Chapter II

Literature Review

Geology, physiography and farming systems are important determinants of soil types and the soil types in turn to soil fertility, so this review will start with a brief look at geomorphology, soils in Bhutan and farming systems in Bhutan. Soil fertility management studies including that of sources of manures in the context Bhutanese agriculture will follow. Towards the end of the review comparative studies on farmers' practices and technical methods will be presented.

2.1 Geomorphology of Bhutan

To have an overview and understanding behind things like physical features, landforms and soils in Bhutan, it is important to look at its physiography. The main geological overviews of the whole Bhutan are in the works of Gansser (1983) and Bhargava (1995). Bhutan is mostly underlain by high-grade metamorphic rocks, predominantly gneiss, with subordinate quartzite, schist and marble, which were emplaced in a series of southward and eastward thrusts (Bhargava, 1995). Lithologically, Bhutan is more homogeneous, and the gneisses stretch southwards almost to the piedmont. Gneisses underlie more than 70% of the country (D.G.M., 2001)

Baillie & Norbu (2004) analyzed the longitudinal profiles of main rivers, interfluves and relief features of Bhutan. In another study, Norbu *et al*. (2003) summarize the provisional physiographic zonation of Bhutan.

The main influence in shaping the landscape of Bhutan has been reported to be as the result of the upliftment of the Himalayas following the collision of the Indian and Asian continental plates giving rise to the basic topographic structure of the country with the High Himalaya in the north from which long ranges formed of metamorphic rocks run southwards and then descend steeply to the Duars. The main valleys and mountain ranges follow more or less north-south course (Figure 4). All the valleys have narrow gorge-like sections in the South but vary in the sections upstream. In western and central Bhutan the riverbeds have stepped profiles and the flatter sections form Inner Valleys with relatively gentle side slopes and wide floors at altitudes ranging from 1,100 m at Wangdi to 2,600 m at Jakar. The rivers in the east are cut deeper, and their valleys are narrow and steep throughout unlike in western and central regions. This structure forms the basis of the proposed provisional zonation, which divides Bhutan into transmontane plateau, High Himalayan peaks, High Himalayan plateau remnants, North- South valleys and ranges, front foothills and Duar areas.

However, the previous zoning study tends to treat Bhutan as an eastwards extension of the Central Himalayas, and characterize the kingdom mainly as a series of East-West trending altitudinal belts (Eguchi, 1987, cited in Norbu *et al*., 2003 and Baillie & Norbu, 2004).

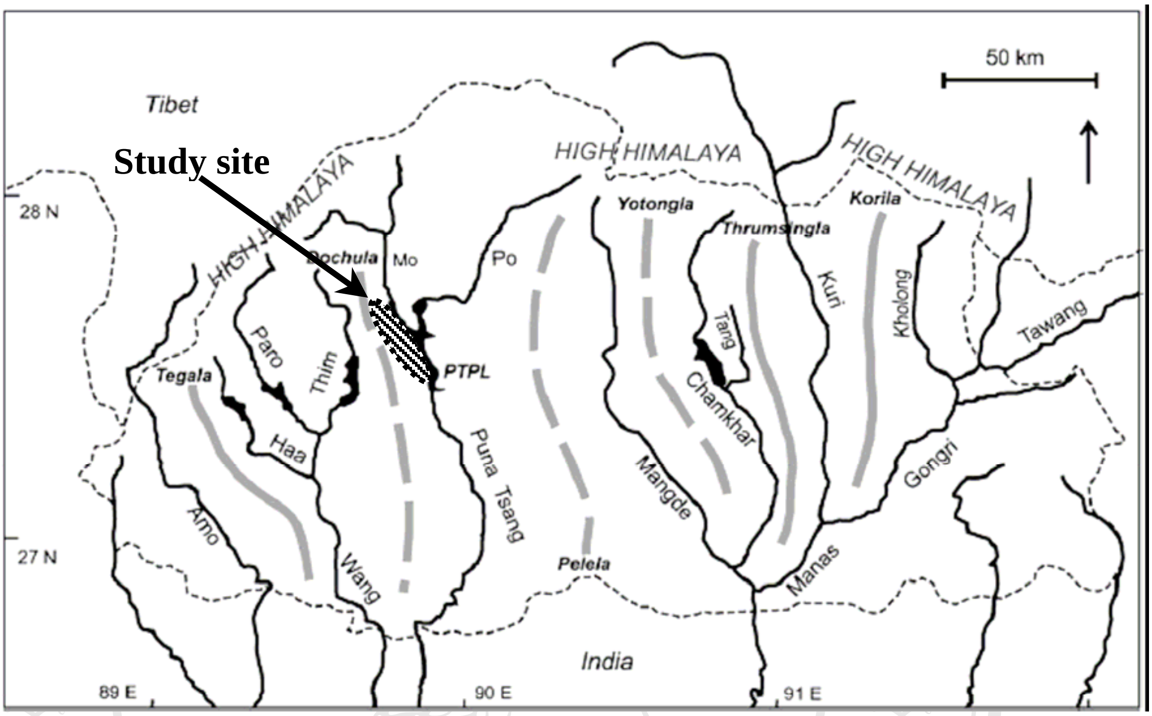

Figure 4. Main N–S rivers and ranges (in shades) of Bhutan, showing inner valleys (solid black)

(*Source*: Baillie & Norbu, 2004).

The physiographic concept has been used on a smaller scale by the Wang Watershed Management Project (WWMP) integrating the land resources within the project area. The four districts of Thimphu, Paro, Haa and Chhukha (15% of Bhutan's land area) were mapped as 29 land systems and one land region. Each land system consists of a landscape type with a limited range of variation in bedrock and surface geology, landform, climate and hydrology, soils, and natural vegetation. This environmental combination determines the range of agricultural and other livelihood options. The land systems mapping enabled identification of areas vulnerable to specific types of environmental degradation, including landslides and soil acidification (Baillie, 2002).

The dominant topographic features are the High Himalaya, close to the northern border, and the large mountain ranges and deep valleys that run southwards from it, main rivers, therefore, flow in north-south direction too, some originating beyond the northern borders (Figure 4). The crests of the main N-S ranges are uneven and rugged, but are reported to have long stretches concordant at 3,500 – 4,500 m. The southern ends plunge down to rugged foothills and the alluvial plains of Assam and Bengal. Several of the ranges in the west and centre of the country (from Dochula to Yotongla) are broken at several points the middle parts and the ranges rise up again to the south (Baillie & Norbu, 2004).

2.2 Soils in Bhutan

Soils are greatly influenced by the nature of the surface materials, with distinctly different groups formed in glacial and periglacial deposits, colluvium, debris flows, main river alluvia, and windblown material. Various combinations of these result in a high proportion of layered profiles, in which recent deposits bury older soils. There are also altitudinal variations in the processes of soil formation, so that distinctive types of soil profiles are formed in the main ecoclimatic zones (Norbu *et al.*, 2003*)*. The main trends are for leaching, acidification and podzolisation to increase with altitude, together with the slower decomposition and greater accumulation of organic matter (Baillie *et al.*, 2004). Over two thirds of the land cover is classified as forests. Temperature and altitude appear to be the most important determinants of the forest types, which range from subtropical mesic rainforest in the wet southern foothills up to about 1,000 masl., through warm (1,000 –2,000 masl) and cool (2,000 – 3,000 masl) temperate broadleaf forests, and mixed conifer forest at 3,000–3,500m, to subalpine East Himalayan silver fir forest at 3,500 – 4,000 masl. Precipitation and moisture supply are also significant, and the altitudinal sequence is clearest in moist areas (Norbu *et al.*, 2003).

The southern foothills of the Eastern Himalayas are seismically active. Local relief is often over 3,000 masl and slopes are long and steep. Although Bhutan is located in a seismic window and is relatively quieter than many other sectors of the Himalayas (Gahalaut and Kalpan, 2001), there are still frequent minor earthquake tremors. These combine with the high relief and the heavy and prolonged rainfalls to render many soils and regoliths unstable, so that there are large areas of recent landslip deposits. The instability of much of the regolith means that few soils have developed mature and pedogenically horizonated profiles. However, there are limited areas of stable soils, and these are deeply and intensively weathered. They have pH values below 5, base saturations below 25%, aluminium occupies more than 50% of the exchange complexes, and some have subsoil argillans (Baillie *et al.*, 2004). “There are no traces of pedogenic carbonates, even in sites with restricted drainage. As most of the soils are under broadleaf forest, their topsoils have of organic carbon contents in the range 2–6% and C:N ratios below 20. This combination of features is characteristic of soils formed in moist conditions, with substantial surpluses of water available for mineral weathering, nutrient leaching, and the decomposition of organic matter. The vigorous dynamics of these landscapes makes it unlikely that the soils are relict. The soil characteristics developed in current conditions, and not in moister palaeoclimates. The data are still sparse, but there are no indications that the soils of the southern foothills in Eastern Bhutan are less weathered or leached than those further west. There are substantial areas of moderately stable regoliths on the slopes of the inner valleys. The soils have had longer to develop than those in the south, and deep weathering, to more than 5 m, is found at altitudes of up to 4,000 masl. However, the moderate rainfalls mean that leaching is only moderately intense, so that the soils retain some chemical characteristics from their parent materials. The soils from granites and gneisses tend to be moderately acid (pH, 6), and have base saturations below 60% and some labile aluminium, whilst limestone, amphibolite, and calcsilicate soils are of neutral pH and are fully base saturated, with no labile aluminium” (Baillie *et al.*, 2004). A study done for north Indian state of Arunachal Pradesh, which is located East of Bhutan and on the northeastern part of Himalyan range has describe the soils as lnceptisols (37 percent), Entisols (35 percent), Ultisols (14 percent), Alfisols (0.5 percent) and the remaining be as miscellaneous (Maji *et al*., 2001).

Baumler *et al*. (2005) found widespread distribution of andic and spodic soils at altitudes between 2,200-3,500 masl in Central Bhutan, which have always been regarded as restricted to small areas. But they have developed in nonvolcanic and nonallophanic conditions and are without typical Podzol eluvial and illuvial horizons.

Caspari (2004) has analyzed the relevance of Bhutan's soil resources in the context of its development philosophy of Gross National Happiness and the relationships between them are presented in Table 3. The relationships show that soil is an important component of not only of natural environment but have direct significance to the development approach that the Royal Government has seriously embraced and pursued.

Table 3. Soils and their relevance to Gross National Happiness

GNH Constituent	Relation of soil to GNH
Economic development	- Soil fertility = "natural capital" - RNR sector made up 33% of the GDP in 2002 - Policy of self reliance - Care of the soil contributes to well managed HEP and national wealth
Promotion of cultural heritage	- "Agri-culture"(e.g. land use techniques) - Belief in deities (*kLu*)
Environmental preservation	- Integral part of ecosystem
Good governance	- Equivalent of "good farming practice" - Concept of "sustainability"

(Source: Caspari, 2004).

2.3 Farming systems in Bhutan

There is a considerable variation in climate, topography and altitude within a small area which give rise to diverse farming systems in Bhutan. According to Ya and Tulachand (2003), Bhutan falls within the five principle agricultural systems: pastoral, agro-pastoral, food grain crops dominated, horticultural crops led and shifting agriculture as it is located in the Hindu-Kush Himalayan region. Upadhyay (1995) has classified farming in Bhutan into three broad categories: pastoral-transhumance system, subsistence-level crop and animal husbandry, and pre commercial farming. Pastoral or pastoral transhumance system comprises of 100% livestock being reared by semi-nomadic people at the altitudes of 2,400 to 4,500 masl, often referred to as 'yak zone' of Gasa, Merak and Sakten including some parts of Bumthang, Paro and

Haa districts. In agro pastoral system, livestock production is supplemented by subsistence food production and is practiced in high altitude districts.

Farming is highly diversified, integrated and interdependent between cereal crops, horticultural crops, livestock and forestry activities. It is generally subsistence in nature. Production is consumed by farmers themselves and very little commonly traded commodities are rice, fruits, vegetables and dairy products. Composition of crop and livestock varies dramatically over the country, and even from village to village (Wissink, 2004) and this system is sometimes referred to as high land mixed farming (Weatherhogg *et al*., 2001).

Maize and rice are most important staples of Bhutan. These staples are grown either sequentially or intercropped with other crops like wheat, millet, buckwheat, mustard, pulses, fruit trees, and vegetables. Following sections will elaborate on maize systems, rice systems and shifting agriculture systems followed by *sokshing* woodlots systems to highlight and capture the big picture of farming in Bhutan.

2.3.1 Maize systems

Maize is the most important cereal in terms of both area and production (LUPP, 1995). It is cultivated mostly on dry land at elevations up to 2,600 m. Maize is grown mostly in eastern and southern Bhutan. Maize is usually grown in combination with other crops, mainly soybeans, wheat, barley, beans, potatoes, pumpkins and *Vigna* species in inter-cropping and sequential cropping systems (Roder and Gurung, 1990). The choice of associated crop species grown with maize depends on the elevation, rainfall and levels of soil fertility (Roder *et al.*, 2001). The same factors together with the type of other crops grown as intercrops with maize or in rotation with maize determine the length of the fallow period while in a shifting agriculture. Maize is a major source of fodder for livestock. Livestock are generally allowed to graze in the fields right after the maize cobs are harvested. This practice contributes to a fast recycling of nutrients through livestock manure (Rinzin and Roder, 2002). Typical maize growing systems in Bhutan is presented in Table 4.

Table 4. Typical maize growing systems in Bhutan.

System	Importance (% of total maize area)	Altitude (masl)
Maize-maize (often inter-cropped with beans, soybeans, or *Vigna* species.)	20	<1,000
Maize-paddy	<5	<1,000
Maize-wheat or barley	25	900-2,000
Maize-buckwheat	10	900-2,400
Maize (often inter-cropped with beans, soybeans, or *Vigna* species)	30	1,500-3,000
Maize inter-cropped with potato	<5	1,500-2,700

(Source: Roder and Gurung, 1990).

2.3.2 Rice Systems

Traditionally in the past, single rice cropping system was the most dominant cropping system but rice-wheat, rice-mustard and rice-vegetables cropping system is increasingly taking place because of development intervention (Chettri *et al*., 2003). Rice-rice and rice-potato/chilli are also seen in some parts of the country especially in warm valleys and temperate region respectively. Rice growing areas, its yield and production by agro-ecological zones and districts is presented in Table 5.

Table 5. Rice area, yield and production by agro-ecological zones and districts

Agro-ecological zones	District	Area (ha)	Yield (ton/ha)	Production (ton)
Warm temperate	Thimphu	1,595	4.5	7,178
	Paro	2,323	3.5	8,131
Dry sub-tropical	Wangdue	3,905	3.5	13,668
	Punakha[1]	3,209	3.5	11,232
	Trongsa	1,942	2.1	4,078
	Trashigang	1,639	2.4	3,934
	Lhuentshe	933	2.3	2,146
Humid sub-tropical	Tsirang	2,266	1.5	3,399
	Dagana	2,090	2.3	4,807
	T/Yangtse	1,996	2.3	4,591
	Chukha	1,017	1.7	1,729
	Zhemgang	1,101	1.9	2,092
Wet sub-tropical	Sarpang	4,474	2.0	8,948
	Samtse	6,208	1.9	11,795
	S/Jongkhar	2,162	2.5	5,405
Total / Average		36,860	2.7	93,133

(Source: DRDS, 2001c).

[1] study area is under this district

Nearly 90% of all rice production is in single rice cropping system. It is planted mainly in June-July and harvested in October-November. As presented in Table 5, rice is grown in four agro ecological zones (Ghimiray, 2003). With crop intensification, issue of nutrient management has become crucial and farmers have no alternative other than supplementing the nutrient requirement by using chemical fertilisers (Chettri *et al*., 2003). Farmers in many parts of the country still grow single rice crop with their local varieties as the local varieties required less inputs. Grain quality of improved varieties are unacceptable to farmers and also have less straw needed to feed cattle (Thinley *et al*., 1999).

The area under paddy had decreased by nine percent during the period spanning from 1989 to 1997, but overall production of rice in the country increased by 58 percent during the period (Shreshta, 2004) and the increase could be the impact of agricultural technologies dissemination.

2.3.3 Shifting agriculture systems

In the highlands of Bhutan shifting cultivation remains an important land use practice. Two systems, slash and burn bush fallow (*tseri*) and grass fallow (*pangshing*) are practiced and these systems are well adapted to available resources (Roder *et al*., 1992). In 2000, 27 percent of Bhutan's total agricultural land area was under *tseri/pangshing* systems. It is commonly practiced in the east and east-central *dzongkhags* including Chhukha and Samtse. Fifty percent of the households in the country still practice *tseri/pangshing* cultivation (MoA, 2002). In *tseri* system, the vegetation, consisting of trees, shrubs, other perennials and annuals, is cut during the dry season, allowed to dry and burnt shortly before sowing the crop seeds. Seeds are sown by either dibbling or broadcasting. *Tseri* system is declining as the Royal Government is making efforts to replace it with other farming systems. The main crops are maize, millet, rice, and buckwheat. In *pangshing* system, the fallow vegetation evolves after abandonment of cropping, and persists under grazing. It is composed of mainly short grasses, sedges and forbes, and is often interspersed with blue pine trees in the cool temperate zone. Over the last two decades, many farmers have sown legume-grass mixtures on *pangshing* as recommended by the Ministry of Agriculture (Rinzin and Roder, 2002).

2.3.4 Sokshing woodlots provide leaf litter for manure

According to the Bhutan Forest Act 1969 and the Forest and Nature Conservation Act of Bhutan 1995, forests in Bhutan include all such areas that have not been registered as private land (RGoB, 1969 and 1995). However, based on use and property rights arrangements, two types of forests are registered in the name of a household as *sokshing* and *tsamdrog*. *Sokshing* is a woodlot or forest usually located next to a village or human settlement to be used as a source of leaf litter and fodder. *Tsamdrog* is a grazing land. Households have no legal right over the trees and land in these two categories of registered plots. Many households in rural villages of Bhutan possess and maintain certain plots of forestland as *sokshing* that are utilized for collection of leaf litter. Leaf litter is used as cattle bedding, which when mixed with cattle excreta produced organic farm manure that is applied to agricultural fields.

Though, a labor intensive practice, it is known to increase water retention capacity, improve soil properties and fertility. It is also advantageous to add organic materials to soil if diseases or pests do not infect material sources (Norbu, 2000).

Besides leaf litter, *sokshing* provides with other the basic forest product needs, and contributes to the sustainability of agricultural production of the local communities. Firewood, construction timber and fodder can be obtained from *sokshing*. The leaf litter collected from the *sokshing* is used as bedding material for the livestock. The dead leaves not only decompose and form high quality manure but also a comfortable bedding for cattle during the cold winter months. The manure that results is one of the best sources of organic fertilizer for agricultural production. Leaf litter of oak or pine mixes very well with the dung to form one of the most effective and safe manure. This sustains the agricultural production and thereby the livelihoods, particularly of the poor farmers who cannot afford to buy chemical fertilizer. Therefore, the institution of *sokshing* can be considered as important element of low input with high level of sustainability (Wangchuk, 2001).

The s*okshing* holding can differ from village to village and region to region. A study on *sokshing* was conducted by Wangchuk (2001) in a *geog* each in three regions, Radhi *geog* in the East, Chumey *geog* in East-central and Shaba *geog* in West. Average *sokshing* holding per household from the study is presented in Figure 5. On national level, the farming communities have user rights over 7,265.88 ha *sokshing* (MoA, 2003). It is a prevailing feature for many farming households to own s*okshing* plots as the source of leaf litter for making manure that helps in maintaining soil fertility.

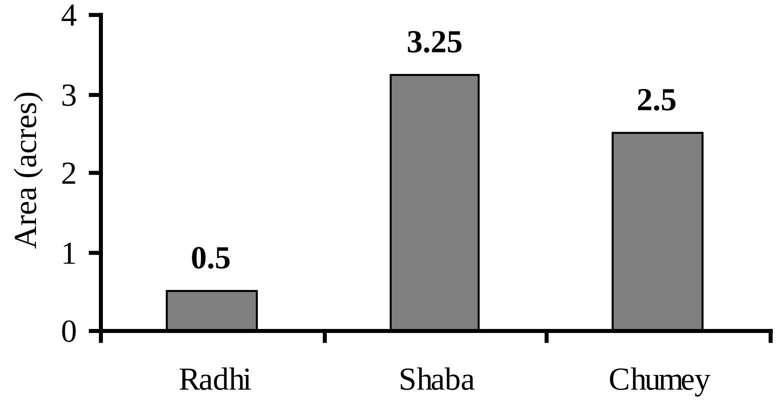

Figure 5. Average *sokshing* holding per household

(Source: Wangchuk, 2001).

2.4 Soil fertility

Soil fertility can be defined broadly as the chemical, biological and physical factors that influences productivity (Scoones and Toulmin, 1999). Chemical factors are the content of macronutrients and micronutrients in appropriate forms, soil pH, cation exchange capacity and base saturation; biological factors include soil flora and fauna; and physical factors include soil texture, tilth, color, bulk density, stoniness, and so on. A quantitative knowledge on the depletion of plant nutrients from soils helps to understand the state of soil degradation and may be helpful in devising nutrient management strategies. Nutrient-balance exercises may serve as instruments to provide indicators for the sustainability of agricultural systems. Nutrient-budget and nutrient-balance approaches have been applied widely in recent years (FAO, 2003). A methodological approach is used by the International Fertilizer Development Center (IFDC) to estimate nutrient balances, depletion rates and requirements combines information on agricultural production, soil characteristics and biophysical constraints with methods and procedures designed for making such estimates (Henao and Baanante, 1999).

2.5 Soil fertility management practices in Bhutan

2.5.1 Use farmyard manure for soil fertility management

About 45% of the fodder requirements for Bhutan's herbivorous livestock is met through grazing in the forest or on permanent grassland, while grazing on fallows, crop residues and browse provide 15%, 20% and 20%, respectively (Roder, 1990). Use of FYM and other organic matter sources like crop residues and leaf litter is the major source of plant nutrients in Bhutanese agriculture. FYM continue to be the single most important source of soil nutrients with at least 139,000 MT applied to cereals and horticultural crops in year 2000 (MoA, 2002). In general the soil organic matter is the key indicator of soil fertility, which controls the physical, chemical and biological properties of soil and so FYM and other OM matter sources essential to be applied to soil.

A baseline survey on use of FYM in Punakha-Wangdue was conducted by RNR-RC, Bajo providing good agronomic information but lacked the information on quality and quantity applied (RNR-RC Bajo, 1994). Other studies on soil fertility management like Roder (1993) provided the useful information on FYM and its use was not examined as FYM was not the focus of the study. Despite its national importance, documentation particularly with regards to the quantity and quality applied by farmers was lacking (SSF and PNM project, 1996) until recently when RNR-RC and SSF and PNM Project conducted a household survey in the Lingmuteg Chhu Watershed (DRDS, 2001b). The amount of FYM applied depended on the frequency of of application rather than the unit rate of application. Farmers' in the watershed was found applying FYM at the rate of 7,750 ± 640 tones per ha. The mean FYM dry matter content was reported to be 50 % with dry matter nutrient contents of 1.38% N, 0.29% P and 1.97% K. This is equivalent to 53 kg N/ha, 11 kg P/ha and 75 kg K/ha (DRDS 2001b). Chettri *et al.* (2003) tested on-station, if farmers' practice of applying of seven t/ha of FYM is adequate to maintain fertility and yields. It maintains soil organic matter levels, though it does not provide with adequate P. The practice is reported to be adequate to produce stable rice paddy yields of 4–6 t/ha/annum.

The shortage of household labor to produce and apply FYM is the major factor limiting its use, and as labor availability will continue to decline, the opportunity cost of FYM use is predicted to continue to increase (DRDS, 2001b). This will, in turn, lead to increased dependence on alternative manuring practices such as the use of fertilizers, especially urea, as it is economically most attractive option (Chettri *et al*., 2003). The study by Norbu and Floyd (2004) has found that indigenous soil fertility management system based on livestock manure have been undermined by socio-economic factors and farmers are increasingly depending on fertilizer, mainly urea, in Bhutan.

2.5.2 Fertilizers and others sources of nutrients for crop production

The survey conducted by the Sustainable Soil Fertility and Plant Nutrient Management Project (SSF & PNM, 1998) in Punakha on fertilizer use by farmers in 1998 confirmed that use of fertilizer in rice is widespread (91% of household surveyed) but that farmers commonly used only urea, and that they apply it as a top-dressing once the crop is well established. This means:

- firstly, that farmers might not be deriving optimum yield and economic benefit from their use of fertilizers, with an associated loss in production and,
- secondly, that there would be potential long term negative impacts on soil properties and soil nutrient status.

Following the fertilizer use survey the Farmer-Extension Fertilizer Use Trials (FEFUT) in Punakha and Wangdue-Phodrang was conducted in 1999 crop season to implement participatory technology development with farmers to determine economically beneficial production through balanced fertilizers and timing of fertilizer application. The results showed a significant yield increase of the ‘Recommended Practice’ of balanced fertilizer use over the ‘Farmers’ Practice’ of using no fertilizers or urea only of respectively 17% and 28% (DRDS, 2001a). In another survey (DRDS, 2001b), urea was reported as being used by 51% of surveyed farmers in rice and by 41% of farmers on wheat, and other fertilizers were rarely used. One of the recommendations that emanated out of the FEFUT in Punakha and

Wangdue is determine soil nutrient status to get relation of fertilizer responses to soil nutrient status and fertilizer recommendation could be refined across soil types and soil conditions (DRDS, 2001a). Farmers are increasingly depending on fertilizer, mainly urea, due to socio-economic factors (Norbu and Floyd, 2004). The Soil Fertility Unit of the National Soil Services Center (NSSC) works directly with farmers and extension on FEFUT trials, farmer-extension training so as to refine/develope fertilizer recommendations for major crops and to study fertility trend on major traditional farming systems.

An experiment conducted for eight years by Chettri *et al*. (2003) compared the effects of farmyard manure application, pre-rice green-manuring with *Sesbania aculeata* and fertilizer application in a rice-wheat rotation. The application of seven tonnes farmyard manure per hectare to both the rice and the wheat crops over eight years increased organic carbon levels from 1.4 to 1.6% but had no yield effect on either crop. P application through farmyard manure was not adequate for rice, whilst an application of 34 kg P/ha to the rotation gave an economic yield increase only in rice and then only in the first four years of the experiment. Green manuring had no effect on the wheat yield but the recommended fertilizer application increased yield. Green manuring increased soil total N and available K levels and reduced base saturation.

2.5.3 Burning practices to release P

Status of available P in the soils of northern Bhutan is extremely low (Roder *et al*., 1992). Burning of topsoil to increase the availability of P and burning of manure to reduce bulk and speed up the release of P (Norbu *et al*., 1996; Roder, 1990; Roder *et al*., 1993) as burning reduces C:P ratio to less than 200 facilitating net mineralization of organic P and there may be net immobilization of P above C:P of 300. These practices are ingenious ways designed by Bhutanese farmers to optimize the use of the limited P pools as the soils are poor in P (Rinzin and Roder, 2002).

2.6 Soil fertility status of soils in Bhutan

Soil analysis indicates the levels of different nutrients available from the Bhutanese soil are typically low in total N, very low in available P and adequate or suplus in available K (DRDS. 2001a). A national soil fertility management survey was carried out in 1999/2000 in a total of 32 villages representing the farming systems with the soil samples being collected from 380 fields. The main fertility features found in the Bhutanese soils from the study are (Norbu and Floyd, 2004):

- Nearly half of all samples had low or very low pH (i.e. pH <5.5), only 15% of samples had exchangeable Al levels in high or very high categories. Except for some lowland subtropical soils, Al toxicity is of limited concern.
- Total and organic C levels were generally adequate although total N levels were low or very low (<0.2%) in 40% of samples. Due to the very low or low total N levels, C:N ratios are favorable (i.e. low or very low [<19]).
- For available P (Bray) and K, 50% of the samples were rated low or very low (<5ppm P and <40ppm K). Of these, low available P is of greatest concern as soil parent materials are generally K rich and this is reflected in predominantly moderate to high levels of exchangeable K.
- The major area of concern is base nutrition and particularly the imbalance between exchangeable bases. Base saturation and total exchangeable base levels are low or very low (>70% of samples).

Though the Bhutanese soil are typically low in total N, very low in available P and adequate or surplus in available K in general (DRDS. 2001a), the nationwide survey results show that many soils are in low or very low classes in available K (Norbu and Floyd, 2004). In the recent soil fertility surveys in Khaling and Drametse *geogs* of Eastern Bhutan too, status of available P is found to be in low class in most villages, while available K is low in some villages and in some villages both available P and K are found to be in the low class (SFU, 2005a; SFU, 2005b). To have an idea of the study area soil nutrient statuses some orchards (topsoil) in Punakha district, under which is Guma *geog*, is presented in Table 6.

Table 6. Nutrient statuses some orchards (topsoil) in Punakha Dzongkhag.

Location	pH (H_2O)	Total N%	Available P (ppm)	Available K (ppm)	Organic C%	Source
Major citrus orchards in Punakha	mostly high and mod.	-	> 30 (high)	ranges from low to high	mostly mod.	NSSC *et al*., 2002
Ritcha[1]	7.23 (high)	0.14 (low)	32.40 (high)	115.60 (mod.)	2.00 (mod.)	SSU/NSSC, 2003
Dabchegang[2]	6.10 (mod.)	0.07 (v. low)	7.90 (low)	56.58 (low)	0.88 (low)	BSS/NSSC, 2005

[1] mean values for a young mango orchard

[2] mean values for a mature orange near Punakha Dzong

The soils have moderate to high pH and this could be due to the added materials such as ash and FYM rich in bases (NSSC *et al*., 2002). With the exception of Dabchegang orchard, the status of organic C, available P and K are mostly in moderate to high level and this could be due to incorporation of FYM and leaf litter in the soils. Farmers largely depend on FYM application (73%) and only 17 per cent depend on chemical fertilizer to provide required nutrients for citrus crops (NSSC *et al*., 2002), unlike in paddy (91% of household surveyed) where chemical fertilizers mainly urea, is applied (SSF & PNM, 1998).

2.7 Land degradation

Owing to extremely mountainous terrain and altitude, Bhutan has inherently limited resources of productive land. The steep slopes in topography has put the limited resources at risks from several forms of degradation, so land degradation is a serious threat in Bhutan than elsewhere. Various types of erosion, waterlogging, river process-caused, *in situ* chemical and physical land degradation are some of concerns in Bhutan (Norbu *et al*., 2002). Table 7 shows the main *in situ* chemical land degradation types in Bhutan that are of particular concerns to soil nutrients which affects crop productivity. The *in situ* chemical degradations types are: reduction in soil OM, depletion of nutrients, soil acidification, and pollution (Longan, 1990).

Table 7. Main *in situ* chemical land degradation types in Bhutan.

Effects	Interactions with other types of degradation and natural hazards	Triggering & intensifying human activities	Occurrence in Bhutan
1. Depletion of soil organic matter			
-Lighter topsoil colours -Reduced soil reserves of moisture & nutrients -Reduced crop cover & yields -Soil structures weakened -Soils harder & more difficult to cultivate -Reduced soil biodiversity	Intensifies: - Nutrient depletion - Acidification - Erosion	-Some depletion inevitable when forest or grassland converted to arable -Offset by organic fertilisers	Most acute on wet land Also in dry land or short fallow *tseri*
2. Depletion of Nutrients			
-Deficiency symptoms -Reduced crop yields and plant cover -Increased susceptibility to pests & diseases (remove)	Intensifies: - Acidification - Erosion	-Excess harvest off-takes without fertilizers -Burning and wind-blow of ash	Widespread (intensively cultivated areas)
3. Soil Acidification			
-Drop in soil pH -Possible P, K, Ca & Mg deficiencies -Decreased nodulation in legumes	-Reduces availability of nutrients & induces deficiencies -Possible nitrate contamination of streams	-Nutrient depletion (Ca, Mg) -Excessive N fertiliser	-Less likely in soils with limestone derived from limestone, e.g. Paro -Excess urea on some maize and rice -No reports so far in Bhutan of nitrate or nitrite toxicity in streams
4. Over-fertilization			
-Induced deficiencies of other nutrients	-Possible eutrophication or contamination of streams	-Excessive P fertilizer (potato and apple crops)	-Possible excess P fertilizer applied to apples in W Bhutan -Eutrophication unlikely in fast flowing streams. -No lakes in Bhutan appear to be vulnerable

(Source: Norbu *et al*., 2002).

The most widespread *in situ* chemical degradation in Bhutan is the depletion of soil organic matter and pollution with industrial wastes are very limited so far in Bhutan (Norbu *et al*., 2002).

2.8 Soil mapping and uses

2.8.1 Spatial distribution studies on soil

Systematic and formal study on soil survey in Bhutan started only in 1996 with set up of, the then, Bhutan Soil Survey Project, now Soil Survey Unit under the National Soil Services Center in Semtokha. The project or unit have undertaken a number studies on spatial distribution of soil characteristics, both at semi-detailed (e.g., BSSP, 1999a; BSSP, 1999b) or detailed level for land areas of RNR-RCs of Yusipang, Bajo, Khangma and Wyengkhar, Royal Botanic Garden, Serbithang, Darla RNR sub-centre, Bhur farm, and so on (BSSP, 2004). Coverage by these studies is mostly for small land areas and are done for different purposes; BSSP, 1999a and BSSP, 1999b; for examples, were basically done to train staff in soil survey and whose output also could be put into meaningful use. Others were done to help RNR and other institutions make informed decisions from the soils point of view (e.g., BSSP, 1998; BSSP, 1999c). However, soils maps for use in RNR extension in *geogs* and districts level are few although all need-based services especially for farming communities on soil are provided by the NSSC.

Soil fertility study by Mandal (2002) for Mahottary district in Nepal used GIS to analyze spatial distribution of different nutrient statuses. In general, the district was poor in soil nutrients and corrective measures like application of appropriate amounts of fertilizer and manures suggested. The study could be utilized to recommend crop and soil management strategies.

2.8.2 Land Evaluation

Land evaluation studies using soil information are of recent origin in Bhutan. One of the first such studies is the multidisplinary land evaluation study conducted for the Baap and Thetsho *geog*s under Thimphu districts by Drukpa (1996). GIS was used for mapping and evaluation and it was done as a part of authors' graduate study at the Asian Institute of Technology in Bangkok. Tshering *et al*. (2001) has proposed physical land evaluation for Bhutan. They have used physical attributes of slope gradient, rooting depth, severity of previous erosion, erodibility of parent material, subsoil texture, stone content in topsoil and subsoil, slope form, flood hazard and drainage of land as physical land capability criteria while soil pH, cation exchange capacity and base saturation% as chemical criteria. The proposal is based on FAO land evaluation frameworks and maximum limitation decision rule is applied. The proposed technique is applied to evaluate orchards at Ritcha (SSU/NSSC, 2003) and Dabchegang (BSS/NSSC, 2005) in Punakha amongst others.

2.9 Need for local knowledge to complement scientific research

Research aimed at improving agricultural and natural resources management is likely to be more effective when local people have a voice in their own development and this approach usually means that research must embrace 'indigenous' knowledge (Pretty, 1995) and this is true for the Bhutanese as planning and implementation of development activities are decentralize to the people at the *Geog Yargye Tshogchung* (GYT) or Block Development Committee from 9FYP beginning July 2002 (Planning Commission Secretariat, 2002). The rationale for studying local knowledge about soils is that most progress towards sustainable land management will derive from the synergy of local and scientific knowledge, then integrating or relating the two knowledge systems is a central issue (Payton et al., 2003). Farmers' knowledge of soil fertility may be used in relation with scientific finding to address issues and problems of soil management to produce a locally informed development plans and interventions of relevance to local people (Sillitoe, 1998a). There are a number of studies showing the potential of 'indigenous' soils knowledge to inform, facilitate or modify the application of traditional scientific research (e.g. Pawluk *et al.*, 1992; Habarurema and Steiner, 1997; Sillitoe, 1998b). Talawar and Rhoades (1998) and Ericksen and Ardon (2003) have highlighted similarities and complementarities between indigenous and scientific soil taxonomic systems showing potential synergy, to solve problems related with soil and land management.

2.9.1 Comparative cases of farmers' and technical ways of managing soil fertility in Bhutan

Farmers apply 7,750 ± 640 kg FYM per ha which is equivalent to 53:11:75 kg NPK/ha (DRDS 2001b) against the recommended rate 70:17:17 kg NPK/ha for rice in Punakha-Wangdue valley (FAO, 1990). On-station test at RNR-RC, Bajo was done to find if farmers' practice of applying of seven ton/ha of FYM is adequate to maintain fertility and yields. It maintains soil organic matter levels, though it does not provide with adequate P. The practice is reported to be adequate to produce stable rice paddy yields of 4–6 ton/ha/annum (Chettri *et al*., 2003) which is much higher than national average of 2.7 ton/ha (DRDS, 2001c). This case, remarkably suggest that the technical recommendations and farmers practices are comparable.

Farmers know that burning of topsoil and burning of bulky manure leads to increased fertility and this can be explained scientifically. Farmers' burning of topsoil increases the availability of P and burning of manure reduces bulk and speeds up the release of P. These are ingenious ways designed by Bhutanese farmers to optimize the use of the limited P pools (Norbu *et al*., 1996; Roder, 1990; Roder *et al*., 1993). Burning reduces C:P ratio to less than 200 facilitating net mineralization of organic P and there may be net immobilization of P above C:P of 300.

Norbu and Floyd (2004) in their nationwide survey assessed household perception of changes in the soil fertility status of wet land and dry land for 10-15 years then and their finding of households' perception of soil fertility management ability (SFM) is as shown in Figure 6. Crop yield is reported as main indicator used by the most of surveyed households to assess soil fertility and other indicators reported were soil color, tilth and texture. The study found association between soil fertility and crop yield. However, laboratory results and households' perceptions were not compared in the study.

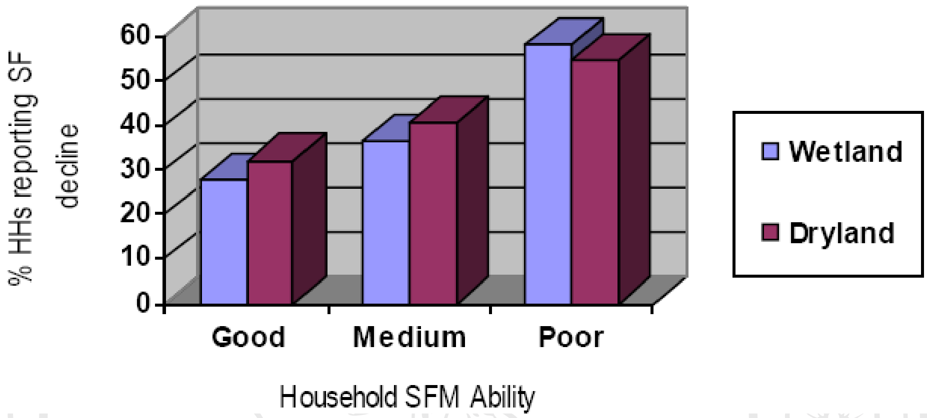

Figure 6. % of households reporting a decline in soil fertility of their wet land and dry land by household SFM ability
(Source: Norbu and Floyd, 2004).

It might of interest to see how farmers' practices compare with technical recommendation in terms of economic measures of performance as farmers would like to maximize profit or spend less. Results of profitability comparison between farmers' practice and technically recommended methods from a rice trial in Wonjokha village of Lingmutey Chhu Watershed is presented in Figure 7 (DRDS, 2001a). Technically recommended methods are more profitable than the farmers' practice. The similar trend is also found from the on-farm FEFUT rice trials in Punakha and Wangdue districts (DRDS, 2001a).

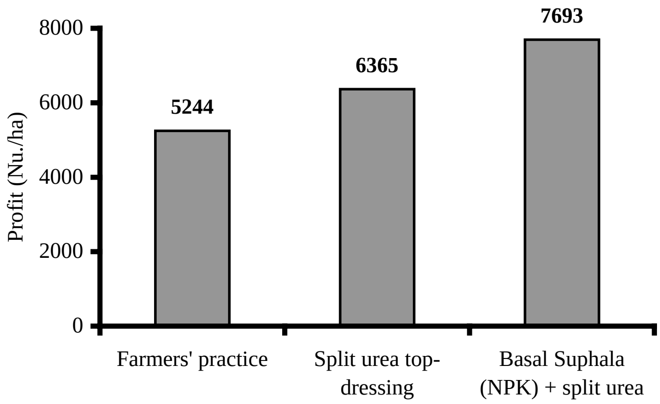

Figure 7: Profitability comparison between farmers' practice and technically recommended methods.

(Source: Adapted from DRDS. 2001a).

2.9.2 Comparative studies of farmers' and technical methods on soils elsewhere

Desbiez *et al.* (2004) compared farmers' perceptions soil fertility and laboratory analytical results for two villages of mid-hills areas of western Nepal. The result of soil laboratory analysis of one of the villages, Upper Pakuwa, is shown in Table 8. They found a strong correspondence between the farmers' assessment of soil fertility and the analyzed fertility characteristics. Fields that were described by farmers as fertile were found on average to have significantly higher values of percentage of OM, total N, available P, and exchangeable K, and a higher pH than those described as infertile. However, this difference was not significant. The data was further analyzed using principal component analysis (PCA). Plotted scores showed clear separation of the fertile and infertile groups, although there was some overlap. PCA1 (predominantly pH and K) and PCA2 (predominantly %N and %OM) were able to explain 69% of the total variation.

Table 8. Soil chemical properties of farmer designated fertile and infertile *khet* and *bari* fields in Upper Pakuwa.

Soil fertility attributes	*Khet* fields		*Bari* fields	
	Fertile	Infertile	Fertile	Infertile
% Organic matter	2.61	1.36	2.91	2.04
% Total N	0.201	0.172	0.216	0.153
Available P (ppm)	36.9	16.2	37.4	15.6
Available K (ppm)	114	84	204	109
pH	4.5	4.5	4.9	4.3
Number of samples *(n)*	9	9	8	8

(Source: Desbiez *et al.,* 2004).

Gray and Morant (2003) discusses local soil knowledge in one small village in southwestern Burkina Faso and relates scientific measures of soil fertility to farmers' perceptions of soil types and changing soil fertility. Farmers' perceptions of soil types and characteristics match up very well with scientific investigations except for soil degradation.

Statistical analysis of physical and chemical properties has been used in many studies to show that local soil classification systems match or reflect scientifically defined soil properties (e.g. Behrens, 1989; Shah, 1993; Krogh and Paarup-Lauresen, 1997).

Close spatial correspondence between scientific soil map units and ethnopedological map units are reported in the study by (Payton et al., 2003). Two contrasting methodologies were used for collection and integration of scientific and indigenous soils knowledge in relation to two interdisciplinary projects involving soil scientists, other natural scientists and anthropologists in two different locations, one in Bangladesh and another in East Africa (north-west Uganda and south-east Tanzania). In East Africa, participatory methods were applied in parallel with scientific soil survey. Indigenous soil classification was explored by a semi-structured, iterative discussion with farmers, resulting in classes to relate to scientific classes. However, the relating farmers' cognitive soil maps to scientific soil maps in the GIS was problematic, and in-depth analysis was only possible through geo-referencing indigenous knowledge. In Bangladesh, ethnographic methods collected local soils knowledge accompanied by scientific surveys. Data processing included database and GIS tools, but it was difficult to systematically relate the two knowledge bases. Such an integrated system would be a useful tool facilitating extension in effectively delivering technologies and services to people.

In a recent study (Barrera-Bassols *et al*., 2005), soil classification system developed by a Purhepecha community in central Mexico was reported as formalized incorporating symbolic, cognitive and practical components. The local soil map units were compared to those provided by a technical soil classification of general scope (USDA soil taxonomy), using spatial analysis within a GIS environment to determine levels of cartographic correlation. The average spatial correlation at high taxonomic level, computed taking into account only the dominant soils in each map unit, is 74% for the technical–local comparison and 75% for local–technical comparison. The similarities and discrepancies between making technical and local soil maps reveal complementarities. Spatial correlation analysis of topsoil properties provides a good basis for collaboration between farmers and soil scientists to formulate sustainable land management schemes.