						24.9	46.3	21.1	68.4	6.7	ZL
/2						56.8	32.3	7.6	39.4	3.2	SL
/3						41.1	22.1	17.4	39.5	14.4	L
/4						51.3	14.6	21.6	36.2	12.4	L
/5						28.6	28.3	32.8	61.1	10.3	ZL
/6						29.6	31.2	23.1	54.3	16.1	ZL

Profile:	**PK024**	
Map unit:	TLm	
Soil classification:	Provisional Bhutan soil series: Soil Taxonomy: FA0	Middle terrace soil (TM) Typic Ustifluvent; thermic, fine Loamy, mixed Eutric Fluvisol
Survey area: Location: GPS: Altitude:	RNRRC, Bajo North east corner of SW section, below lower road. 27^0 29.34' N, 89^0 53.95' E 1290 m a. s. l.	
Described & sampled:	26.11.97, I.C Baillie	
Climate:	General: Recent weather:	Warm temperate, P = ca 700 mm pa Sunny
Regional topography: Site position:	River valley Top end of lower terrace	
Slope: Site drainage:	6 %, terraced, ca 200 m long, SW aspect (250^0) Good	
Parent material:	Solid: Drift:	Mixed rocks Old alluvium
Land use: Vegetation	Fallow wetland agricultural trial. Broadleaf & forb weeds	
Surface:	Litter: Outcrops: Stones: Cracks: Roots: Microrelief: Faunal activity: Other features:	Scattered rice straw None. Very rare round hard quartz cobbles, up to 15 cm diameter Few discontinuous, up to 2 mm wide. None Cultivation rows running downslope at 1.5 m spacing, 25 cm deep None None

Profile description: (Colours are moist unless indicated)
cm

0 – 17	10YR 4/3 (brown); fine sandy loam +; moderate coarse & medium crumb; many fine pores; dry & soft - friable tilth; few fine roots; common fine wormcasts; common very fine muscovite flakes; clear regular boundary to: [Sample PK024/1 @ 0-10]
17 –30	10YR 5/4 (brown), with many few fine distinct orange, black & reddish yellow mottles; medium sandy clay loam; many moderate fine subangular blocky; common fine pores; slightly moist - dry & hard - firm; few medium roots; few large soft & hard weathered gneiss stones; black manganese stains; very slow to wet; many very fine muscovite flakes; gradual regular boundary to: [Sample PK024/2 @ 20 - 30]
30 – 57	2.5Y 5/3 (light olive brown) with many medium & fine dark red linear reddish brown & orange mottles; very fine sandy clay loam; massive breaking to medium angular blocky; many fine pores; moist & very firm; rare fine roots; rare rounded hard coarse quartz cobbles & stones; few charcoal; slightly slow to wet; abrupt regular boundary to: [Sample PK024/3 @ 40 – 50]
57 – 58	Thin line of reddish yellow - strong brown, ferric stains; too soft to be a pan; abrupt regular boundary to: [Not sampled]
58 – 75	10YR 5/4 (brown) dry, 10YR 4/3 (brown) moist, with many medium faint strong brown, yellow & black mottles; very fine sandy clay loam; weak medium subangular breaking to moderate fine angular blocky; discontinuous weak dark cutans; many very fine pores, moist, & very firm; rare rounded coarse pebbles & cobbles; very slow to wet; many fine muscovite flakes; gradual slightly wavy boundary to: [Sample PK024/4 @ 60 – 70]
75 – 90	7.5YR 5/4 (brown), with many fine faint distinct black, yellow, yellowish brown & orange mottles; coarse - medium sandy loam +; weak medium subangular breaking to moderate fine angular blocky; many fine pores; moist & firm, rare fine roots; few soft round gneiss & quartz gravel; slow to wet; clear wavy boundary to: [Sample PK024/5 @ 80 - 90]
90 – 147	7.5YR 4/3 (brown), with many fine faint orange, dark brown & black mottles; medium - coarse sandy loam+, weak - moderate coarse angular blocky; weak discontinuous cutans; abundant medium, coarse & fine pores; moist & slightly friable; few fine roots; rare hard rounded pebbles; slow to wet; many very fine muscovite flakes; diffuse boundary to: [Sample PK024/6 @ 110 – 120]

147 – 165 + 5YR 4/4 (reddish brown), with common medium linear black, brown, yellowish brown & orange mottles; medium - coarse sandy loam; moderate medium breaking to fine subangular blocky; few discontinuous weak cutans; common medium & fine pores; moist & friable; rare fine, hard, rounded pebbles; slow to wet; many very fine muscovite flakes: [Sample PK024/7 @ 150 – 160]

Comments: This is typical of the soils of the upper end of the low terrace, in that the loamy textures perist to below 1.5 m. There is no sign of an underlying loose sandy substratum. Unlike middle and most lower of terrace soils, the organic carbon contents vary erratically with depth, so that this profile qualifies as an Ustifluvent in Soil Taxonomy, rather than an Ustorthent.

SPAL analytical results for BSS **Profile PK024** **Survey area: Bajo RNR-RC**

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK024 /1	0-10	4486	7.3	6.4	0.9	-	35	1.2	0.11	10.9
/2	20-30	4487	7.6	6.5	1.1	-	2	0.4	0.04	10.0
/3	40-50	4489	7.3	6.1	1.2	-	5	0.9	0.09	10.0
/4	60-70	4489	7.6	6.3	1.3	-	3	0.8	0.08	10.0
/5	80-90	4490	7.6	6.4	1.2	-	1	0.4	0.03	13.3
/6	110-120	4491	7.6	6.0	1.6	-	2	0.4	0.05	8.0
/7	150-160	4492	7.3	6.3	1.0	-	2	0.3	0.03	10.0

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAC	EBS%
PK024 /1	6.0	1.7	0.9	0.1	8.7	-	10.9	-	80	
/2	9.8	1.6	0.0	0.2	11.6	-	13.6	-	85	
/3	12.2	1.6	0.1	0.1	13.9	-	14.8	-	94	
/4	14.6	1.3	0.1	0.0	16.0	-	16.4	-	97	
/5	6.5	1.3	0.0	0.0	7.8	-	10.1	-	78	
/6	7.5	1.6	0.0	0.0	9.1	-	11.9	-	77	
/7	8.1	1.3	0.1	0.1	9.5	-	10.8	-	88	

Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	**Total sand**	20-50 micron	2-20	**Total silt**		
PK024 /1						47.9	7.8	18.1	25.9	26.1	SCL
/2						50.1	10.6	17.9	28.5	21.4	SCL
/3						49.0	8.0	19.1	27.1	23.9	L
/4						45.5	8.9	19.3	29.1	25.3	L
/5						59.4	11.6	13.2	24.8	15.8	SL
/6						53.0	78	16.7	24.5	22.5	SCL
/7						60.0	7.9	12.2	20.1	20.0	SL-SCL

Profile:	**PK025**		
Map unit:	TM		
Soil classification:	Provisional Bhutan soil series: Soil Taxonomy: FAO:		Middle terrace riser soil (TMr) Fluventic Ustochrept; *thermic, fine loamy, mixed* Eutric Cambisol
Survey area: Location: GPS: Altitude:	Bajo RNR-RC Path from Shengana road to Druk Seed Corporation production area. 27^0 29.50'N, 89^0 53.86' E. 1260 m a. s. l.		
Described & sampled:	26.11.97, I.C.Baillie		
Climate:	General: Recent weather:	Warm temperate, P = ca 700 mm pa Sunny	
Regional topography: Site position:	Major river valley Lower edge of middle river terrace		
Slope: Site drainage:	28%, convex, ca 250 m long, WSW aspect (250^0) Good		
Parent material:	Solid: Drift:	Mixed rocks Old alluvium	
Land use: Vegetation	Waste land at side of road. Thick scrub of *Artemisia* & *Opuntia spp*		
Surface:	Litter: Outcrops: Stones: Cracks: Roots: Microrelief: Faunal activity: Other features:	Discontinuous dry *Artemisia* litter Rare hard, round, quartz pebbles None None None About 5 cm between *Opuntia* plants None None	

Profile description: (Colours are moist unless indicated)
cm

0 – 16 7.5YR 6/4 (light brown) dry, 7.5YR 4/4 (brown) moist; silty clay loam; moderate fine crumb; abundant fine & medium pores; slightly moist - dry & loose - very friable; abundant moderate *Opuntia Artemisia* roots; few medium hard rounded quartz pebbles; HCl negative; common fine casts; buried pockets of leaves; clear regular boundary to: [Sample PK025/1 @ 0 – 10]

16 –36 10YR 6/4 (light brown) dry, 10YR 4/4 (brown) moist; silty clay loam; moderate medium breaking to moderate fine subangular blocky & crumb; many fine & medium pores; slightly moist - dry & slightly hard, friable when moistened; many fine & medium *Opuntia* and *Artemisia* roots; HCl negative; clear regular boundary to: [Sample PK025/2 @ 20 - 30]

36 – 55 7.5YR 5/4 (brown), with many medium faint dark brown, reddish brown & reddish yellow mottles; silty clay; strong medium subangular blocky; common medium & fine pores; moist - slightly dry & hard to very firm; few fine & medium roots; rare round hard pebbles; HCl negative; few coarse krotovinas; diffuse boundary to: [Not sampled]

55 – 102 5YR 5/4 (brown), with many fine distinct red & orange mottles; very fine sandy clay; strong medium - fine subangular blocky stocky; abundant medium & fine pores; moist - slightly dry & hard, very firm when moistened; rare medium roots; few round hard pebbles; HCl negative; few coarse krotovinas; gradual wavy boundary to: [Sample PK025/3 @ 75 – 85]

102 – 148 7.5YR 6/4 (light brown), with common medium distinct pink, red & orange mottles; silty clay loam; massive breaking to weak medium subangular blocky; abundant medium & coarse pores; moist - slightly dry & hard, very firm when moistened, few coarse & medium roots; few rounded hard pebbles; HCl negative; few ant holes; few charcoal near base; abrupt regular boundary to: [Sample PK025/4 @ 120 – 130]

148 – 150 Layer of ash & charcoal continuous across 10 m face: [Not sampled]

150 - 172 10YR 6/3 (light brown) dry, 10YR 3/2 (dark brown) moist; very fine sandy loam+; moderate medium subangular blocky; abundant medium fine & coarse pores; moist - slightly dry & slightly hard - friable; few coarse roots, mostly at top horizon; few angular slightly hard weathered rock; HCl negative; many ant holes; common scattered charcoal; clear regular boundary to: [Sample PK025/5 @ 155 - 165 cm]

172 – 190 9YR 6/6 (brownish yellow), with few fine faint reddish yellow mottles; fine sandy loam; massive breaking to weak medium angular blocky; many fine & medium pores; moist - dry & slightly friable; few fine roots; common hard quartz & gneiss & slightly weathered round pebbles; HCl negative; few ant holes; [Not sampled]

190 – 250 + Rounded hard boulders of mixed quartz, gneiss & granite up to 30 cm diameter in variable matrix of yellowish red lenses of sand - sandy clay loam. [Not sampled]

Comments: The depth of hard silty clay (almost 1.5 m) is typical of the lower end of the middle terrace. The distinct ash and charcoal layer at 148 – 150 cm contains sufficient carbonaceous material for C^{14} dating. A similar layer has been dated at about 350 years BP (Takada 1991). This implies extremely rapid downcutting by Tsang Chhu, and that both the middle (and therefore the lower) terrace soils are very young.

SPAL analytical results for BSS **Profile PK025** **Survey area: Bajo RNR-RC**

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK025 /1	0-10	4493	6.6	6.2	0.4	-	35	4.2	n.d.	n.d.
/2	20-30	4494	5.8	4.1	1.7	-	35	0.4	0.38	1.0
/3	75-85	4495	8.2	7.4	0.8	-	35	0.4	0.04	10.0
/4	120-130	4496	8.3	7.6	0.7	-	35	2.1	0.09	22.3
/5	155-165	4497	7.6	6.3	1.3	-	35	0.6	0.09	6.6

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAC	EBS%
PK025 /1	16.7	3.6	1.0	0.1	21.4	-	22.3	-	96	-
/2	5.6	1.1	0.8	0.1	7.6	-	15.3	-	49	-
/3	13.0	1.0	0.9	0.2	15.1	-	14.8	-	100	-
/4	11.9	2.0	1.0	0.3	15.2	-	14.7	-	100	-
/5	14.9	2.3	0.8	0.1	18.1	-	18.7	-	97	-

Fine earth granulometric.

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	**Total sand**	20-50 micron	2-20	**Total silt**		
PK025 /1						47.6	12.5	21.0	33.5	18.9	L
/2						48.1	13.4	15.9	29.3	22.6	L
/3						40.1	12.4	15.3	27.7	32.1	CL
/4						49.8	12.1	14.5	26.6	23.6	L
/5						56.0	11.2	13.3	24.5	19.5	SL

Profile:	**PK026**	
Map unit:	TMu	
Soil classification:	Provisional Bhutan soil series: Soil Taxonomy: FAO:	Middle terrace soil (TM) Typic Ustochrept; *thermic, loamy over loamy skeletal, mixed* Eutric Cambisol
Survey area: Location: GPS: Altitude:	Bajo RNRRC 50m south west from the Northeast fence 27^0 29.57'N, 89^0 54.08' E 1280 m a. s. l.	
Described & sampled:	27.11.97, K Tshering	
Climate:	General: Recent weather:	Warm temperate, P = ca 700 mm pa Partly cloudy
Regional topography: Site position:	Major river valley Upper end of middle terrace.	
Slope:	11%, terraced concave, ca 500 m long, W aspect (275^0)	
Site drainage:	Good	
Parent material:	Solid: Drift:	Mixed rocks Old alluvium over colluvium
Land use: Vegetation	*Sesbania* green manure trial *Sesbania* stubble	
Surface:	Litter: Outcrops: Stones: Cracks: Roots: Microrelief: Faunal activity: Other features:	None None. None None None Worn cultivation ridges None. None

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

0 – 28	10YR 5/3 (brown), with many medium faint grey, orange & reddish mottles; fine sandy loam; moderate coarse subangular blocky; with thin moisture films; many fine pores; moist & very hard, plastic when wet; many medium & fine roots; common medium subangular quartz, gneiss & granite; HCl negative; few earthworm casts; gradual regular boundary to: [Sample PK026/1 @ 0 - 10]
28 – 57	10YR 5/2 (greyish brown), with many medium faint yellow & orange mottles; medium sandy loam +; moderate medium subangular blocky; many medium & fine pores; moist & very hard, plastic when wet; many fine roots; few moderate subangular quartz & gneiss stones; HCl negative; clear regular boundary to: [Sample PK026/2 @ 40 - 50]
57 – 89	10YR 4/1 (dark grey), with abundant dark brown, dark red & orange mottles; medium sandy loam; moderate medium subangular blocky; many fine pores; moist & slightly firm; few fine roots; few medium subangular hard quartz, gneiss & granite stones; HCl negative; gradual regular boundary to: [Sample PK026/3 @2 70 – 80]
89 – 114	10YR 4/1 (dark grey), with abundant medium dark brown, dark reddish & orange mottles; coarse sandy loam +; weak medium subangular blocky breaking to fine crumb; many fine pores; moist & friable; rare fine roots; few medium hard quartz & gneiss stones; HCl negative; gradual regular boundary to: [Sample PK026/4 @ 90 - 100]
114 – 141	7.5YR 4/2 (dark greyish brown), with abundant prominent dark brown mottles; coarse sandy loam; weak medium subangular blocky breaking to fine crumb; many medium & fine pores; moist & friable; rare fine roots; few medium rounded hard quartz & gneiss stones; HCl negative; gradual regular boundary to: [Sample PK026/5 @ 120 – 130]
141 – 180 +	7.5YR 4/2 (dark greyish brown), with many coarse dark brown mottles; gravelly sand loam; weak medium subangular blocky breaking to crumb; moist & friable; rare fine roots; many medium hard round quartz & gneiss stones; HCl negative: [Sample PK026/6 @ 155 - 170]

Comments: The partially colluvial origin of this soil shows in the generally subangular stones in the upper horizons. The stones below about 1 m depth are mostly rounded alluvial gravels. The relative shallowness of the friable sandy loam, at 50 – 90 cm is typical of the soils on the concave upper section of the middle terrace.

SPAL analytical results for BSSP **Profile PK026** **Survey area: Bajo RNR-RC**

Reaction, P & organic matter

BSS No.	Depth cm	SPAL Lab No	PH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK026/1	0-10	4498	7.0	6.0	1.0	-	5	1.1	0.14	7.8
/2	40-50	4499	7.7	6.2	1.5	-	3	1.0	0.06	16.6
/3	70-80	4500	7.9	6.4	1.5	-	3	0.3	0.05	6.0
/4	90-100	4501	7.9	6.5	1.4	-	1	0.4	0.04	10.0
/5	120-130	4502	7.9	6.5	1.4	-	1	0.1	0.03	3.3
/6	155-170	4503	7.9	6.5	1.4	-	3	0.5	0.01	50.0

Exchangeable base status

BSS No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAC	EBS%
PK026 /1	6.2	1.5	0.0	0.1	7.8	-	10.3	-	75	-
/2	8.4	1.5	0.0	0.2	10.1	-	11.9	-	85	-
/3	8.2	1.6	0.0	0.0	9.9	-	11.4	-	86	-
/4	6.2	1.2	0.1	0.0	7.5	-	10.3	-	73	-
/5	7.2	1.0	0.0	0.0	8.2	-	9.7	-	85	-
/6	7.4	0.8	0.1	0.1	8.4	-	8.7	-	96	-

Fine earth granulometric

BSS No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	**Total sand**	20-50 micron	2-20	**Total silt**		
PK026 /1						40.3	11.3	23.2	34.5	25.3	L
/2						46.6	9.3	20.9	30.2	23.3	L
/3						54.6	6.7	18.3	25.0	20.3	SCL
/4						61.2	10.7	14.1	24.8	13.9	SL
/5						62.4	8.3	13.4	21.7	15.9	SL
/6						73.3	6.1	8.8	14.9	11.8	SL

APPENDIX C: CORRELATION OF BAJO SOILS

APPC 1 Soil classification and correlation in Bhutan

Table 5.3 in the main report summarises the correlation of the Bajo soil classes with the international soil classifications. This appendix discusses the correlations assigned. This is necessary because BSSP is still in its formative stages, and the soil correlations need to be worked out. Some of the correlations will undoubtedly be revised in the future, as we learn more about the soils of Bhutan, and as the international systems are modified.

There are two main international systems of soil classification. The USDA Soil Taxonomy was originally developed to meet the needs of soil survey in the continental United States. It has been extended 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 quite comprehensive. It has the advantage that it uses more traditional and comprehensible soil names.

Pedologists working in Nepal have mostly used the Soil Taxonomy but previous consultants in Bhutan have preferred the FAO system. At this stage it is not necessary for Bhutan to decide which, if either, of the two systems to adapt. For the present, BSSP will use local soil classes and names within Bhutan, and will correlate them against both of the international systems (AHT 1995).

APPC 2 General criteria

Before considering the individual soil classes, there are some environmental characteristics that need to be determined before the application of Soil Taxonomy.

APPC 2.1 Soil moisture regime

This is necessary for the assignment to suborders or great groups in Soil Taxonomy. In the absence of soil moisture data, soil moisture regimes are approximated from rainfall totals and distribution. All of the soils at Bajo have an ustic moisture regime, which is defined as having more than 90 consecutive dry days per year and a summer rainfall distribution.

APPC 2.2 Soil temperature regime

This is a criterion for classification at family level in Soil Taxonomy. In the absence of soil temperature data, atmospheric temperatures are used. Bajo is warmer than any other RNR-RC's and has a thermic atmospheric temperature regime, with an annual mean between 15^0 C and 22^0 C and a summer – winter difference greater than 5^0 C. All of the soils at Bajo are assumed to have thermic soil temperature regimes.

APPC 2.3 Mineralogy class

This is another family criterion in Soil Taxonomy. Although muscovite is a highly visible component in many soils at Bajo, mica contents are less than 40 % of the sand and gravel fractions, so that the soils do not qualify as micaceous, and have to be classified in the mixed mineralogy class.

APPC 2.4 Particle size class

This varies with stone content and fine earth texture, and is therefore various for the different soil classes at Bajo, although most are coarse or fine loamy.

APPC 3 Correlation of Bajo soils

APPC 3.1 Hillslope soils (HS).

These soils consist of colluvial deposits of moderately weathered material. In Soil Taxonomy, the degree of weathering has priority over layering in keying out, so that most of these soils probably qualify as Typic Ustochrepts. A few of these soils have high contents of unweathered minerals, and the soils may therefore qualify as Typic Ustorthents. In the FAO system most of these soils qualify as Eutric Cambisols, although some be Eutric Regosols.

APPC 3.2 Terrace riser soils (THr and TMr)

The occurrence of layering and distinct boulder beds in the subsoils of some of these soils appears to qualify them as Typic Ustorthents in Soil Taxonomy and Eutric Regosols in the FAO system. However the degree of weathering and less pronounced layering in other profiles qualify them more as Typic Ustochrepts in Soil Taxonomy and Eutric Cambisols in the FAO system.

APPC 3.3 Middle and lower terrace soils (TM and TL)

These are clearly alluvial soils but of different ages and therefore different degrees of weathering since deposition. The older soils on the middle terrace are less obviously layered, and are more weathered and have redder colours. They probably therefore qualify as Typic Ustochepts in Soil Taxonomy or Eutric Cambisols in the FAO system. The soils of the lower terrace are more distinctly layered and less weathered. They appear to qualify as Entisols in Soil Taxonomy. The low levels of organic matter in the subsoils make some them Orthents rather than Fluvents, deposite the obviously fluvial origin of the alluvium, although other profiles (PK024 & PK027 are have erratic subsoil Organic C contents, and are therefore Ustifluvents.

In the latest developments of the FAO system allowance is made for soils with topsoils that have been drastically modified by prolonged cultivation for irrigated rice (FAO, 1998). The topsoils of the middle and lower terrace soils have probably been artificially gleyed to a sufficient degree to quality as anthraquic horizons, and the subsoils with black manganese mottling may qualify as hydragric horizons. This qualifies these soils as Anthrosols. However the full implications of the FAO (1998) modifications have not yet been fully assimilated and they are not yet being applied by BSSP.

APPC 3.4 Floodplain soils

These soils show very distinct layering, are little weathered, and have organic matter contents that fluctuate erratically with depth. They therefore qualify clearly as Fluvents in Soil Taxonomy and Fluvisols in the FAO system.

APPENDIX D: SOIL MAP BAJO RNR-RC