Annex 1

Factors Influencing Soil Formation in Nepal

Soil fertility research in Nepal is notable for the almost complete absence of information on soil classification, genesis, or geomorphic features as they influence the soil. In this annex, soil-forming factors are considered as they relate to important management characteristics.

Soil-forming Factors

The physical and chemical characteristics that influence a soil's inherent fertility are largely based on differences in parent material, climate, stability of the land surface, and the effect of vegetation and animals on the soil. Man has had a profound effect on the soil resource over the past 500 years. A thorough understanding of soil-forming factors influencing any landscape permits a high level of predictive value on what the soil characteristics will be and how they will affect crop production. A brief discussion of the major soil-forming factors influencing Nepalese soils is provided here.

Parent Material

A wide range of parent materials occurs in Nepal and can be divided into two broad classes: a) *In Situ* Bedrock - on which soil is developed directly over native rock - and b) Transported Material - on which soil is developed over unconsolidated material that has been transported, either by water, ice, and wind and/or gravity.

In Situ Bedrock

The major rock types in Nepal include phyllites, schists, granites, limestones, quartzite, and sandstone - all in varying degrees of metamorphism. Most soils on mountain slopes are dominated by the bedrock underneath and soil properties will reflect the characteristics of the underlying bedrock to varying degrees. Water-holding capacity, cation exchange capacity, base saturation, and overall slope stability are all strongly influenced by rock type. The major rock types and their characteristics are considered below.

1. Phyllite. Phyllites or phyllitic schists are the most common bedrock material in the more populated Middle Mountains of Nepal. This rock type tends to weather rapidly, develops into moderately sloping terrain, and the soils over them tend to be relatively stable. There are many grades of phyllite, degrees of competence, and amount of fracturing and these in turn influence the physical and, to a lesser degree, chemical properties of the soil. The weathered products of phyllite generally form a deep, loamy, occasionally stone-free, solum with moderate levels of inherent soil fertility. They are used extensively in both rainfed and irrigated agriculture. Phyllite-based soils are often mistakenly considered to be much older by soil scientists unfamiliar with the terrain. Green phyllites have the peculiarity of turning brilliant red when oxidised, which results in the many red-tinged soils that occur sporadically, but commonly, throughout the Middle Mountains of Nepal. These reddish soil spots are readily observable on the Naubise-Mugling section of the Kathmandu-Pokhara highway. If these reddish soils are used for irrigated rice production, they turn yellow over one or two monsoon seasons as the iron oxides in the soil matrix are reduced.

2. Quartzite. Quartzite and quartzitic soils are also common in Nepal, particularly in the steeper landscapes of the Middle and High Mountain Regions. The soils tend to be acidic, shallow, stony, and relatively non-fertile. They are usually associated with forest uses rather than agriculture. As quartzites are generally competent rocks, when the rock formations are thick, they create steep cliff and bench-dominated terrain. However, the majority of quartzite occurs as thin layers within other rock formations and, in such cases, it modifies the characteristics of soils developed from the mother rock.

3. Granite. Granites and granodiorites are common in well-defined masses along the southern region of the Middle Mountains, and in the the High Mountains and the High Himalayan Region. Soils developed over

these rock types tend to be shallow, stony, and acid and generally do not support agriculture. The large granite massive transected by the Dandledhura road is a classic example of acidic granitic rock that will only support forestry uses. Granites in the Mahabharat are generally deeply weathered - possibly due to the greater fracturing of the bedrock caused by past tectonic movement and the greater proportion of feldspar found in the mother rock. Bedrock around the town site of Dhankuta and the horticultural station at Daman are two examples of areas with agricultural soils developed on the deeply-weathered granites. In contrast, the granites and granodiorites of the High Mountain and Himalayan regions above the Main Central Thrust tend to be relatively unweathered, possibly because of less fracturing, lower content of weatherable mineral (mainly feldspar), and the relatively recent glaciation that has removed any unconsolidated material that had formed before that event.[11] Micronutrient deficiencies frequently occur on the deeply-weathered granites throughout the country.

4. <u>Limestone/Dolomitic Limestone.</u> Limestones occur sporadically throughout much of Nepal, north of the Main Boundary Fault. The soils developed over them are usually shallow, stony, and loamy textured. While the pH of these soils is initially around 6, over time they are leached and tend to become red and acidic, at least on the surface. The high base saturation of subsoil in limestone and dolomitic areas makes for growing conditions that are particularly suited to leguminous trees, such as *Acacia catechu*, below 1,000m. The natural occurrence of *Acacia* is a good indicator that the soil is not acidic and that the subsoil is actually calcareous. *Leucaena leucocephalla*, a multipurpose tree used extensively in the 70s and up until 1987 (when it was attacked by the psyllid), did not perform very well in Nepal unless it was planted on calcareous or at least non-acidic soils. This, in part, explains the patchy success foresters were experiencing with *Leucaena* in the early 1980s.

5. <u>Interbedded Tertiary Sediments</u>. The interbedded Tertiary Sediments of the Siwalik Range are readily recognised as being strikingly different from the other bedrock formations of Nepal. Their lack of consolidation, strong interbedded nature, and extreme hydrological properties make many of the soils developed on these rock types shallow, stony, and infertile. High rates of surface erosion, a result of the intense tropical rainstorms and the many impervious layers that stop infiltration or deep percolation, are a major feature of many areas in the Siwaliks. Severe erosion occurs here even under natural forest. Certain marls and interbedded siltstones have the added hazard of being extremely unstable and subject to landsliding and slumping. Road closures on the north south corridors from the *Terai* to all hill districts are especially plagued by mass failures here. The fact that these rocks are so variable has resulted in a tremendous range of both opportunities and constraints when working in the Siwalik area, and this needs to be considered during development efforts.

Transported Materials

Most of the agricultural soils occur on materials that have been transported, at least to some degree. The resulting unconsolidated materials can be extremely coarse, as on boulder talus slopes, such as those found north of Buddhanilkantha or fine, such as in the historic lake basins of Kathmandu Valley. In general, these deep, relatively stable parent materials have a higher fertility than found in soils developed directly over bedrock, partly because of the greater mixing of a diverse range of minerals. The following are the major transported parent materials found in Nepal.

1. <u>Alluvium</u>. Alluvium covers 17 per cent of the whole country and consists of unconsolidated sediments resulting from active, recent, and ancient deposition of the rivers and streams of Nepal. Virtually all of the *Terai* and much of the Dun valleys are made up of alluvium that accounts for over 90 per cent of all of the alluvium found countrywide. However, within the Middle and High Mountains, the small proportion of alluvial terraces plays a critical role in the overall food security of the area. Although the soils themselves are not especially fertile, it is the proximity to irrigation water and the ongoing dissolved and particulate additions to the soil from the irrigation water that boost overall productivity. In the village, most farmers have at least a small plot consisting of 1 or 2 ropanis (.05 ha) of alluvial land as part of their holdings.

11. These granites are more competent because of less fracturing of the parent rock, their lower content of weatherable minerals (mainly feldspar), and the recent glaciation that has removed any unconsolidated material.

Within the Mountain Regions, catastrophic alluvial events, including glacial lake outburst floods and landslide dam breeches have produced the major terrace systems (*Tars*) found along the rivers today. Relatively recent downcutting through those deposits by the rivers, creates the terrace forms as we know them today.

2. Colluvium. Colluvium refers to those parent materials that have been deposited by gravity, either rapidly - as in a landslide runout deposit - or slowly by the process of soil creep. Soils developed on colluvium tend to be stony throughout the profile without clearly defined depositional horizons. They may or may not be stable. Given the steepness of the highly dissected river systems of Nepal, it is not surprising that many soils are developed on parent materials that are at least partly colluvial in nature. On the steeper mountainous landscapes, major agricultural production pockets are developed entirely on these colluvial deposits; the surrounding terrain is too steep to support any arable agriculture. The large rice-growing area west of Naubise is a classic example of a colluvial landscape - resulting from a major landslide/debris torrent issuing from the Mahabharat Range to the south.

In many instances gravity and water work together and the resultant debris flows occur throughout all of the mountainous regions. While the initial result is one of destruction, the material laid down becomes the basis for much of the productive agriculture found in the mountainous terrain of Nepal. There is considerable speculation that the current deforestation is causing the major landslides and debris torrents; but, in the majority of cases, there is no evidence to support this.

3. Glacial. Glacial materials are those that have been deposited by glacial action. In areas above 5,000 metres, this process is still going on today. The last major glaciation occurred around 10,000 years ago and strongly influenced areas in the High Himalayan and High Mountain Physiographic Region. All major valleys above 2,000 metres issuing out of the High Himalayan Region show evidence of glaciation. A classic glacial deposit is found at Lukla where the airport that services the Khumbu region is situated. The diagnostic U-shaped valleys are not apparent below 2,500 metres because the extremely high rates of downcutting of the river systems. Where these rivers cross the 1,200 metre elevation line, the mountain masses around them are experiencing the most rapid tectonic uplift of any landscape in the world. Consequently glacial deposits are often left stranded at as high as 500 metres above the present valley floor. Evidence of glacial advance down to 800 metre elevations has been observed south of Pokhara where a tremendously active glacier issuing off the south face off the Annapurna Massive has surged. This till has been covered by the much more recent glacial outburst flood (700 years B.P.) that has totally reshaped the Pokhara Valley. The importance of glaciers in fertility analyses is that unexpected physical and chemical properties of soils occur where glacial deposition has unknowingly occurred. Strongly calcareous materials, representing rocks higher in the watershed, may occur inexplicably in areas with strongly acidic bedrock.

4. Lacustrine. Lacustrine deposits are those that are laid down in relatively quiet water, thus excluding the coarser sand and rock components. While the total area of lacustrine parent materials is very small in Nepal, they are important.

The Kathmandu Valley is the largest single lacustrine deposit in Nepal and the occurrence of the fertile soils on that lacustrine has strongly influenced the development of the country. The soils developed on lacustrines are deep, fine-textured, stable, and provide an ideal medium for plant growth. Given their low topographic position, they are relatively easy to irrigate. Without this unusual soil type, the *Newari* culture would not have developed as we know it today. The *Jyapu*, the *Newari* cultivators, have an extremely rich culture and their agricultural system is an anomaly within the Himalayas. Even the use of the *kodalo* (the short-handled cultivating implement) is perfectly designed for the deep, fine-textured, stone-free lacustrine soils of the Kathmandu Valley, Banepa, and the Tistung/Palung area. The deep cultivating action of the *kodalo* permits higher productivity than is possible in the shallower soils of the adjacent hilly areas. The fact that the plough was not used in the valley[12] was likely a recognition on the part of the *Jyapu* that shallow ploughing with oxen would not optimise the production potential of the local soils.

12. There is a legend that ploughing in the Kathmandu Valley is forbidden because it would offend Lord Pashupatinath who makes his home on the Bagmati river at Pashupati.

A serious drawback to the development of the country is that most agricultural research has been carried outwithin the Kathmandu Valley on these lacustrine soils which are strikingly different from soils in the areas targetted as extension domains for research. Consequently many of the results based on trials conducted within the valley are not relevant to the farmers of the hills.

5. Aeolian Deposits

Aeolian, or wind-deposited, materials are not common in the Himalayas and, where they occur, they are usually in association with other parent materials. The most active and significant aeolian deposition is found in association with alluvial soils in the western *Terai* and in the adjacent hills, a direct result of the strong, dry winds blowing out of the Rajasthan Desert during the pre-monsoon period. While the winds carry dust into Nepal, significant fine sands and silts are picked up from the many dry river beds in the *Terai*. As many of these materials are calcareous, it is possible that this is one mechanism that explains the significantly higher pHs common throughout western Nepal.

Climate

Climate is a critical factor in the formation and resultant characteristics of the soils of Nepal. Temperature and effective precipitation strongly affect the rates of chemical and physical reactions in the soil. The wetter and hotter the climate, the greater the weathering. The most weathered soils are found in the tropical areas, while the least weathering occurs in the arid, cold regions within the High Himalayas. Although this is a well understood factor in soil development, the extremely dynamic geomorphology of the area often masks the important role of climate on the soil. Few of the soils in the tropical areas are actually strongly weathered.

A tremendous range of climatic conditions exists within the country. This is a direct result of the high relative relief and the different effect the monsoon has both regionally (from the west to the east of the country) and locally due to varied orographic effects caused by differences in the relief and orientation of mountain ranges. These differences, in turn, strongly affect the properties of the soils of Nepal. Wymann (1991) concluded that microclimate was a major determinant influencing the soil fertility indicators (organic matter content and base saturation percentage) of the upper Jhikhu Khola. Climatic differences are central to the development of the Agroecological Zones of Nepal and are discussed at length in Annex 3.

Stability of the Landscape

In a mountainous, tectonically active landscape such as that of Nepal, with its overwhelming geomorphic events, it is not surprising that the stability of a surface strongly influences the properties of the soil found there. The major soil types are classified, indirectly at least, by the stability of the alluvium or mountain slope on which they develop (Annex 2). All other factors being equal, the more stable the surface, the more developed the soil profile. This explains why the vast majority of the tropical regions, while under a strongly weathering climatic regime, do not have old, weathered soils. In most cases, the surfaces are too young, and the return period of destructive events too frequent, to permit sufficient weathering to age the soils. Landslides, debris torrents, slumps, and flooding occur, or have occurred, in the geologically recent past on most landscapes in the Himalayas of Nepal. The oldest soils of Nepal occur on the high alluvial terraces (*Tars*) of the major river systems and on uplifted fan and delta deposits of the ancient Dun basins within the Siwaliks. These landscapes have remained undisturbed for more than 20,000 years and, consequently, the landscapes are deeply weathered. At the other end of the scale, many landscapes (including those resulting from catastrophic flooding, landslide scouring of mountain slopes, and landslide deposition in valleys) have soils that are virtually unweathered.

Flora and Fauna

Although parent material, climate, and soil strongly influence the type of vegetation that can occur on any landscape, flora and fauna themselves can have a strong effect on overall soil development. Good forest cover promotes good infiltration of rainfall, greatly reducing the rate at which a soil material would otherwise erode. Extensive tree root systems can extract nutrients and water from deep within the solum and recycle substances that would otherwise be lost to vegetation by deep leaching. Certain species, such as the *chir* pine, can colonise difficult sites but, at the same time, prevent the introduction of other species. It is well recognised that conifers, in general, and pines, in particular, can significantly reduce the pH of soils that were originally in hardwood forests. This can be a problem in places where soils are already highly acidic. Oak forests, on the other hand, tend to be much better at recycling calcium and magnesium bases than pine forests.

Insects, such as ants and termites, over the years, can selectively carry fine materials to the surface, leaving the coarser materials at depth. The older alluvial terraces (*Tars*) of Nepal owe some of their characteristics to the termites that, over thousands of years, have developed deep stone, free surface layers from what were rock-strewn wastelands. The deep red soils of the ancient Marsyangdi *Tars*, above Dumre, and the Trisuli *Tars*, northwest of Kathmandu, started out essentially the same as the shallow, calcareous boulder-strewn terraces now observed in the Pokhara Valley. The difference between them is the length of time weathering and termite and ant action have had to take effect on the once similar parent materials. Man, of course, in the past 500 years has had a tremendous effect on the soils of Nepal through terracing, irrigation, fertility management, forest clearing, fire and roads, and trails and settlement construction. This is discussed at length in the main body of the report.