II. The Land

In any discussion of soil fertility, particularly when one is concerned about long-term sustainability issues, an understanding of the land and soil resources is imperative. The Nepalese farmer is working within a dynamic geomorphic system, and the characteristics and performance of soils must be considered within that framework.

The Nepalese Landscape

The landscape of Nepal is the result of the ongoing collision between two massive continental plates - that of India to the south and Asia to the north. The land surface itself is extremely dynamic. The *Terai* is being subducted at the rate of more than 4 cm a year. A new, massive frontal uplift sheet has recently developed some kilometres away from the Siwalik front, resulting in an unprecedented erosional landscape on the otherwise featureless *Terai*. The main Himalayan chain, including Mount Everest, is considered to be still rising at an exceptionally high rate. Major breaks in the plates occur at the Main Boundary Fault and Main Central Thrust that straddle the whole country from east to west. Active transverse faulting can be found everywhere with many examples of shearing of recently deposited alluvium. This violent, tectonic movement creates unparalleled geomorphic activity. Landslides, debris torrents, and floods are every day features and result in a very high rate of natural erosion. The Nepalese farmer has learned to live with a degree of uncertainty that would be unacceptable to European farmers. Over time, the farmer has developed agricultural systems that require relentless maintenance and a highly developed sense of risk management, in order to survive normal and accelerated geomorphic events. The constant exposure and mixing of subsoils and parent rock provide for fresh exposure of certain minerals that would otherwise leach away. Soil fertility management must be considered within the context of this greater geomorphic dynamism.

Nepal is made up of 14,748 sq.km. of land, which is readily subdivided into 5 major physiographic regions: including the *Terai*, Siwaliks, Middle Mountains, High Mountains, and the High Himalayas. Not surprisingly, boundaries between these major physiographic regions correspond to the major faults and thrust plains of the ancient, now crumpled, Indian plate. These regions have distinct bedrock, geological, climatic, and hydrological characteristics; so soils and land use within these zones are significantly different. Based on traditional perceptions of land types in Nepal, with modifications by Nelson (1980) and later the Land Resource Mapping Project (LRMP 1986), these regions are now used in major planning exercises within the National Planning Commission. A brief description of the Physiographic Regions of Nepal is provided below.

The Terai

The *Terai* Region comprises 14 per cent of the land area of Nepal (2,122 sq. km.). It is made up exclusively of recent and post-pleistocene alluvial deposits forming a vast piedmont plain adjacent to the main Himalayan range. Elevations range from 60 to 330 metres, with slope gradients of 0.2 to 1 per cent. The land is flat, with the exception of minor local relief caused by river action and, in a few areas, recent, active, tectonic uplifting. The *Terai* Region is subdivided into 3 units based on alluvial history: active, recent, and older alluvium.

Making up 1.3 per cent of the land of Nepal, the active alluvial plains are flooded, or have been flooded, on a frequent basis (less than every 10 years), and the soils are generally coarse, highly porous, and lack significant weathering. Given the risk of monsoon inundation, these areas are usually managed in a less intensive manner, including grazing and low risk perennial crop production- including *Dalbergia sissoo* and, more traditionally, the pigeon pea.

The recent alluvial plains of the *Terai* make up over 7.9 per cent of the total land area of Nepal and could be considered the "bread basket" of Nepal. Soils are stable, water tables are never far from the surface (particularly during the monsoon), and the natural tendency for water to pond facilitates rice production. Virtually all of these soils are already in agricultural production.

The older alluvium, making up 4.9 per cent of the land area of Nepal, is made up of soils that are not subject to ponding as the slope gradients are higher and, in many cases, the soils are of a coarser texture. Areas of local uplifting, caused by the emergence of a new Siwalik plate some kilometres south of the present Siwalik front, are common, particularly in the western *Terai* where local relief as much as any other factor has discouraged settlement. Otherwise, government zoning for forestry and lack of readily accessible groundwater, or surface water, presently limit cultivation on much of these lands.

The *Terai* Physiographic Region is still considered to be the last frontier of Nepal, in spite of the fact that most of the best lands have already been settled. A year round growing season, good soils, availability of irrigation water, a relatively well-developed infrastructure, and easy access to the major markets of India suggest an optimistic future for agriculture. There are, however, some serious constraints centred around a population dominated by traditional landlord-tenant relationships, as a result of which the will to develop a more dynamic and productive agricultural system is lacking. Large landlords find investment in agriculture unattractive compared to other options: small farmers without assured tenure and a feudal crop-sharing arrangement see any investment beyond a bare minimum as unwise. Soil fertility management here, although much more closely bound to chemical fertilizers than in the hill regions of Nepal, still depends to some extent on livestock manures. Farmers, in areas where Sal forests are still to be found nearby, make active use of these forests for firewood and, to a lesser extent, fodder. Where fuelwood is absent, farmers are using dried livestock manure for cooking fuel and the lack of compost use on their soils is becoming increasingly serious. In the future, the agricultural system in the Nepalese *Terai* will undoubtedly increasingly benefit from experience gained in adjacent areas in India where some of the management problems now coming up in Nepal have long ago been solved.

The Siwaliks

The Siwaliks account for 1879 sq. km., or approximately 12.7 per cent of the land area of Nepal. Relief of less than 300 metres is common and rarely exceeds 1,000 metres in any watershed. Within the mountainous landscapes of the Siwaliks, slopes are generally too steep or unstable and soils too shallow to support any type of agriculture. The Siwalik Ranges are made up of relatively complex interbedding of Tertiary conglomerates, sandstones, siltstones, and mudstones of varying degrees of consolidation and form a very rugged and sometimes broken and gullied terrain. Local differences in rock type are often responsible for the tremendous variability in vegetation cover in the Siwaliks. Unfortunately, these differences are often not recognised by planners. Bedrock types that can only support scrub-type vegetation are viewed as areas that have been seriously degraded by man. The extensive shale areas north east of Lahan show inherently poor conditions for forest growth - man has had little effect on the apparent degradation. Conversely, the north facing slopes of gently, northern dipping sandstones support highly productive, mixed tropical hardwood forests that could conceivably be managed in a much more intensive manner. It is unfortunate that all of the lands in the Siwalik ranges have been lumped together as a single management unit. This lumping has resulted in many lost opportunities for effective use of resources. Large blocks of land have been included in Protection Forest Areas when they could support sustained selective logging. Conversely, many areas within the drought-prone shales have low forestry potential, and well-intended rehabilitation programmes repeatedly fail, if reclamation goals are set beyond the inherent capability of the land. Geomorphic instability within the Siwalik mountains has resulted in extremely expensive road construction and maintenance costs. Road closures caused by landslips frequently occur in the monsoon, particularly in the mudstone and shale areas.

Agriculturally, the most important areas within the Siwaliks are the Dun valleys where virtually all of the presently cultivated land is found. All Dun valleys (originally lake basins dammed as a result of tectonic uplifting of the Siwaliks to the south) have distinct features based largely on the characteristics of the watershed that served the prehistoric basins. For example, the Dang Valley and the upland areas of the Chitwan Valley were deposited by adjacent small local watersheds over 20,000 years ago. Now, those same small watersheds do not provide enough irrigation water to service the agricultural lands found downslope. Conversely, the Deukhuri and the lowland areas of the Chitwan were, and still are, strongly influenced by major rivers and have significant areas of alluvial soils with great potential for surface and groundwater development. The Surkhet Dun, while similar to the Dang in formation, has only been drained in recent geological time. The poorly drained, unweathered soils on the south side of the valley reflect their youth. Because the soils of the Duns are so variable, agricultural workers should be discriminating when determining research and extension domains.

Before 1960, these basin areas were sparsely populated by the indigenous Tharus, as malaria kept the hill people from settling there permanently. In the last 30 years, the Chitwan, Dang-Deukhuri, and Surkhet valleys have undergone tremendous change in land use and land tenure. There are still opportunities for agronomic innovation where the pioneer spirit is evident, particularly in the Chitwan. The negative effects of a rigid caste system are least felt in the Dun areas, because farmers have left their original homesteads behind and, along with them, they have left behind old ideas that prohibit more appropriate land management. As in the *Terai*, serious land tenure issues, particularly in the Dang and Surkhet areas, make introducing agricultural innovations difficult.

The Middle Mountains

The Middle Mountains make up 4,350 sq. km. or 29.5 per cent of the land area of Nepal. Relief of up to 1,000 metres is common between valley bottom and adjacent hill top, while maximum relief of 2,000 metres occurs throughout the Mahabharat Lekh - which runs the length of the southern boundary of the Middle Mountain Region. Bedrock is predominately phyllite and various degrees of metamorphosed schist with interbedding of quartzite. Isolated exposures of limestone, granite, shale, and other rocks also occur - a result of extensive long-distance thrusting of native rock from areas to the far north. For example, bedrock on the top of Phulchowki, on the south side of the Kathmandu Valley, appears to have been "pushed" via an ancient tectonic thrust plate from areas in the High Himalayas to the north. Most of these rocks are of Pre-cambrian age and are usually highly fractured due to the tremendous tectonic thrusting that has occurred in the distant geological past. Unlike in the Siwaliks to the south, where agriculture is restricted to the basin soils, most of the cultivation occurs on the moderately sloping phyllitic landscapes. Slopes are more gentle than in the Siwaliks, and a significant portion of the sloping hills is cultivated under relatively sophisticated terrace systems. The majority of the Nepalese population traditionally lived in the Middle Mountains because the soils are suited to terracing, the climate in most of the area permits two croppings per year, and the forest was well suited to meeting most of the villagers' household needs. Kathmandu Valley is an anomaly in the Middle Mountains, because of its gentle slopes and deep lacustrine soils at 1,200 metres' elevation. This fact is of importance when determining the extension domains of the central research stations of Khumaltar and Kirtipur.

Brahmins, Chetris, and occupational castes tend to occupy the lower elevations while *Tamangs, Magars, Gurungs*, and other hill tribes are more common at higher elevations (Plate 1). *Newars* traditionally inhabited the Kathmandu Valley and the adjacent areas of Banepa, Palung, and Tistung.

Land ownership tends to be more equitable in the Middle Mountains than in the Duns or in the *Terai*; however, holding size is very small with a significant portion of the population owning less than 1/2 ha of land. Any one farmer may own 5 or 6 separate plots, including both irrigated and rainfed land; in part to reduce the risk of catastrophic flooding of alluvial lands or landslide destruction of his uplands.

The forests of the Middle Mountains are extremely heavily exploited for fodder, firewood, litter, and timber collection. There are few examples of unexploited forests in the region and the increasing pressure of the local population is making ever-increasing demands on these forests. Unfortunately, the management of these forests does not match the generally excellent management of the adjacent agricultural lands. Lack of tenure or assured right of harvest has severely dampened the Nepalese farmer's enthusiasm for managing these forests in a more intensive manner. Low stocking rates of undesirable species and a virtual absence of care in management of the grass and browse species are two serious aspects of local management. Given the importance of these forests in providing the nutrients and energy to run the agricultural systems of the Middle Mountains, better management of these lands will be a theme repeated throughout this study.

The High Mountains

The High Mountain Region comprises roughly 2,899 sq. km., 19 per cent of the land area of Nepal. Relief in the order of 2,000 metres is common, so the range of tropical to cool temperate conditions can occur within the same valley. Bedrock is dominated by more competent phyllites, mica schists, and other more highly metamorphosed sedimentary rocks. Areas of gently sloping land are much less common than in the Middle Mountains because the rocks are less easily weathered and river cutting is more intense. Deep "V"-shaped valleys are common throughout the region. Many of the most intensively cultivated lands occur on landslide runout material that occurs adjacent to the valley bottoms. At higher elevations remnants of glacial till provide the basis for soils suited to cultivated agriculture. The High Mountain Region (with the exception of areas accessed by the proposed lead-zinc mine on the south slopes of Ganesh Himal and the area bisected by the Kodari highway) is isolated-with an average of 3 to 5 days' walk to a road head. As might be expected, this strongly influences the types of farming system that are found. Farmers are closely tied to subsistence production.

Individual production pockets tend to be self-sufficient, and cash cropping is not common. Region-wide populations are much lower than in the Middle Mountains; but, on a per cultivated hectare basis, overall densities are similar.

Forests in the High Mountains tend to be in much better condition than in the Middle Mountains, largely because the pressure from the local population is much less severe. Many of the forest areas are actually too far from the population centres to be accessed easily. There are, however, areas of local forest resource mismanagement with problems similar to those in the Middle Mountains.

The High Himalayan Region

The High Himalayas make up 3,447 sq. km. or 23.7 per cent of the land area of Nepal. Bedrock is predominantly more competent rock that forms very steep, rugged terrain. Relief can be over 3,000 metres. Most of the area below 4,300 metres is in natural forest. Whereas on the south side of the Himalayas this forest may be lush, being in an area of high rainfall, dry forest types and even grassland steppes occur in the rain shadow behind the main mountain ranges.

The area has a very low permanent population because of lack of cultivable land and cold winter conditions. Where local climate permits and irrigation water is available, small but dense pockets of population occur. Potatoes, millet, and naked barley have been the mainstay of production, but, with the increased importance of tourism in these areas, there is a growing interest in horticultural crops. Monsoon grazing of livestock and collection of forest plants for medicine are the major uses of the region. Isolation, with 3 to 8 day walks to the nearest market, strongly influences the type of farming system found here. In the future, an ever-increasing use of the area by tourists can be expected and this will play a major role in the management of agricultural lands in the High Himalayan Region.

Characteristics of Nepalese Soils

The confusion in the literature regarding natural resource degradation and the significance of soil fertility decline in Nepal is based, at least in part, on an ignorance of the soils and their properties. The extreme variability in soils and their properties is a result of differences in the major soil-forming factors: parent material, climate, geomorphic stability, and the types of organism that are living on its surface. The significance of these soil-forming factors is described in Annex 1. An acknowledgement of this variability is the first stage in developing appropriate soil fertility management strategies for the country. This section introduces the most important physical and chemical characteristics of Nepalese soils and indicates their significance for management techniques.

Physical Characteristics

Physical characteristics are those that influence energy and water flows through the soil. While often not considered strictly within a soil fertility framework, physical soil characteristics cannot be separated when attempting to understand farmer management of soils for production. Inexperienced researchers tend to analyse soils for chemical fertility problems when the constraints to production are a result of adverse physical conditions, particularly those related to water management. There appear to be many instances in which a farmer applies compost as much for its influence on the soil-water regime as for its nutrient content.

<u>Texture</u>. Soil texture refers to the relative portions of sand, silt, and clay in the soil. When all three constituents are present in the right proportions, the soil is called a loam. Nepalese soils are most often developed from micaceous parent material (phyllites, schists, gneisses, granites), and consequently most soils contain a high portion of mica. Loams and sandy loams are by far the most common soil texture throughout the hill regions on both the sloping lands and the alluvial terraces. They are well regarded by the farmer because of the ease with which they can be ploughed on upland fields regardless of moisture conditions. Loams have a good water-holding capacity and provide optimum aeration for plant roots. Infiltration rates tend to be higher

than the normal rainfall intensities that occur in most areas in Nepal, so surface erosion is usually not severe.

Finer textured soils (i.e., those with a higher clay content) result from sediment deposition in quiet water, and/or intense weathering, and are much less common. Such soils require special consideration when tilling as the soils are too hard to plough with cattle-drawn ploughs when dry land ploughing results in large unworkable clods if ploughed too wet. Erosion, particularly by gullying, can be serious when local relief is high. The fine-textured red soils of many of the ancient terraces along major river systems and in the Dun valleys suffer from such erosion. Occasionally, the bedrock materials of the Siwalik mudstones break down to a fine-textured material. These fine-textured sloping soils are extremely unstable and virtually impossible to farm. Nepalese farmers rate clay soils as the most difficult to work. However, the perception of their value differs considerably depending upon whether one is responsible for tillage operations (as are most tenant farmers) or entitled to a portion of the yield (as is the case for landlords). Those who have travelled or worked in Gulmi or Salyan are familiar with the strongly sloping terraces and red, fine-textured soils used in upland maize production. Farmers have learned not to attempt to terrace these soils as the fine textures are not conducive to good drainage without a strong surface slope. Maize root systems are suppressed by poor internal drainage, and slopes tend to fail *en masse* if terracing is attempted.

The puddling requirement of the rice fields and the use of standing water places excessively high demands on many irrigation systems developed to service coarse-textured alluvial soils. Most of the irrigated hill soils are loamy by nature but, over the years, have developed a plough pan at about 10 cm below the surface. Where internal drainage rates are high and plough pans are not well developed, irrigation duties are exceptionally high.

Soil Stoniness. Stony land is hard to till. The water-holding capacity is lowered in proportion to the amount of stones present and a fine seed bed cannot be prepared. Most soils formed directly over competent bedrock are stony. Commonly, bedrock in the Middle Mountain Region has well-defined fracture planes and the colluvial churning mixes the stones plucked from the bedrock throughout the profile. While large areas of the *Terai* and the Dun valleys are stone free, stoniness is a common feature of areas draining the conglomerate, rock-dominated watersheds found in the Siwaliks. Initially the whole of the Bhabar Region of Nepal was thought to be very stony, but this fallacy was based actually on repeated observations of the same area adjacent to Amlekhgunj where conglomerate Siwalik rock is found to the north.

Because phyllitic bedrock is so variable with respect to competence and degree of fracturing, stoniness is quite variable throughout the Middle Mountains. Terrace riser cutting commonly occurs on the stone-free phyllitic soils of the Middle Mountains. Higher up in the Himalayas, where rock becomes harder and weathering less intense, soils are found to be increasingly stony.

Root crops are difficult to grow and harvesting can be difficult. A common observation of agronomists and soil scientists is that the excessively stony soils of Nepal hill areas are a sign of infertility and there is a tendency to consider the soils to be much worse than their actual productivity indicates. While stoniness is an important management feature, it is not as detrimental to soil productivity as commonly inferred. Stones up to 25 per cent of the soil volume do not seriously affect plant growth, but, they can significantly reduce surface soil erosion by protecting the soil surface. Where heat retention of soils is critical at higher altitudes; a stony soil can absorb and hold more heat during the day, slowly releasing it at night when frost might otherwise occur. Stones have been used by many farmers to make terrace risers, drop structures for drains, and irrigation canals.

Soil Depth. Soil depth refers to the thickness of unconsolidated soil material found above bedrock (or other restricting layers) and is a critical factor affecting the management of the soil. About a 50 cm thickness of soil material is required to support rainfed crop production. Soils shallower than this are considered to be marginal and are usually reserved for grazing and forestry uses. Soils in the *Terai* and in the Dun valleys of the Siwaliks are deep and support a range of agricultural activities. The exception to this is where high water tables restrict aeration and limit the vigour and/or type of vegetation that can be grown. Fortunately these soils are well suited to rice production (Plate 2).

Within the Siwalik hills, 20 degree slopes appear to be the upper limit on which cultivation can occur - a result of the shallow soils that are naturally found on steeper gradients. Within the Middle and High Mountains, slopes up to 30 degrees are generally deep enough (greater than 1 m deep) to support arable agriculture when terraced. As soil depth and slope gradient are so closely linked, land use planners are often interested in determining slope cut-offs above which cultivation would not be permitted. This approach to land management has many pitfalls and leads to potentially serious misjudgments on how land should best be managed.

Soil Structure. Soil structure describes how individual soil particles are arranged within a soil. Good structure is extremely important for proper root growth, for good water management, and to resist the effects of rainfall erosion. Soil structure breaks down as organic matter levels drop. Soil organic matter levels have declined throughout the rainfed, cultivated uplands of Nepal, as scarce compost resources are increasingly being diverted to the irrigated lands. In many cases, farmers are using compost as a physical amendment to enhance soil structure as much as for nutrient additions. Recommendations for compost management, based on fertilizing value alone, reflect a lack of understanding of the soil's physical constraints.

Soil Horizons. Soil horizons are the natural or man-made layers that occur in most soils and provide important information on geomorphic stability and past management. Certain horizons provide diagnostic criteria for classification of the soil into internationally recognised systems such as Soil Taxonomy. (A description of the major soils of Nepal is provided in Annex 2.) The primary purpose of a classification system is to permit the transfer of specific management information about a particular soil from one geographical area to the other. The soil horizons of most Nepalese landscapes of Nepal are surprisingly underdeveloped; a result of the dynamic, geomorphic nature of the area which is constantly changing the soil surface. The most important soil horizons are described here.

1. Topsoil

The surface soil in its natural state is dark coloured, has high organic matter levels, and the best soil structure. This layer is the most fertile within a soil and so supports the major feeding roots of most vegetation. This topsoil layer is quickly degraded by poor management. Ploughing tends to increase the rate of oxidation of organic matter, and, without organic matter additions, the soil structure breaks down. If the soil surface is unprotected during intense rainfall, surface erosion quickly removes the topsoil. Topsoil degradation and loss are possibly the most serious processes affecting sustainability of farming systems in the mountain regions of Nepal, so keeping topsoil in place is central to better soil fertility management.

2. Subsoil

The subsoil is the horizon immediately below the topsoil and usually contains much less organic matter, nitrogen, phosphorous, and other essential plant nutrients than the topsoil. Pedologists have differentiated many different types of subsoil depending on whether the horizon is enriched with clay, iron oxide, or humus or impoverished by leaching. Soil structure tends to be massive and less conducive to plant feeder root penetration. Plant roots exploit this layer to provide support to the plant and to provide water that has percolated beyond the reach of feeder roots in the topsoil. As topsoil erosion proceeds, this horizon is increasingly depended upon to nurture agricultural crops, which it can only do with increasing fertilizer or compost additions. Agroforestry systems are important for the management of Nepalese soils in that they provide an opportunity to better exploit water and nutrients that have leached from the surface into the subsurface layers.

3. Saprolite

Saprolites are strongly weathered, rotten rock with some of the original rock structure still apparent. They are usually extremely infertile and have poor water-retention characteristics. In many of the more marginal agricultural landscapes throughout the mountain regions, saprolitic materials can be found at, or near, the surface. Where this occurs, it should be recognised that severe erosion has taken place and that land rehabilitation will require significant investment and sufficient time. The strongly weathered feldspar granites are commonly almost pure white and are recognised by farmers as the most impoverished soils. Without heavy compost additions, crops cannot be produced on any of these saprolitic materials. Fortunately, certain pioneer species such as alder (*Alnus nepalensis*) thrive on severely disturbed sites.

Chemical Characteristics

Chemical properties of soils are closely tied to overall soil fertility. However, a strong and dangerous western bias considers fertilizers and the maintenance of soil fertility to be synonymous. Many of the original tests for nutrient availability within soils are tied to chemical extraction methods that were developed for soils receiving high chemical fertilizer inputs. These laboratory tests do not adequately reflect the productivity of soils for which fertility management is dominated by compost additions. Soils shown by sophisticated laboratory procedures to be severely deficient in one or more nutrients often produce a satisfactory crop without special fertilizer additions. Soil fertility management specialists in Nepal have been in the untenable position of working with artificial chemical fertilizer-based management and western style analytical procedures within a system that is largely based on organic soil management. There has been little appreciation of indigenous soil fertility management techniques used by the farmer. Major chemical characteristics include those described in the following passages.

Soil pH. Possibly one of the most important but, at the same time, least understood characteristics of soil chemistry management is that associated with the soils' reaction, i.e., its relative acidity or alkaline nature. Strongly acidic soils are common in Nepal because of the predominance of coarse-textured, acid-forming parent materials and the high effective rainfall which selectively removes bases from the soil. Natural pH readings range from as low as 4.0 in Abies forests on the wet southern slopes of the main Himalayan range to 8.0 for calcareous active river sediments in the Siwaliks and the *Terai*. Soil pH is an important chemical characteristic because it determines the availability of many other plant nutrients and toxic elements. The average, cultivated upland soil in Nepal has a pH of around 5.4 (LRMP 1986) which is not limiting to agricultural production. However, severe acidity problems have begun to show up in the eastern and central hill districts. The average pH for the whole Jhikhu Khola Watershed, just east of Kathmandu Valley, was 4.8 (Schreier et al. 1991). The pH problem in this watershed may be considered representative of areas with cash cropping opportunities provided by good access to the Kathmandu markets. In these areas, the natural soil acidity is aggravated by the relatively heavy use of chemical nitrogen fertilizer and the tendency for government projects to reforest with pine trees. Pine tree plantations, unlike the original hardwood forests, are not efficient base recyclers and the pine needles produce fairly strong organic acids that accelerate leaching of bases from the soil. Traditionally, amelioration of soil acidity has depended on maintaining high rates of organic matter additions through compost use to buffer the soil. With fodder shortages and labour constraints, compost is no longer available in the quantities nor qualities required to buffer the excess acidity.

The agricultural research station at Bhairahawa, after only ten years of consistent chemical fertilizer use, has found heavily acidic soils on a number of fertilizer trial plots. Yields on these soils have decreased significantly. Where heavy applications of compost are not feasible and green manures are not used, the only alternative for managing severely acid soils is to apply crushed limestone. Where pH levels have dropped below 4.5, depending on the soil's exchange capacity, rates of 2 to 4 tons of limestone per ha are prescribed to restore the soil to a more acceptable pH. Unless local lime sources are available, it is unlikely that remote villages will ever be able to use crushed limestone as part of their soil fertility management strategy. For this reason, soil acidification caused by chemical fertilizers is potentially a much more serious problem in the less accessible agricultural production pockets of Nepal. Any policy to increase chemical fertilizer use in remote areas (such as the fertilizer transport subsidy) should consider the possible negative effects of acidifying soils in areas without reasonable access to liming materials.

Because of the complex lithology, diversity of forest types, range in amount and type of chemical fertilizer used, variability of compost management, and the differing water chemistry of irrigation waters, variability of soil acidity can be quite high - even between fields on two adjacent farms. Generalised regional, district, *ilaka*, or village level pH levels, determined by single samples, should not be considered reliable. Given the ease with which field pH measurements can be taken, recommendations involving pH management should be carried out only as a result of on site field investigations.

Nitrogen. Nitrogen is the single most important element influencing the yield of traditional farming systems in Nepal and has been given considerable attention by agronomists and soil scientists. Nitrogen is different from other major soil nutrients in that atmospheric nitrogen can be locally fixed and added to the nutrient pool. Trees, such as *Alnus* and *Acacia*, and crops, such as lentils and soya beans, are used extensively for their nitrogen-fixing ability. Through appropriate crop rotations and better management of off-farm resources, considerably more nitrogen could be fixed locally. In traditional farming systems, nitrogen and livestock waste management are synonymous. The vast majority of agricultural production in Nepal is dependant on organic nitrogen production, and this method of supply will be of paramount importance in the foreseeable future.

Over 68,000 tons of urea, 13,000 tons of ammonium sulphate, and 80,000 tons of NP complex were imported into Nepal in 1989, accounting for over 95 per cent of the total of chemical fertilizer used (Crown Agents 1991).

Laboratory analyses of nitrogen levels in farmers' fields always show deficiencies and a significant crop response to nitrogen fertilizers is almost universal when it is first used. In the last 10 years, there has been an increasing awareness that, while the initial response to fertilizers is almost always favourable, long-term chemical fertilizer use without modifications in overall fertility management is not sustainable. Mismanaged use of the manufactured nitrogenous fertilizers can lead to breakdown of soil structure, increasing soil acidification, deficiencies in other macro- and micro-elements, and drastic reduction in yields. However, the problem is not whether nitrogen fertilizers are good or bad, as often debated among agricultural workers, but how to promote an overall fertility management technology that will ensure optimum levels of sustainable production within the present economic framework.

Phosphorous. Phosphorous is the second most important element of significance to the agricultural soils of Nepal. Base levels of phosphorous in the soil are invariably low and, after nitrogen, phosphorous is most often restricting to plant growth. As with nitrogen, most of the phosphorous in traditional fertility management is supplied via the compost and livestock manures. Unlike nitrogen, phosphorous is either available or absent from the soil. It cannot be produced locally. If soils are deficient, phosphorous must be added to the soil. Forest and grazing lands, through grass and fodder production, feed livestock which in turn provide manures to sustain the phosphorous levels required for agricultural production. Without these sources to replace the losses from the nutrient pool, phosphorous levels would continually decline to the point that profitable agriculture would no longer be possible.

In 1989, 40,000 tons of NP complex (8,000 tons of elemental phosphorous) was imported as chemical fertilizer. At the traditional low levels of production, phosphorous deficiencies are usually not apparent. With increasing nitrogen use and higher yields, phosphorous soon becomes limiting to crop production. With increasing use of nitrogen, whether biologically fixed or imported from outside Nepal, phosphorous will become an increasingly deficient element. Its role in future fertilizer management strategies is critical.

Potassium. While potassium is a major element required for plant growth, Nepalese soils are generally endowed with high base levels of potassium and major deficiencies are not readily observed. Sherchan et al. (1991) considered that until phosphorous deficiencies are met, chemical potassium fertilizer will not be required. Only with increasing intensity of production of certain horticultural crops (such as potatoes and bananas), and higher targetted yields, will potassium become a significant constraint to production.

Calcium, Magnesium, and Sulphur. As yet there is little indication that calcium, magnesium, or sulphur are limiting to plant growth in Nepalese soils. It is anticipated that with increasing use of the major elements through chemical fertilizers, these minor elements will commence to be increasingly deficient in Nepalese soils and supplements will be required. At present compost is providing all these elements that plants need.

Micronutrients. If compost fertilizers are provided in adequate amounts, the micronutrient elements rarely become deficient. However, with the increasing shortage of compost, the introduction of plantation and orchard systems, and the lack of use of compost materials, micronutrient deficiencies are increasingly being recognised. It is generally more instructive to think of the soils as being mismanaged rather than deficient in micronutrients. To date, micronutrient deficencies (including zinc, iron, manganese including zinc, iron, manganese, copper, molybdenum, and boron) have been reported in both agricultural and forest soils. Horticultural crops (in particular apple and citrus trees) have been known to respond to a foliar spray containing combinations of micronutrients at a number of locations in Nepal. In the Western Development Region at Lumle, molybdenum was shown to significantly increase yields of grain crops when added in small amounts directly to the seed. As more work is done on micronutrients, many more deficiencies (including zinc, iron, manganese, copper, molybdenum, and boron) pertaining to specific crops will be recognised. Given the nature of the problem it is recommended that foliar analysis be used rather than soil sample analysis, because what the plant roots are in contact with may or may not relate to what the plant actually can take up.

Organic Matter. While organic matter is considered here as a component of the soil, it has a far reaching effect on many aspects affecting soil management and sustainability. Organic matter plays a dominant role in nitrogen supply and, to a lesser extent, in phosphorous, sulphur minor, and micronutrient supply. Higher soil organic matter levels improve infiltration rates and water-holding capacity. This, in turn, has a positive effect on reducing surface runoff and limiting soil erosion. Organic matter can ameliorate the negative effect of low pH, as well as problems caused by having too coarse or too fine a texture. Additions of organic matter will increase the cation exchange capacity, break up surface crusts, improve the tillage after ploughing, serve as a mulch to cushion soil from high intensity rainfall, and provide a substrate in which micro-organisms can maintain high activity, thus releasing nutrients tied up in the mineral soil. The amount of organic matter in a soil is dependent on the ecological zone in which it occurs, as well as on the land use and management of the soil. Levels of organic matter on cultivated soils below 2,000 metres range from 0.5 to 3 per cent and average just under 1 per cent. Forest soils tend to be 1 or 2 per cent higher. Above 2,000 metres, climatic and vegetation changes are quite dramatic, and the soil organic matter content increases by 2 to 3 per cent for both agricultural and forest soils. This is because decomposition rates are lower and litter production is higher in the less disturbed, cool temperate forests. Because of their cooler temperatures and wetter conditions, north facing slopes have higher organic matter levels than south facing slopes. Areas under natural forest have considerably higher organic matter levels than those cleared for cultivation. Newly-opened forested areas in the *Terai* may have levels of 4 or 5 per cent organic matter on initial clearing; but, generally, after a few years of cultivation, the levels have dropped to less than 2 per cent.

Organic matter quality, which is crucial from the perspective of plant productivity, is, as yet, poorly understood - particularly with respect to Nepalese soil fertility management. This will be covered later in the discussion on fertility management.