SOIL FERTILITY, NUTRIENT DYNAMICS AND SOCIO-ECONOMIC INTERACTIONS IN THE MIDDLE MOUNTAINS OF NEPAL

by

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ABSTRACT

Understanding soil fertility issues in the Middle Mountains of Nepal requires interdisciplinary research, integrating biophysical and socio-economic factors. Soil degradation is associated with a wide range of human activities, natural processes, and the wider economic, political and social aspects of their setting. This study focuses on a subwatershed in the Middle Mountains and addresses four research questions: What is the current soil fertility status? How is it changing? Why is it changing? and What are the implications for production, sustainability and management? Soil surveys, plot studies, nutrient balance modelling, household questionnaires and GIS mapping techniques are used to address these questions.

The overall soil fertility conditions of the study area are poor and appear to be declining under most land uses. Soil pH averages 4.8 $\pm$ 0.4 and is below desirable levels for crop production. Soil carbon (0.99 $\pm$ 0.5 %) and cation exchange capacity (10.8 $\pm$ 4.1 cmol kg^{-1}) are low, and available phosphorus (16.6 $\pm$ 18.9 mg kg^{-1}) is a concern given the low pH. Land use is the most important factor influencing soil fertility with khet (irrigated agriculture) showing the best fertility status (pH 5.2, Ca 5.3 cmol kg^{-1} and available P 21.6 mg kg^{-1}), followed by bari, and grassland, with forest soil fertility being the poorest (pH 4.2, Ca 0.9 cmol kg^{-1} and available P 0.7 mg kg^{-1}). Soil type is the second most important factor influencing soil fertility, with red soils displaying significantly lower available P than non-red soils (9.8 versus 22.1 mg kg^{-1}). Phosphorus sorption studies indicate the high P fixation capacity of red soils, 1.2 g kg^{-1} compared to 0.3 g kg^{-1} calculated for non-red soils. Extrapolation from site specific data to a spatial coverage using statistical analysis and GIS techniques indicates that only 14% of the classified areas have adequate pH, available P and exchangeable Ca, and 29% of the area has a high P fixation capacity (>1.5 g kg^{-1}).

Nutrient balance modelling provides estimates of nutrient depletion from the soil pool and raises concerns about the sustainability of upland farming, intensive vegetable crop production and forest nutrient cycling. Dryland maize production results in deficits of 188 kg N, 38 kg P_2O_5 and 21 kg Ca per ha furrow slice.

Rice-wheat cultivation on irrigated land appears to have limited impact on the soil nutrient pool, but the addition of premonsoon maize to the rotation results in deficits of 106 kg N and 12 kg P_2O_5 per ha furrow slice. Rates of soil fertility depletion estimated from differences in soil fertility between land uses indicate substantial N and Ca losses from forest land (94 and 57 kg ha per furrow slice respectively).

Land use change, the impact on nutrient flows and relationships between nutrient inputs, crop uptake, nutrient balances and soil fertility provide an understanding of why soil fertility is changing. Historical forest cover data indicates substantial deforestation during the 1950-1960 period, a subsequent reversal in the 1972-1990 period associated with afforestation efforts, and renewed losses in the 1990s. Forest soils receive minimal nutrient inputs and large biomass removal results in a low soil fertility status. Expansion and marginalization of dryland agriculture were noted from 1972-1990, as former grazing, shrub and abandoned lands were terraced and cultivated. Nutrient fluxes indicate that inputs are insufficient to maintain the soil nutrient pool under dryland cultivation due to the high nutrient requirements of maize and nutrient losses through erosion. Nutrient balances for maize and wheat are positively correlated with nutrient inputs but relationships with soil fertility are weak. On irrigated khet lands, cropping has intensified and cash crop production has prompted the use of agrochemicals. Excess fertilization is leading to eutrophication and the high use of agrochemicals is a health concern. Nutrient fluxes on khet fields appear to be sustainable due to the addition of nutrients through irrigation and sediment trapping, but may be insufficient to maintain triple cropping. Grass and shrub land dynamics are characterized by minimal inputs and low productivity. The traditional farming system appears to have been sustainable, but triple cropping and increased vegetable production are threatening sustainability. The transfer of nutrients within the farming system is unbalanced. Under intensive production, nutrients on khet land are being depleted, poor farmers are shifting their limited compost inputs from bari to khet fields, and biomass collected from forests, disrupts the natural nutrient cycle.

Population growth, land tenure, culture and poverty are the underlying socio-economic factors which influence farming system dynamics, directly impact nutrient inputs, and indirectly drive soil fertility degradation. Population growth rates of 2.6% have contributed to agricultural intensification and marginalization, and pressure on forest resources. The distribution of land is highly skewed with 15% of the surveyed households owning 46% of the land. Women play a central role in soil fertility management through their responsibilities for livestock care, litter collection and compost application, but increasing workloads related to commercial milk production, cash cropping and the off-farm employment of males are a major concern. Agricultural assets, farm gross margins, market oriented production, commercial milk production and off-farm employment provide indicators of economic well-being and are positively correlated with nutrient inputs. Total returns and gross margins are greatest for households growing vegetable crops as part of their rotation, and these households apply significantly more compost and fertilizer to both khet and bari land. Access to land is a key factor driving nutrient management and influencing economic well-being. Land is the main agricultural asset in the study area, khet land is the most productive and khet provides the greatest opportunity of cash crop production. However, given the increased labour demands for triple cropping, vegetable production and commercial milk production, the social sustainability is being threatened. Some 47% of the households were not able to fulfil their basic need requirements from the land they farm. They will have no alternative but to exhaust the capital stock of soil nutrients rather than investing in soil fertility.

Maintenance of soil fertility is essential to meet the basic food and resource needs of the growing population. Organic matter management is critical, supplying macro- and micro nutrients, reducing acidification, maintaining soil structure and enhancing microbial activity. Water management and sediment trapping on lowland fields provide additional nutrients on khet land; soil acidity on upland fields and forest land needs to be better managed given the increased fertilizer use on bari and high biomass removal from forests; and the incorporation of N fixing species into agricultural production systems are an option which may provide additional animal fodder and help sustain soil fertility.

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1. INTRODUCTION

Maintenance of soil fertility is essential to meet the basic food and resource needs of Nepal's rising population. The population of Nepal reached 21.9 million in 1995. In 1961, it was 9.4 million. In response to declining mortality rates, the average annual population growth rate increased from 1.6% in 1961 to 2.7% in 1981 (FAO 1996). Population continues to grow at 2.7% per annum, implying Nepal's food requirements will double in 26 years. The implications of this growth are staggering given that only 16% of Nepal's 140,800 km^2 are suitable for agriculture. Despite Government attempts to increase food production and productivity, official statistics indicate that the growth in food production in Nepal has not kept up with population growth. Per capita food production decreased through the 1960's and 1970's, increased in the 1980's with the introduction of high yielding crop varieties, but has decreased in the 1990's. The total estimated cereal grain production from 1965 to 1990 has increased at an average of 2.2% per annum. This increase in total production is attributed to an expansion of the area under cultivation and increases in cropping intensity, while changes in crop yields have been small. Cropland has increased at an average of 2.2% per annum but expansion has largely occurred on low productivity and steeply sloping sites. To assist in meeting the increasing demand for food, double and triple annual crop rotations are applied where irrigation is available. Agricultural intensification, the use of short growing season crop varieties and the application of chemical fertilizers have helped increase total production, yet food shortages are still widespread (FAO 1996, Biot et al. 1995, Sharma 1993, Chitrakar 1990, Schreier et al. 1991a, Sharma and Banskota 1992, Carson 1992, Dahal 1987).

The Middle Mountains of Nepal make up 30% of the land area, are home to 41% of the country's population, and account for roughly 35% of the total agricultural production (Chitrakar 1990). Production problems are more acute in the Middle Mountains where the expansion of agriculture is limited by topographic conditions and yields are reported to be declining. Low and declining soil fertility has been recently recognized as a significant cause for the stagnation or decline in crop productivity, but how soil chemical and physical properties are changing and why are poorly understood (Pandey et al. 1995, Sherchan and Baniya 1991). This study was conducted to examine the dynamics of soil fertility in the Middle Mountains of Nepal, and the human activities that impact soil fertility and the resultant production capacity.

1.1 Soil Fertility Degradation

Soil fertility degradation may be defined as a reduction in the quantitative and / or qualitative productive capacity of the soil. To sustain plant or crop production, the soil provides four basic functions: a rooting medium, gaseous exchange, water holding capacity, and exchangeable nutrients. Degradation results when at least one of these functions is impaired (Lal et al. 1988, FAO 1976, Barrow 1991, Lal and Stewart 1993). Soil degradation is associated with a wide range of human activities and natural processes, and the wider economic, political and social aspects of their setting.

1.1.1 Inherent Soil Properties and Natural Processes

Inherent properties influencing soil fertility are a function of parent material, climate, biota, topography and time as illustrated in Figure 1.1. The dominant bedrock in the Middle Mountains consists of silica rich materials (sandstone, siltstone, quartzite and phyllite) which are inherently acidic and contain low phosphorus levels. Some of the soils are deeply weathered, and kaolinite is the dominant clay mineral in these red soils. Micro-organisms and termites play an active role in organic matter decomposition and the development of soil structure. Organic matter decomposition is enhanced with increasing soil temperature, but may be limited by waterlogging, while the physical and chemical weathering of parent material is promoted by high temperature and precipitation. The high monsoonal rainfall leads to high rates of leaching, and high intensity rainfall events increase soil erosion. Relief up to 2,000 metres is common in the Middle Mountains, slopes often exceed 30° and natural erosion rates are high (Foth 1990, Chitrakar 1990, Schreier et al. 1995, Schreier et al. 1990b, Sivakumar et al. 1992, Lavelle et al. 1992).

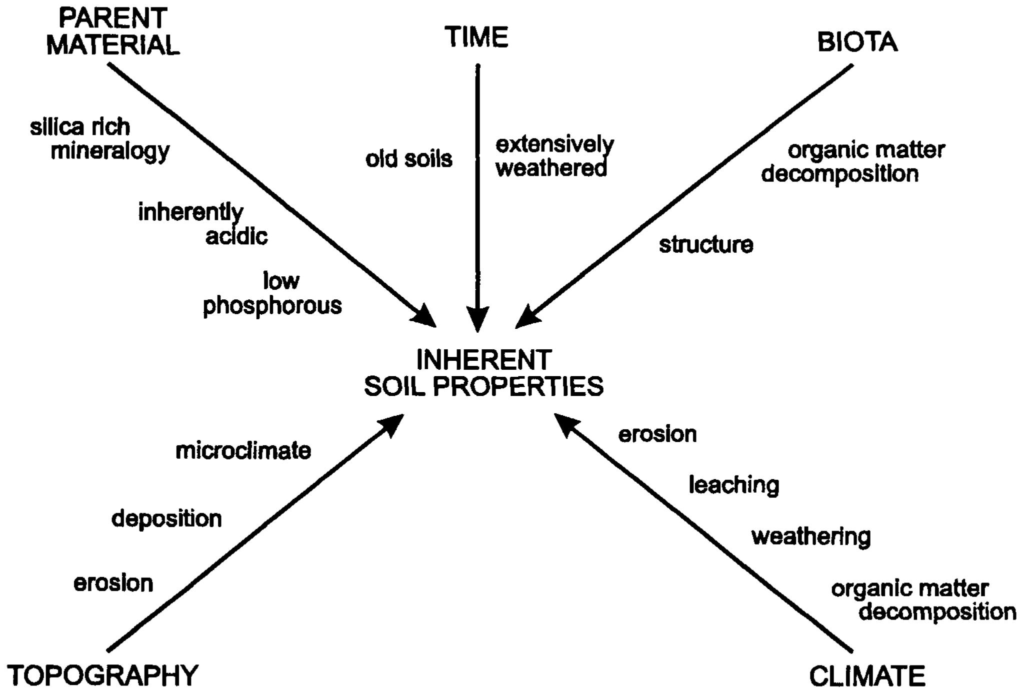


Figure 1.1. Factors influencing inherent soil properties in the Middle Mountains.

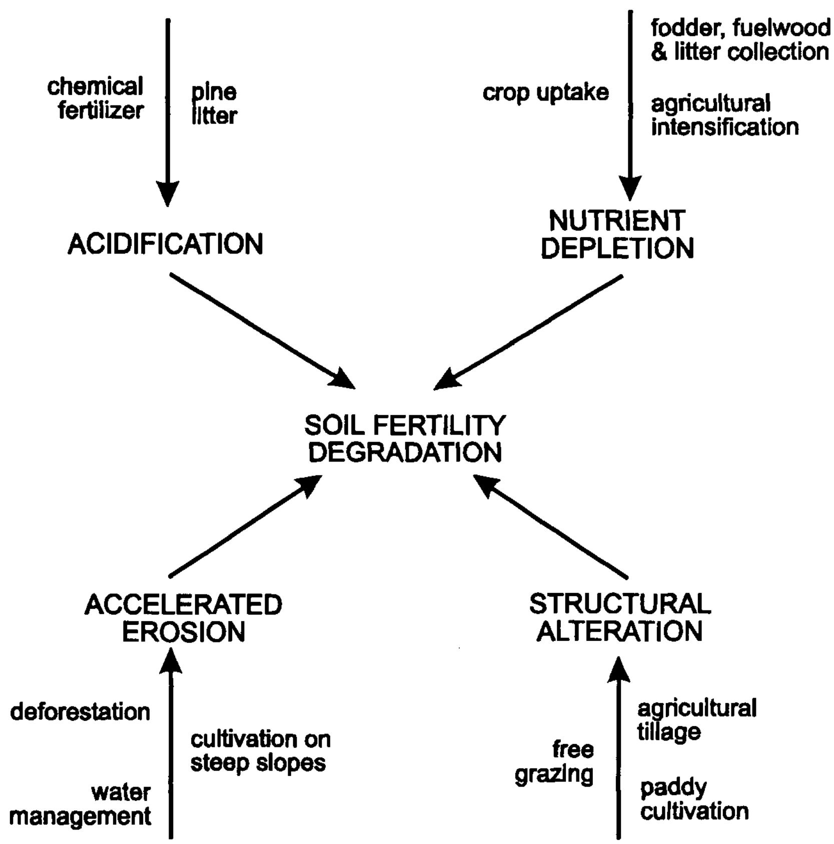


Figure 1.2. Human activities influencing soil fertility degradation in the Middle Mountains.

1.1.2 Human Activities

The human activities influencing soil fertility and productivity in the Middle Mountains are summarised in Figure 1.2. Soil acidification is a concern in relation to the use of chemical fertilizers and the addition of pine litter compost during the dry season. Soil pH is an important chemical characteristic as it influences the availability of plant nutrients and toxic elements. With intensification of the cropping system, the nutrient requirements have dramatically increased, and forest litter is heavily utilized as a soil amendment resulting in a one-way flow of nutrients from the forests to agriculture. Low nutrient inputs are negatively impacting the nutrient balance and contribute to poor productivity. Loams and sandy loams are common throughout the Middle Mountains, but the inherent soil structure is dramatically altered through paddy cultivation and free grazing, resulting in reduced infiltration and water holding capacity. Natural erosion rates are high in Nepal, but are accelerated by cultivation on steep slopes, deforestation and overgrazing. Erosion is a concern not only because of soil loss, but also the associated redistribution of nutrients (Lal 1993, Carson 1986, Schreier et al. 1995, Shah and Schreier 1991, Sherchan 1990, Miller and Donahue 1990, HMGN 1988, Carver 1995).

1.1.3 Contextual Framework

The main social, economic and political factors influencing soil fertility depletion in Nepal are shown schematically in Figure 1.3. The four interrelated categories: population growth, poverty, land tenure, and culture, define the contextual framework under which soil fertility depletion is occurring in the Middle Mountains.

Population Growth

Rapid population growth and the resultant increase in the demand for food are important factors in agricultural intensification and marginalisation, particularly with Nepal's subsistence oriented agricultural economy and poor transportation system. The availability of cultivated land per capita has decreased from 0.17 ha per capita in 1971 to 0.12 ha per capita in 1993. Agricultural intensification is placing increased nutrient demands on soil resources, and expansion onto marginal lands has resulted in reduced productivity due to inherently poor soil fertility conditions and soil erosion (FAO 1996, Mather and Chapman 1995, Barrow 1991, Blaikie and Brookfield 1987, Seddon 1987, Sharma and Banskota 1992, Chitrakar 1990).

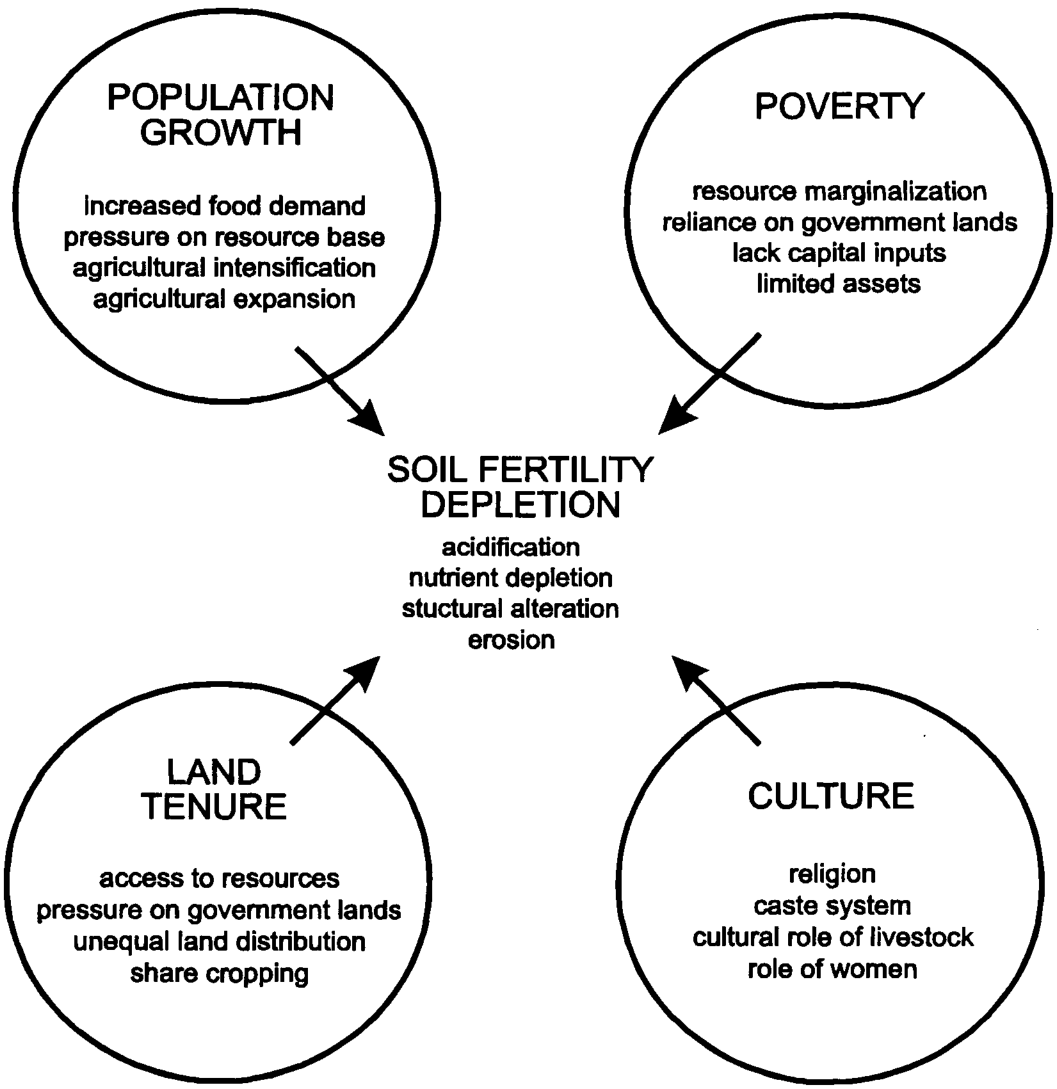


Figure 1.3. Contextual framework affecting soil fertility depletion in the Middle Mountains.

Poverty

Ninety percent of Nepal's population represent small scale farmers with average personal incomes of approximately $170 Cdn per annum. Nepal's rural poor lack long term property rights, are often forced to cultivate marginal lands, do not produce enough food to permit the fallowing of land, and lack the capital to maintain soil fertility through technical solutions (Blaikie and Brookfield 1987, World Bank 1992, NRC 1993, World Bank and UNDP 1991, Panday 1992, Dahal and Shrestha 1987, Blaikie et al. 1980a).

Land Tenure

Land is a critically important production resource in Nepal. Access to land, its inherent fertility and tenure arrangements influence how soil is managed, and consequently how soil fertility may change. Land ownership varies dramatically, with 5% of owners controlling about 40% of the cultivated land, while 60% of owners control only 20% of the cultivated land and typically own less than 1 ha per family. Even under intensive agriculture, it is difficult to meet subsistence requirements from these small holdings. Approximately 25% of households rent or sharecrop additional land, but lacking secure tenure, these poor farmers have little incentive to conserve, manage, improve or invest in soil fertility. Poor farmers are reliant on common property resources to meet their fodder and fuelwood needs, but extensive use and poor management have resulted in the degradation of open access grazing and forest lands (World Bank and UNDP 1991, Carson 1992, Paudel and Tiwari 1992, Seddon 1987, Regmi 1976, NRC 1993, Yadav 1984, Blaikie et al 1980a, Dahal 1987).

Culture

Nepalese culture originates from a mix of Hindu and Buddhist philosophies and indigenous customs. Religious beliefs and traditions strongly influence social, economic, legal and political activities in Nepal. The caste hierarchy determines status (pure / impure) and influences social interaction, occupation and the division of labour. The dimensions of Nepalese culture which may influence soil fertility include ethnicity, the religious role of livestock and the role of women within the farming system. Ethnic divisions and caste affiliation reflect socio-economic status and thus may influence access to land, capital availability, labour allocation, and consequently soil fertility. Livestock play an important cultural role in Hindu societies. Slaughtering of cows is prohibited by religion and law, resulting in overstocking with unproductive animals. Women are predominantly responsible for livestock husbandry, the collection of forest products, the provision of household water, manure collection and application, and the planting, weeding and harvesting of crops. Due to their traditional role as resource users and managers, women play an important role in soil fertility maintenance (Fox 1987, Gould 1987, Gurung 1995a, Hofer 1979, Mishra 1989, Bista 1991, Kennedy and Dunlop 1989, Thapa and Weber 1990, Panday 1992).

1.2 Problem Statement and Objectives

Numerous papers and discussions have focused on soil degradation in Nepal, but there has been little long term research to verify if soil degradation is increasing, and if it is, to explain why. Low and declining soil fertility has been noted as a 'crucial' problem by the Nepal Agricultural Research Council, the Central Soil Science Division, FAO, USAID and the World Bank (Pandey et al. 1995, Maskey and Joshy 1991, World Bank 1996, Carson 1992). The Pakhribas Agricultural Centre has initiated soil related studies focusing on nutrient inputs and crop yield, and the Lumle Agricultural Research Centre has conducted Rapid Rural Appraisal (RRA) and Participatory Rural Appraisal (PRA) studies on farmers' perceptions of soil fertility trends. However issues of uncertainty, limited data, and data reliability raised by Thompson and Warburton (1985), Ives and Messerli (1989) and Kennedy (1989) have largely been ignored. Comprehensive and systematic research on soil fertility and relationships with nutrient flows is lacking. Cultural / sociological and biophysical conditions need to be included, as they influence soil fertility in an integrated manner. Farms in Nepal need to be viewed as systems, incorporating the farming household, cropped fields, forests, and livestock. Soil fertility is a dynamic process influenced by both natural and social factors, and long term research is required to determine the underlying processes. Without knowledge of the underlying processes of soil degradation, it is difficult to suggest management practices which will improve the situation.

The main objectives of this research are:

1) to determine the soil fertility status of a subwatershed in the Middle Mountains of Nepal;

2) to determine if the soil fertility status is changing;

3) to explain the underlying processes driving any changes; and

4) to draw implications of soil fertility status and change for production, sustainability and management.

1.3 Study Area

The Bela-Bhimsenthan study area is located in the Kabhrepalanchok District of the Middle Mountains, approximately 40 kilometres east of Kathmandu (Figure 1.4). The study area covers 1,927 ha and is located within the Jhikhu Khola Watershed Project. It is part of a larger collaborative research program between the University of British Columbia and the International Centre for Integrated Mountain Development (ICIMOD) in Kathmandu. The Jhikhu Khola Watershed Project, sponsored by the International Development Research Centre (IDRC), is focusing on the long term monitoring of soil fertility and erosion processes, resource dynamics and rehabilitation options (Schreier et al. 1995).

The study area is a site where land use intensities are some of the highest in Nepal and resource problems associated with population growth, agricultural intensification and deforestation are acute. Agriculture is the dominant economic activity, but off-farm employment is also an important source of supplemental income. Population pressure has led to double and triple annual crop rotations, and the cultivation of steeply sloping lands. Chemical fertilizers and forest litter are used in an attempt to maintain crop production, but total nutrient inputs are low. The region is subject to a monsoonal climate with an extensive dry season from October to May, and erosion is a concern during the pre-monsoon period prior to biomass growth. Major afforestation efforts have occurred in the region, but heavy pressure on forest resources results in a transfer of nutrients from the forest to agricultural lands. Overall soil fertility conditions are poor and the ability to sustain current production levels is uncertain (Shah and Schreier 1995a, 1991, Schreier et al. 1993).

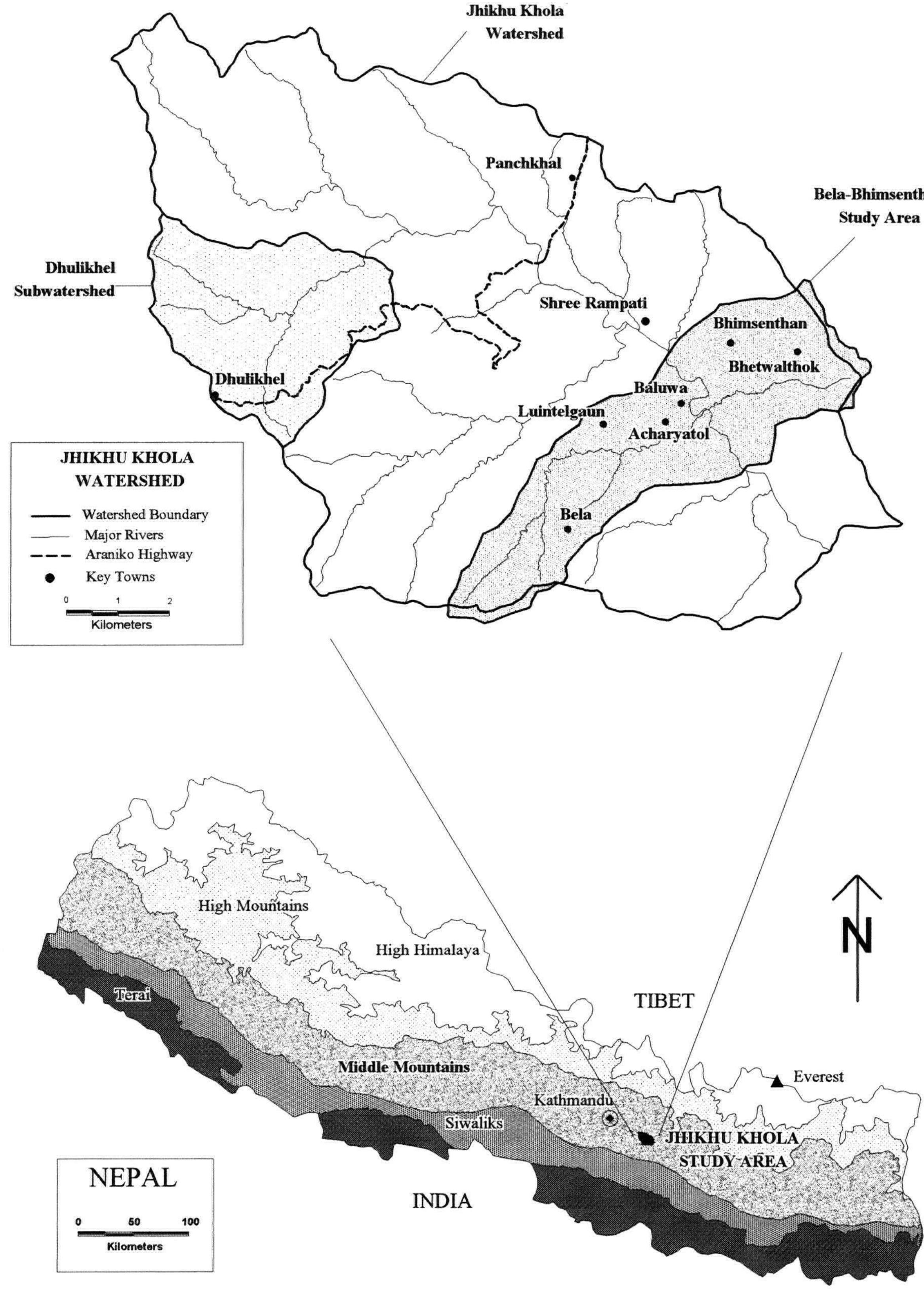


Figure 1.4. Location of the Bela-Bhimsenthan study area.

The study area is typical of the Middle Mountains in many aspects, but is somewhat unique as the Arnica highway connecting Kathmandu with Tibet passes through the Jhikhu Khola Watershed. Traditionally, subsistence agriculture dominated the region but the highway has provided the opportunity to develop a market oriented economy. The increased nutrient and water requirements associated with agricultural intensification and cash crop production, however, are placing additional demands on soil and water resources. Understanding the dynamics of soil fertility in the region is critical to the success of future biomass production strategies. The potential to promote market oriented production makes the region somewhat futuristic and allows the documentation of soil fertility issues resulting from modernization. The implications of management strategies on soil fertility may then be applied to other watersheds in the Middle Mountains.

1.4 Overview of the Dissertation

The approach taken is summarised in Figure 1.5. The methodology used to determine soil fertility conditions and rates of change, assess socio-economic factors, and integrate data is presented in Chapter 2. Soil surveys, plot studies, nutrient balance modelling, household questionnaires and GIS mapping are techniques discussed. The research setting is described in Chapter 3, specifically the biophysical and cultural settings and interactions within the farming systems. Chapter 4 summarises current soil fertility conditions, evaluates inherent conditions versus the impact of land use management, and assesses how soil fertility is changing. The direction and rates of change are estimated through nutrient modelling and plot studies. Why soil fertility is changing is discussed in Chapter 5 relative to land management and nutrient dynamics. Nutrient management on forest, agriculture, grass and shrub lands are evaluated relative to their impact on soil fertility and production. The underlying socio-economic factors influencing nutrient management and soil fertility are discussed in Chapter 6, specifically population growth, land tenure, culture and poverty. Finally, Chapter 7 contains a summary of the major conclusions of this study, and options for soil fertility enhancement.

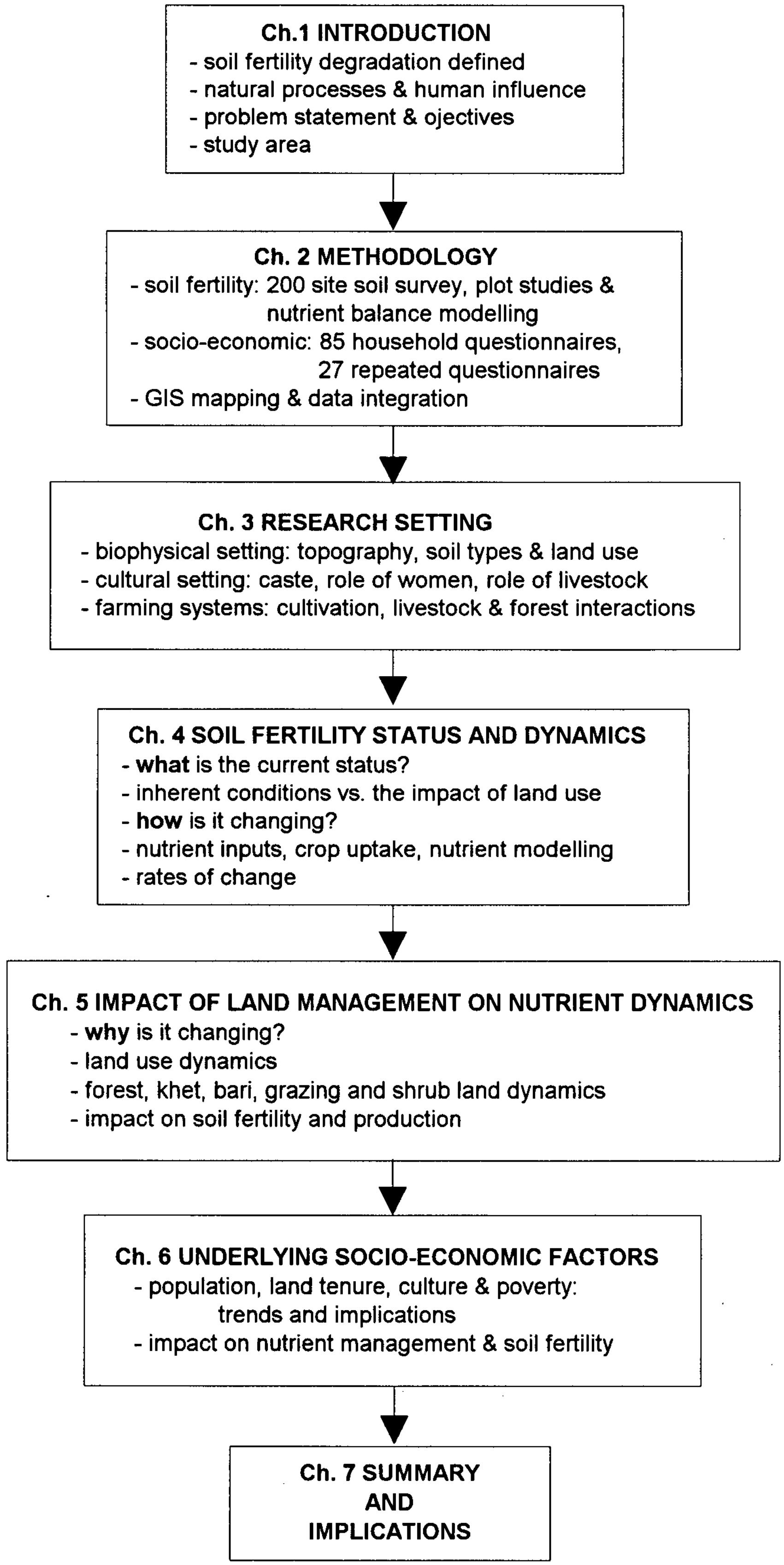


Figure 1.5. Structure of the dissertation.

2. METHODOLOGY

Several approaches were utilized to assess soil fertility conditions and dynamics, and the socio-economic factors which influence soil fertility. Soil surveys and plot studies were used to determine the current soil fertility status and rates of change. Socio-economic data were compiled using household questionnaires. Hydrometric, soil fertility and land use data compiled as part of the Jhikhu Khola Watershed Project were used as supplement information. Geographic Information System (GIS) mapping techniques were used for data compilation and integration. Table 2.1 provides a summary of the studies reported and lists their principle investigators.

Table 2.1 Summary of studies reported and principle investigators.

Year	Study	Principle Investigators
1989	Baluwa household survey (n=27)	Kennedy and Dunlop
1989	Jhikhu Khola forest plot studies (n=12)	Feigl
1991	Dhulikhel agricultural nutrient status	Wymann
1992	Dhulikhel forest nutrient status	Schmidt
1993/94	Bela-Bhimsenthan soil survey (n=200)	Schreier, Shah and Brown
1994	Bela-Bhimsenthan household survey (n=85)	Brown
1994	Jhikhu Khola nutrient cycling plot studies (n=30)	Schreier, Shah, Lavkulich and Brown
1994	Jhikhu Khola forest plot studies repeated (n=12)	Schreier and Brown
1995	Jhikhu Khola land use dynamics	Shrestha and Brown
1996	Baluwa household survey repeated (n=27)	Brown
1996	Bela-Bhimsenthan key informant questionnaire (n=5)	Brown
1996	Bela-Bhimsenthan land use dynamics	Brown and Shrestha
1996/97	Bela-Bhimsenthan GIS integration	Brown
1997	Jhikhu Khola sediment dynamics	Carver

2.1 Soil Fertility

Soil fertility evaluations previously conducted in the Jhikhu Khola and Dhulikhel watersheds identified topographic conditions and soil type as key factors influencing land use and productivity (Schmidt 1992, Schmidt et al. 1993, Wymann 1991). To determine the long term effects of land use management on soil fertility, detailed soil fertility surveys were conducted. Agricultural and forest soils were surveyed separately, and soil chemical properties were measured. All surveys were georeferenced and their locations were transferred to the GIS for analysis.

A detailed soil fertility survey of cultivated and grass lands was conducted in 1993/94 in the Bela-Bhimsenthan region. The main factors believed to influence soil fertility were isolated, specifically topography, soil type and land use. The sampling design was a 2x2x2x3 factorial; elevation $\pm$ 1200 m, north versus south aspects, red and non-red soils, and land use (irrigated agriculture, dryland agriculture and grassland). The two elevation zones represent a climatic break evident by a change in the natural vegetation. The aspect subdivision is important as south facing sites are significantly drier than north facing sites. The red and non-red soil types reflect different parent materials and age of soil development, and consequently inherent characteristics. Differences in soil fertility due to land use may then be ascertained, while keeping the main biophysical conditions constant. For each combination of factors, 10 fields were sampled for soil fertility (Table 2.2). At each field, 10 samples were collected from 0-15 cm depth and one bulk sample was generated for analysis. A short questionnaire was conducted summarizing the crops grown, yields and nutrient inputs for each cultivated field (Appendix A, questionnaire 1). Note, of the 24 possible combinations only 20 occurred, as above 1200 m there is limited irrigated land and red soils. All samples were collected in the middle of the dry season (December - February). Soil analysis included pH, organic carbon, available phosphorus, exchangeable cations, base saturation and moisture content measurements. Sample locations were marked on enlarged aerial photographs and georeferenced to the GIS database for analysis. Figure 2.1 displays the spatial distribution of the 200 sampling locations; note these include only cultivated and grassland sites.

Forest soil fertility was examined through a series of plot studies. In 1989, 12 forest plots were selected within the Jhikhu Khola watershed for long term monitoring of soil fertility and biomass production. Seven of the plots are located within or near the Bela-Bhimsenthan study area (Figure 2.2). Of these seven, three

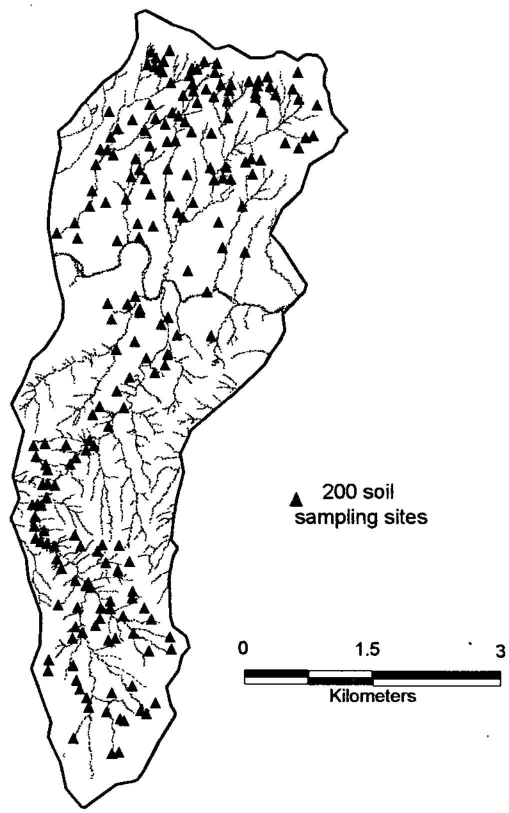


Figure 2.1 Bela-Bhimsenthan soil fertility 200 site locations.

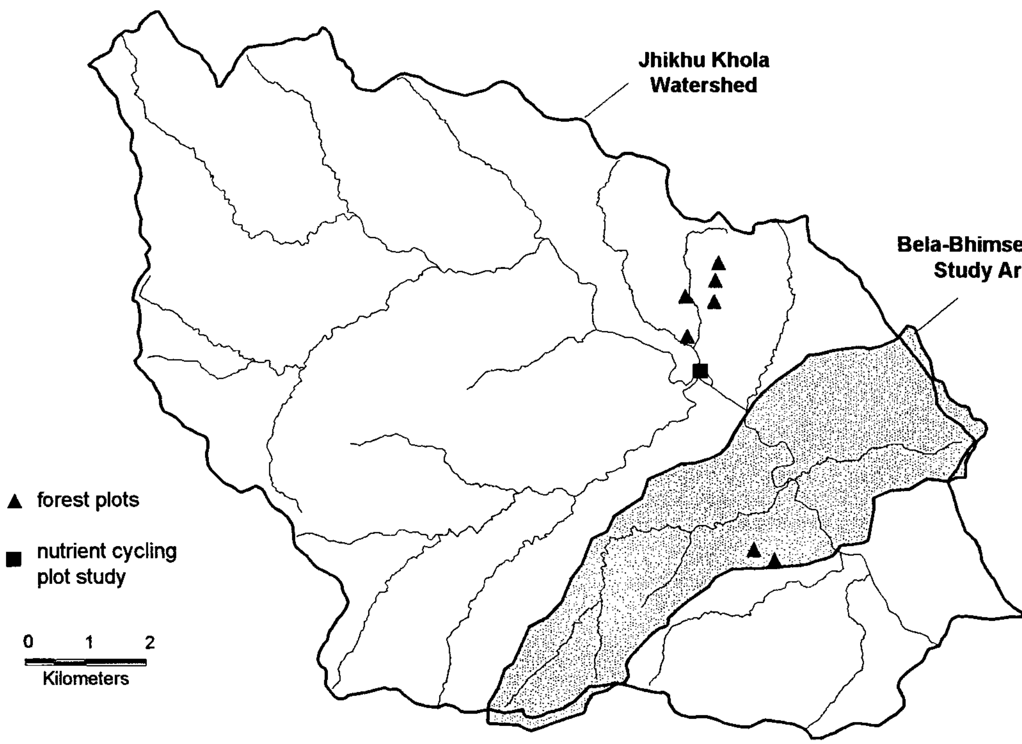


Figure 2.2 Location of forest and nutrient cycling plots referenced in this study.

Table 2.2. Bela-Bhimsenthan soil and household survey sampling design.

Elevation (m)	Aspect	Soil Type	Land Use	No. Site Descriptions	No. Households Interviewed
< 1200	north	red	khet[1]	10	6
			bari[2]	10	9
			grassland	10	0
		non-red	khet	10	5
			bari	10	5
			grassland	10	0
	south	red	khet	10	6
			bari	10	6
			grassland	10	0
		non-red	khet	10	7
			bari	10	5
			grassland	10	0
≥1200	north	red	bari	10	7
		non-red	khet	10	7
			bari	10	8
			grassland	10	0
	south	red	bari	10	7
			grassland	10	0
		non-red	bari	10	7
			grassland	10	0
total				200	85

[1] khet = irrigated agriculture [2] bari = dryland agriculture

plots are dominated by chir pine (*Pinus roxburghii*) with no understorey, one is pine dominated with an understorey, and three are sal (*Shorea robusta*) dominated. Each plot covers an area of 20 by 20 metres. One soil pit was excavated and described, and 16 surface soil samples and 1-2 subsurface soil samples were collected in each plot (Feigl 1989). Samples were analyzed for pH, organic carbon, total nitrogen, available phosphorus and exchangeable cations. The plots were re-examined in 1994 for standing biomass and change in the number of trees relative to 1989 was determined.

All soil samples were analyzed in the Pedology Laboratory at the University of British Columbia. The soil samples were air dried and passed through a 2-mm sieve. Soil pH was measured in 0.01 M $CaCl_2$ with a 1:2 soil-water ratio. CEC, Ca, Mg, K and base saturation were determined using the ammonium acetate method (pH 7.0). Available P was determined using the Bray 1, acid ammonium fluoride method and %C was determined using the Leco induction furnace (Soil Science UBC 1981, Peech 1965, Page et al. 1982, Olsen and Dean 1965). Soil characteristics were summarized and differences between soils evaluated using descriptive statistics (mean, standard deviation, minimum, maximum), Pearson correlation, analysis of variance, t-test and Mann Whitney U-tests (Siegel 1956, Norusis 1993a and 1993b, Easterby-Smith et al. 1991).

Phosphorus Fixation

Phosphorus fixation was assessed by evaluating P sorption in relation to extractable Fe and Al for a subset of the 3x10 soil survey plot study. P sorption was measured for 16 red soil samples using a standard batch equilibrium technique (Yuan and Lavkulich 1994, Nagpal 1981). For each sample 15 g of soil were added to 300 ml of phosphate solution containing between 0 and 80 ppm P, and shaken for 24 hours. Differences in the phosphate concentration of the supernant before and after shaking were used to calculate the quantity of phosphate sorbed by the soil samples. Fe and Al were extracted using ammonium oxalate (AAO) and citrate-bicarcarbonate-dithionite (CBD) methods (McKeaque and Day 1966, Weaver et al. 1968). Sorption characteristics were related to Fe and Al concentrations using Borggaard et al.'s (1990) model:

$$P_m + P_i = 0.223\ Al_{AAO} + 0.120\ Fe_{AAO} + 0.04(Fe_{CBD} - Fe_{AAO}) + 0.3$$

where:

P_m = P sorption maximum
P_i = initial P concentration
Al_{AAO} = oxalate extractable Al
Fe_{AAO} = oxalate extractable Fe
Fe_{CBD} = CBD extractable Fe

Borggaard's model was then used to calculate P sorption characteristics under different land uses on red and non-red soils. The 30 samples in the soil fertility plot studies were extracted for Fe and Al using AAO and CBD methods and P sorption was calculated for red soils under khet, bari and forest land uses. P sorption on non-red soils was calculated for a subset of the 200 site soil survey (n=30) covering khet, bari and grassland sites. For the non-red soils only AAO extractable Fe and Al were used to calculate P sorption as well crystallized Fe oxides (CBD extractable) were found to be less significant (section 4.1.3).

2.1.1 Soil Fertility Dynamics

A nutrient budget model was developed to assess nutrient inputs, redistribution and losses relative to soil fertility. Compost, ferilizer, sediment, water and biota are the main sources of nutrient inputs; erosion-sedimentation, mineralization-immobilisation and adsorption-desorption are redistribution processes incorporated in the model; and leaching, denitrification, volatilisation, chemical fixation, erosion and plant uptake are loss mechanisms. Deficit / surplus values of N, P_2O_5 and Ca were calculated for the main land uses and changes in the soil nutrient pool were estimated. A sensitivity analysis was conducted to identify important model variables and sources of error. Best management practice and deficit elimination scenarios were run to assess alternative management options to reduce soil degradation. Nutrient budgets for individual fields were calculated to determine between site variability for the main crops and cropping rotations. Detailed descriptions of the management of soil nutrients and the nutrient budget model are provided in sections 4.2 to 4.4.

Rates of Change in Soil Fertility

Nutrient cycling was evaluated as part of the Jhikhu Khola Watershed study (Schreier et al. 1994b) by comparing the fertility characteristics of soils originating from the same parent material, but subject to different land uses. The test area covered approximately 50 ha of red soils (Rhodustults) at 800-900 m elevation near the village of Shree Rampati (Figure 2.2). Three land uses were examined: irrigated agriculture, rainfed agriculture and plantation forest. All the agricultural land is terraced, and the irrigated fields have been used for rice production for 5-20 years. The rainfed fields have been under cultivation for more than 30 years and the plantation forest was established 17 years ago. Typical soil profiles under forest and rainfed agriculture consisting of AB, Bt and BC horizons were sampled to test the assumption that all soils in the test area are of similar origin and original composition, and that differences in surface horizons result from recent changes in land management. Rates of change in soil fertility induced by land use were then assessed by comparing composite surface samples (0-15 cm depth) taken from 10 fields on rainfed terraces, 10 rice paddies and 10 sites within the pine forest. Soil fertility was characterised by measuring exchangeable cations (ammonium acetate), CEC, base saturation, available P (Bray method), total carbon (Leco combustion), total nitrogen (auto-analyzer) and pH in $CaCl_2$ (Page et al. 1982).

2.2 Socio-Economic Surveys

To understand why farmers choose different management and cultivation practices it is necessary to appreciate the intricacies of the system within which they are operating. Detailed surveys (Questionnaire 2 Appendix A) were conducted with 85 households (Figure 2.3) to compile information from the farmers about their constraints (social, economic and physical) and their aspirations (individual, household and village-wide). A semi-structured interviewing approach based on the Rapid Rural Appraisal method (Lightfoot et al. 1988, Conway 1986, McCracken et al. 1988) was utilized. The main purpose of the interviews was to gather information about the household-farming system, thus, the selection of respondents was biased towards the decision-makers within the farm household and towards equal representation of men and women farmers. Interviews were conducted during April and May, 1994. Simultaneous and separate man / woman farmer interviews were conducted to incorporate a cross check system and to compare perceptions and problems of both the male and female farmers. In most cases, the interviewing was conducted at farmers' homes with the women (female Nepali interviewer and the woman farmer) holding the discussion indoors while simultaneously the men (male Nepali interviewer and the man farmer) talked out of earshot in the courtyard (Kennedy and Dunlop 1989).

The sample of 85 households was chosen as a cross-section of agricultural land types in the region and biophysical conditions in the study area. The study sample was not chosen to be statistically representative of the population and farm distribution in the region, but was a subset of the 200 site soil fertility survey. A total of 85 paired interviews (male and female farmers) were conducted from the possible 130 cultivated

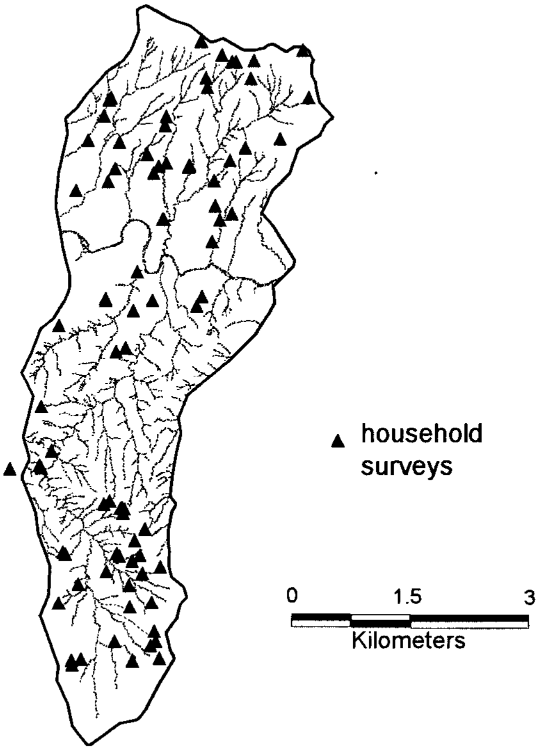


Figure 2.3. Bela-Bhimsenthan 85 household survey locations.

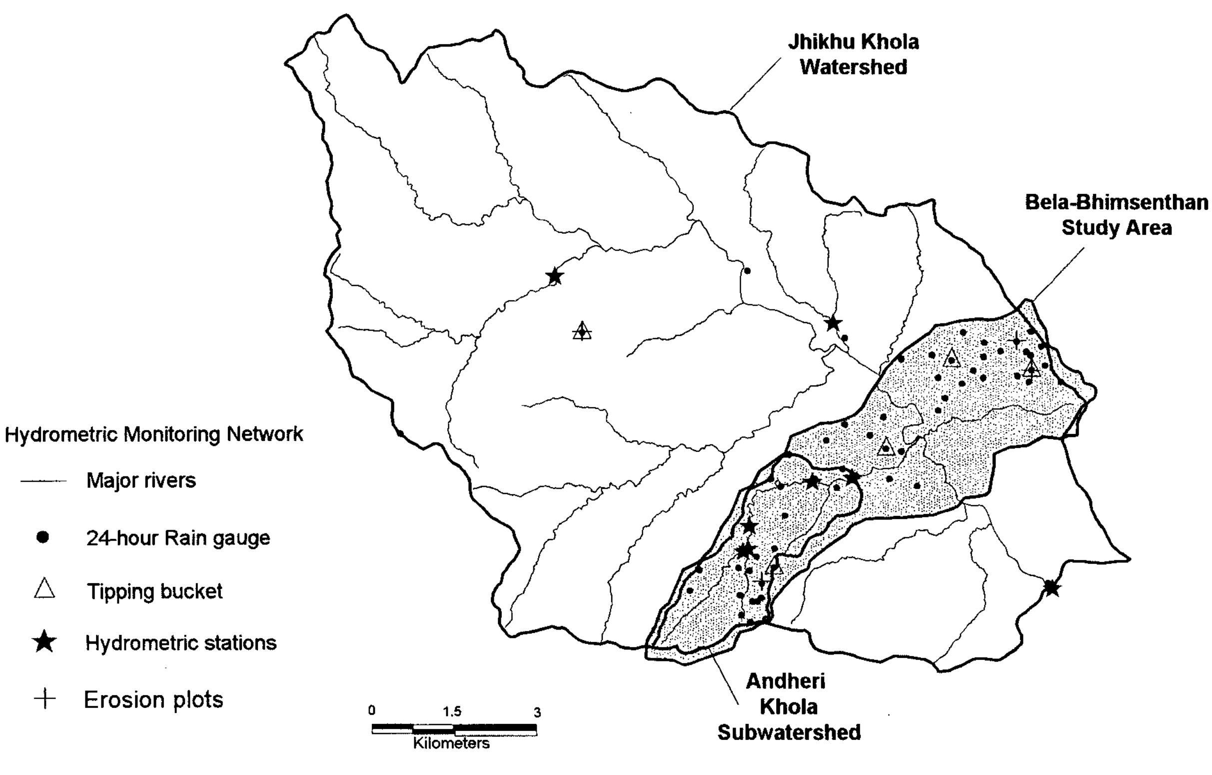


Figure 2.4 Hydrometric monitoring sites (source: Carver 1997).

sites (Table 2.2). Information on crop production, livestock operations, forest products, sufficiency status, ethnic distribution, and off-farm employment were compiled and analyzed to evaluate household access to resources and indices of poverty. Female, male and combined responses were used depending on the activities most familiar to men and women farmers. Female farmers' responses were used to summarize activities such as livestock care and forest production collection. Male farmers' responses were used in the analysis of production information, land holdings and nutrient inputs. Combined responses were used to summarize sufficiency status and off-farm employment. Differences between households were evaluated using descriptive statistics (counts, minimum and maximum), Pearson correlation, Fisher's exact test, t-test and Mann Whitney U-tests. In the case of highly skewed distributions (e.g. compost use) median values were calculated (Siegel 1956, Norusis 1993a and 1993b, Easterby-Smith et al. 1991).

2.2.1 Farming System Dynamics

Changes within the farming system, such as a shift toward market oriented production or an increase in chemical inputs, are often cited in the literature as key factors influencing soil fertility, but typically anecdotal evidence is provided. To quantitatively evaluate farm dynamics, 27 household surveys conducted in Baluwa by Kennedy and Dunlop in 1989 were repeated in 1996. A semi-structured interviewing approach based on Rapid Rural Appraisal methods was utilized (Khon Kaen University 1987, McCracken et al. 1998). The men and women farmers surveyed in 1989 were asked the same questions in 1996. Two surveys were conducted (Appendix A, questionnaires 3 and 4), focusing on the activities most familiar to men and women farmers. Topics discussed included labour allocation, land holdings, cropping systems, livestock operations and forest access. Simultaneous and separate man / woman farmer interviews were conducted to account for the typical division of labour, and to elicit open responses (Kennedy and Dunlop 1989, Schreier et al. 1991b).

Key informant questionnaires (Appendix A.5) were used as a cross check. Informants from the five main villages in the study area (Bhewalthore, Acharyatol, Luietail, Bela and Bhimsenthan) were surveyed in

1996 on changes in cropping patterns, yield, market oriented production, water shortages and land ownership.

2.3 Supplemental Data

Detailed hydrometric monitoring has been conducted as part of the Jhikhu Khola Watershed project since 1989, and is used to document nutrient redistribution through erosion and sedimentation. The monitoring network consists of four automated hydrometric stations, four manual hydrometric stations, five erosion plots, five tipping bucket rain gauges and 40 24-hour rain gauges. The majority of the hydrometric measurements are concentrated in the Andheri sub-watershed (Figure 2.4). Intensive flow and sediment monitoring programs were conducted through the entire 1992, 1993 and 1994 monsoon seasons (June through September). Sediment - discharge relationships were developed for each of the subcatchments and sediment budgets were calculated for individual storm events. Surface soil erosion was determined from runoff and soil loss measurements at the five erosion plots. The plots, located in upland bari fields, are delineated by metal sheets and encompass an area of 70-100 m^2 over 2 sloping terraces. Runoff and sediment are collected in a series of oil drums and a tipping bucket rain gauge located at each site records rainfall intensity and duration. Sediment accumulation in lowland irrigated fields was measured using pins placed in 23 khet fields before the onset of the flood season. The depth of accumulated sediment was measured after harvest, and samples of the accumulated sediment and residual sub-soil were collected for nutrient analysis (Carver and Schreier 1995, Carver 1995, Carver 1997, Schreier et al. 1991b).

Land use mapping conducted under the Jhikhu Khola Watershed Project was used to document historic land use changes. Changes in land use between 1947 and 1981 were evaluated using historic 1:50,000 scale mapping. The original topographic basemap produced in 1947 was used. In addition to the topographic information, three land use classes were delineated: jungle, shrub with a few scattered trees and agriculture. The Land Resource Mapping Project (LRMP) utilized the same topographic base for displaying the land use survey conducted in the early 1980s. In this nation wide integrated survey, all major land resources were mapped using aerial photo-interpretation and field verification. The study area was examined as part of the overall survey in 1981.

A second set of land use data was generated by photo-interpretation of 1972 and 1990 aerial photography at 1:20,000 scale. A 1:20,000 scale topographic basemap was produced using conventional photogrammetric techniques and the 1990 aerial photographs taken specifically for the Jhikhu Khola Watershed Project. After interpretation of the 1990 photos, a detailed field verification program was conducted. The same team then interpreted the 1972 photographs. All information was transferred into GIS format.

2.4 GIS Mapping and Data Integration

Geographic Information Systems (GIS) provide tools for the collection, maintenance, analysis and display of geographically referenced data and facilitate data integration through a common format. GIS based analytical functions provide the capability to selectively search and reclassify data both spatially and temporally. Digital terrain modelling generates slope, aspect and elevation maps which may be analyzed in conjunction with other themes. Overlay operations combine multiple data layers in a vertical fashion to generate new attribute data tables. GIS provides the capability to build complex models by combining analytical functions and by integrating data from external models (Aronoff 1989, Burrough 1986, Laurini and Thompson 1992, Star and Estes 1990).

2.4.1 GIS Based Mapping

Topographic information was available from 1:20,000 scale aerial photographs flown in 1990. A 1:5,000 digital base map was produced using conventional photogrammetric techniques and this map provides information on planimetric position and topography, including: 5 m contours, rivers, streams, roads, trails, and houses. The TerraSoft™ GIS system (PCI Inc.) was utilized for compilation, analysis and integration of the georeferenced data. Elevation, slope and aspect themes were generated from the contour feature class using the terrain modelling capabilities.

The soils in the study area can be broadly divided into red and non-red soils (Schmidt 1992, Schreier et al. 1990). Soil type was mapped using enlarged (1:5,000 scale) aerial photographs and verified with soil pits and auger samples in the field. Soil colour was used to distinguish between red and non-red soils, with a hue of 2.5YR to 5YR and value from 3-6 required to meet the red soil criteria. The soil types delineated on the aerial photographs were then transferred to digital format for GIS analysis.

A historical comparison of land use was compiled for 1972 and 1994 using land use maps and aerial photographs. Enlarged aerial photographs (1:5,000 scale) from 1990 and 1972 were interpreted by Nepali team members as part of the Jhikhu Khola watershed project. The 1990 photographs were interpreted and updated to 1994 through field verification. Six land use classes were designated: khet (irrigated agriculture), bari (dryland agriculture), forest, shrub (crown closure < 10%), grassland and 'other' land categories. For cultivated lands the dominant cropping pattern and the proportion of the area under cultivation were recorded. For forest land the cover type, species, crown density and maturity were recorded. Plantation forests were designated separately. Degraded lands, defined as regions with >50% soil exposure, were also identified and partitioned into degraded shrub and degraded grassland. The 'other' category includes sand and boulders, waterbodies and villages. All information was transferred into digital format and comparative evaluations were obtained using GIS reporting and overlay techniques.

Population dynamics in the study region were evaluated for 1972, 1990 and 1995 using house counts and family size data. The number of houses were counted on the 1972 and 1990 aerial photographs and compared to the number of houses observed in the field in 1995. Population numbers were calculated from the number of houses and the average family size, determined from census data and fields surveys. The recent growth in population is used as an indicator of pressure on the resource base.

2.4.1 Data Integration

All information compiled as part of this study was collected in a georeferenced manner and entered into the GIS. Through the use of one standard format at 1:5,000 scale, data on soils, topography, land use and socio-economic factors are readily accessible from the same database in a compatible format. GIS is used to delineate, reference and measure spatial and temporal trends, and to display the results of queries from external databases. Biophysical data are typically collected and analyzed in a georeferenced framework, but sociological and economic data are often summarized by political subdivisions. Through collecting socio-economic data in a georeferenced manner, data integration is facilitated. GIS overlay and reporting functions can then be utilized to examine spatial relationships such as dryland agriculture by soil type, and temporal trends such as land use change. Area and object oriented themes can be integrated to analyze site characteristics such as soil pit data by land use. Statistical relationships and classification techniques can be used to model data both spatially and temporally. For example, soil chemical properties determined from soil pits can be extrapolated spatially from relationships with site characteristics. Rate of change data, such as soil fertility trends, can be used to develop scenarios documenting potential long term impacts. GIS combined with database, statistical and graphical software thus provides an interactive information system for data analysis, integration and modelling.

3. RESEARCH SETTING

The biophysical and cultural characteristics of the study region, and a description of the dominant farming systems are presented to provide context for soil fertility issues within the study region.

3.1 Biophysical Setting

The biophysical setting has a potentially important impact on soil fertility. Topography and the related microclimatic conditions influence soil formation through erosion, leaching, weathering, and decomposition processes. Soil type determines the inherent nutrient status and physical properties. Land use and its associated management influence soil fertility through anthropogenic processes such as accelerated erosion, impeded drainage, fertilizer induced acidification and cropping induced nutrient depletion.

3.1.1 Topography

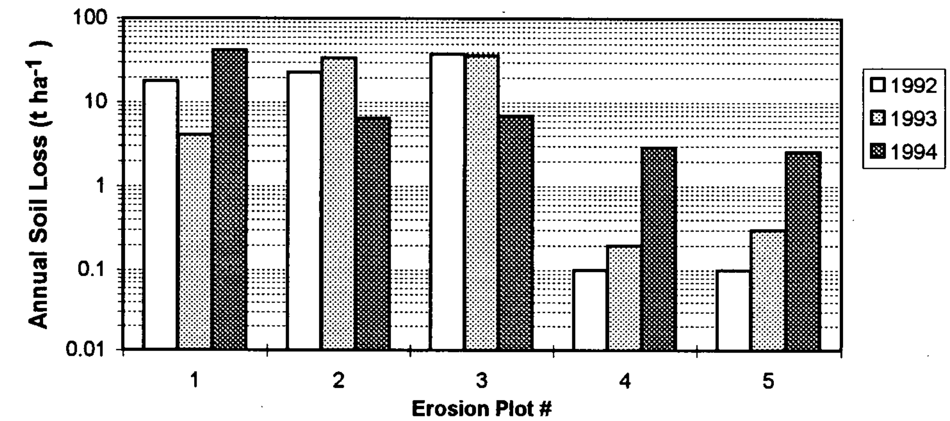
The topographic conditions are summarized in Plates 1-3. Plate 1 displays elevation ranges in 100 m increments. Elevation ranges from 810 to 1729 metres, but 35% of the region is below 900 m and 55% is below 1000 m, while only 5% of the area is above 1500 m. Aspect (Plate 2) is dominantly north - south encompassing 32% and 34% of the area respectively. Elevation and aspect reflect micro-climate conditions in the region with high elevation north facing sites being cooler and moister than the hot dry, southerly sites. Plate 3 displays slope in 10° increments. Slope affects the terrace type, water management and erosion. The distribution of slope classes is relatively uniform with 12% of the area in the 'flat' category, 42% of the area has slopes less than 10° and 14% has slopes greater than 30°. The study region may be subdivided along the Jhikhu Khola into the Bela region (59%) to the south and the Bhimsenthan region (41%) to the north. Topographically, the Bhimsenthan region is steeper particularly above 900 m and is dominantly south facing, while the north facing Bela region has more incised river valleys and covers a greater elevation range (810-1720 m compared to 810-1451 m).

3.1.2 Erosion

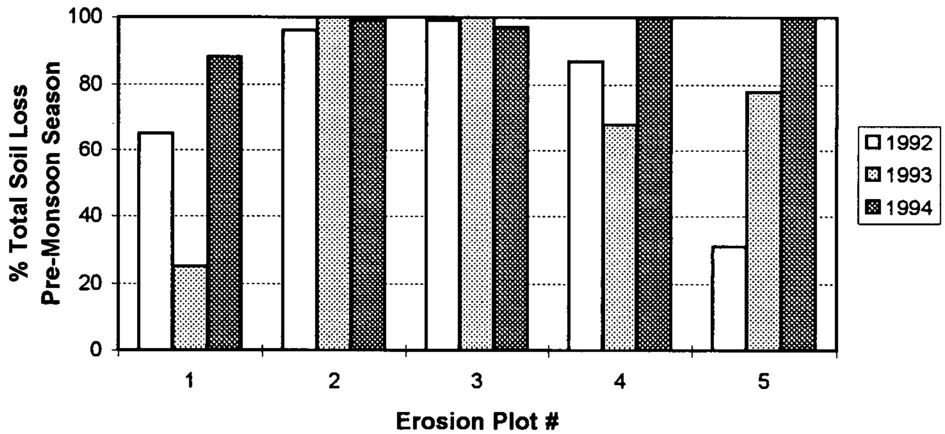
The loss of topsoil from cultivated and grazing lands is a serious problem, as soil fertility and productivity decline with topsoil loss (Carson 1986, Carson 1992, Carver 1995). Annual soil losses from each of the erosion plots during 1992-1994 are shown in Figure 3.1a. Annual erosion rates range from 0.1 to 42 t ha^{-1}, and are within the range of values measured by other researchers in the Middle Mountains reported by Carver (1997). The large variation in soil erosion between plots is a reflection of the variation in soil properties. Regardless of soil properties, however, most of the annual erosion occurs in the pre-monsoon period (Figure 3.1b). If an intense rainfall occurs before the summer crop is developed, erosion losses can be large. Figure 3.1c shows the percentage of annual soil loss from each plot that occurred in the two most damaging storm events. In all years and on all plots, about 50-90% of the annual total soil loss occurred during only two events. In plots 2 and 3, during 1992 and 1993, intense pre-monsoon storms occurred very early in the pre-monsoon season when vegetation cover was at a minimum, and the resulting high erosion rates are reflected in Figure 3.1a.

In addition to vegetative cover, the condition of the soil surface is important in determining erosion levels. The erosion plots are situated on well managed cultivated fields, while large tracts of land in the Middle Mountains are degraded as a result of over utilization and extreme erosion. These degraded sites are characterised by exposed soil, extensive rills and gullies, and surface crusting. Carver (1995) used a paired catchment study to compare sediment output from basins with different surface characteristics. The basins examined are of similar size but the Dhap Khola watershed has gentler slopes (dominantly $<10^{\circ}$) than the Andheri Khola watershed (5-30°). Greater sediment output from the steeper Andheri Khola watershed was anticipated, but the opposite effect was measured. The higher sediment output from the Dhap Khola watershed is related to the extent of soil degradation. The Dhap basin has 14% gullied lands, while only 5% of the Andheri basin is degraded.

a) Annual soil loss (t ha^{-1}) from erosion plots, 1992-1994.



b) Percent of total soil loss occurring in the pre-monsoon season.



c) Percent of annual soil loss occurring in the two most damaging storms.

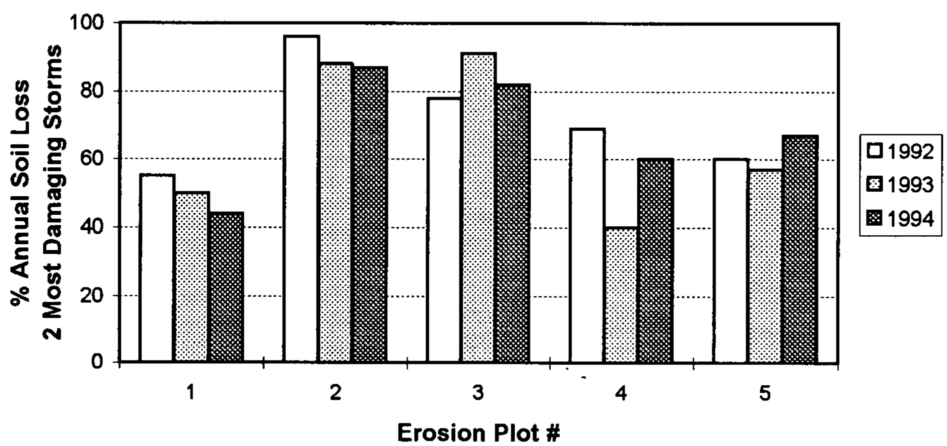


Figure 3.1 Annual soil loss, 1992-1994 (data source: Carver and Narkarmi 1995).

3.1.3 Soil Types

The red soils of the study region are Rhodustults and Haplustults formed on quartzitic phyllite, and the non-red soils are dominantly Ustochrepts and Dystrochrepts formed on phyllite, schist, quartzite, sandstone and siltstone (Schmidt 1992, Schreier et al. 1990a). Red soils are the oldest soils in Nepal and are widespread in the study region (Plate 4), covering 1190 ha (62%). In the Bela region, red soils are dominant below 1150 m except where they have been eroded along major river valleys, and red soils cover 68% of the Bhimsenthan region. Red soils play a unique role in Nepali society. They are used as surface sealant for walls and floors of farm houses and decoration for temples. Their high clay content and low infiltrability makes them hard when dry and slippery when wet, limiting their workability for agriculture and making them prone to erosion. Under good management, red soils may provide high crop yields, but some of the most degraded sites occur on red soils (Sherchan 1990, Schreier et al. 1989, Carver 1995).

3.1.4 Land Use

The majority of land in the Middle Mountains is used for arable agriculture, livestock grazing or forestry. There are two major types of cultivated land: khet and bari. Khet land is comprised of bunded lowland terraces with sufficient water during the monsoon rains to grow a crop of rice. Bari land is comprised of flat or sloping terraces on rainfed uplands, and flood irrigation is not readily possible. Forest, shrub (degraded forest) and grasslands make up the remainder of the dominant land use types.

Plate 5a displays the current land use within the study region. Khet land is dominant along the Jhikhu Khola with 80% of the khet land occurring below 900 m elevation and 82% found on slopes $\leq 10^{\circ}$. Khet land is also important along the Andheri Khola where water is supplied through an intricate irrigation system. Bari cultivation dominates the land use covering 42% of the study region, and is an important source of biomass. Forest and shrub land cover 32% of the area, and a large degraded government forest is located NE of Bela. The density of the forests is generally low (75% of the forest has crown density

<50%), and pine trees comprise 40% of the forest area. Grasslands scattered throughout the region, are the result of lopping, cutting, and grazing in forests, and abandoned cultivation.

3.2 Cultural Setting

Nepalese culture is an intricate blend of Hindu and Buddhist values and traditions, and religion influences social, economic, legal and political activities. Nepali society is structurally complex with many different caste groups and ethnic minorities. Divisions of ethnicity and caste reflect class distinctions, influence the role of women within the household, and determine the cultural significance of livestock (Sayami 1980, Hofer 1979, Bista 1972).

3.2.1 The Caste System

Caste distinctions within Nepali social structure are not rigid, but the caste hierarchy is correlated with ritual and economic allocation. The ethnic distribution within the region therefore has potentially important implications for soil fertility management as the class hierarchy influences access to land and capital resources. The ethnic distribution within the 85 households surveyed is presented in Table 3.1. The bulk are agriculturalists, but mercantile occupations are strong within some groups. Brahmins (priest caste) are the highest in the caste hierarchy and comprise 54% of the sample. Brahmins are traditionally the most influential and wealthy households. Kshatriya (rulers and warriors) include Chhetri and are ranked second in the hierarchy. Vaishya (agriculturalists and traders) include indigenous tribal hill groups such as Newar, Danuwar and Magar, and comprise 27% of the sample. Sudra (service groups) include blacksmiths (Kami), leather workers (Sarki) and musicians (Jogi). The Hindu occupational castes are considered as low caste or 'untouchables', and economically and socially inferior to other groups. Tamangs (8% of the sample) are a Tibeto-Burman community of relatively poor people who practice Bhuddism and are not part of the Hindu caste hierarchy, but may be ranked on the basis of their social status (Table 3.1). Although the caste system has not been anchored in legislation since 1963, the system of relations remains (Bista 1991, Fox 1987, Gould 1987, Hofer 1979, Kennedy and Dunlop 1989, Mishra 1989, Bista 1972, Muller-Boker 1988).

Table 3.1. Ethnic distribution within the Bela-Bhimsenthan sample.

Ethnic Group	Distribution[1] (%)	Traditional Occupation	Rank in Caste Hierarchy[2]
Brahmin	54	priests / farming	highest
Chhetri	6	rulers / military / farming	high
Newar	15	merchants / farming	medium
Jogi	1	fakirs / farming	medium
Magar	1	military / farming	medium
Tamang	8	military / farming	low
Danuwar	11	fishing / hunting / farming	low
Kami	3	blacksmiths / farming	low
Sarki	1	leather workers / farming	low

[1] dataset: 1994 Bela-Bhimsenthan household survey, n=85; combined male and female farmer responses
[2] Bista 1991, Shah 1996

3.2.2 Role of Women

Women are allocated different roles and activities based on cultural ideas of capability and appropriateness. Nearly all women in the study area work in agriculture. They are largely responsible for the day-to-day tasks within the farming system such as fetching water, domestic activities (cooking, cleaning and child care), and gathering fuelwood. Planting (Photo 1), weeding and harvesting are almost exclusively female tasks and constitute 85-95% of the labour requirements for the main crops grown (rice, maize, millet and potatoes). Women are solely responsible for 'polluting' work, which in this context refers to direct contact with human or animal excrement; therefore men do not carry manure. However, women should refrain from working with animals (ploughing) as it is considered sinful and causes pain to the animals. Men are responsible for the heavier work such as land preparation, terrace repair and irrigation system maintenance. In animal husbandry, the role of women depends on the availability of pasture. Children are often assigned the responsibility of animal grazing and watering, but women collect fodder, stall feed the animals, and milk any female goats, cattle or buffalo. Time use data for Nepal indicate that females work longer hours than males in all age groups. Adult women work an average of 10.8 hours per day compared to an average of 7.5 hours per day by men (Acharya 1982, Kennedy and Dunlop 1989, Pfanner 1987, Gurung 1995b, Scheper 1989. Bhatt et al. 1994, HMGN 1993).

The collection of fuelwood, fodder and litter (Photo 2) within the study region is representative of the high labour demands placed on women. Collection by the 85 households sampled in the Bela-Bhimsenthan region is summarized in Figure 3.2 and Table 3.2. Wives, daughters and daughters-in-law collect 86% of fuelwood, fodder and litter for a typical household. A median household makes one trip per week to collect fuelwood, seven trips per week to collect fodder, and three trips per week to collect litter. The median return trip takes two hours and up to 100 hours per household per week may be spent in the collection of fuelwood, fodder and litter.

Table 3.2. Frequency of fuelwood, fodder and litter collection (median values).

Product	**Frequency** (trips week^{-1})	**Time / Trip** (hours)	**Time Spent** (hours week^{-1})
Fuelwood	1.0	3.0	3.8
Fodder	7.0	2.0	14.0
Litter	3.0	2.0	7.0
total	13.5	7.0	28.0

dataset: 1994 Bela-Bhimsenthan household survey, n=85; female farmer responses

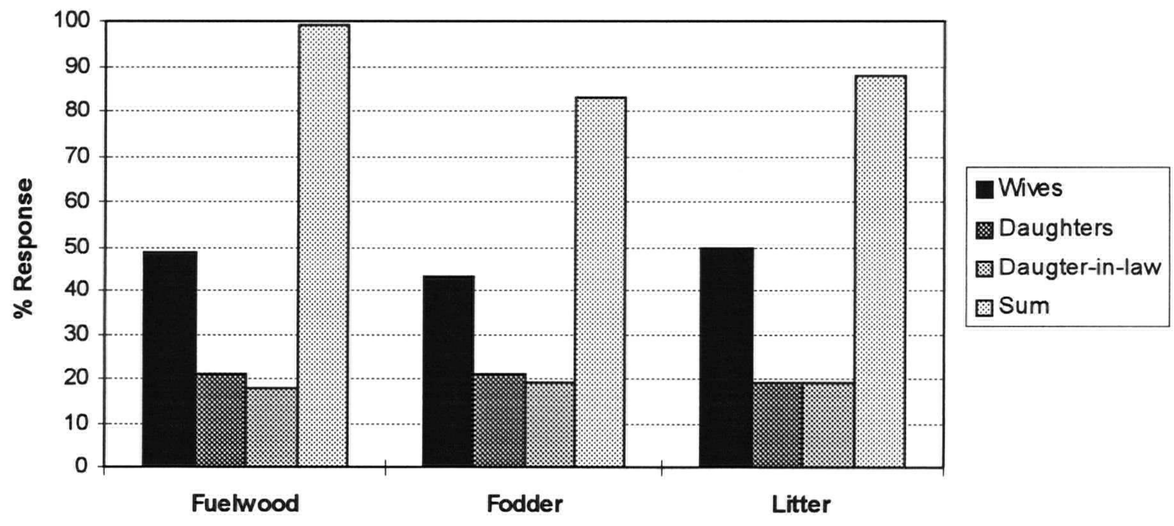


Figure 3.2. Fuelwood, fodder and litter collection by women
(dataset: 1994 Bela-Bhimsenthan household survey, n=85, female farmer responses).

3.2.3 Cultural Role of Livestock

Livestock play a significant role in Nepali culture. Bullocks are used as draught power for land preparation. Cows are kept primarily for cultural / religious purposes and manure production (local cows are not good milk producers). Female buffalo are kept for milking purposes and for manure. Male buffalo are not extensively used for draught power due to the small terraced plots in the area but are raised and sold for meat. Many families require goats for religious sacrificial purposes, and goats are also sold for meat. Poultry is raised for meat and eggs; however, Brahmins traditionally do not eat eggs or poultry (Chitrakar 1990, Kennedy and Dunlop 1989, Fox 1987, Gurung 1995a).

Religious beliefs and the law prohibit the slaughter of cattle and female livestock in Nepal, resulting in the accumulation of low productivity livestock. The ratio of cows to calves provides an indication of the productivity of the cows kept (Fox 1987, Carson 1992, Chitrakar 1990). Farms sampled in the study region owning both cows and calves (n=37), had an average cow-calf ratio of 1.0, with a maximum cow-calf ratio of four (two Brahmin households with four cows and one calf each). In addition, 19 households maintained cows but have no calves, while only three households have calves but no cows. While cows provide status to Hindu households, maintaining cows beyond their reproductive period for religious reasons places additional stress on the already limited fodder resources.

3.3 Farming Systems

Farming systems integrate rainfed and irrigated cultivation, animal husbandry, forest products and household labour. These interrelationships, illustrated in Figure 3.3, indicate the complexity of the farming system and soil fertility issues in the Middle Mountains. Pressure on one component will impact the entire system and alter the transfer of nutrients within the farming system. The farming system is extremely labour intensive: land is prepared primarily with a bullock drawn wooden plough; planting, weeding, harvesting and threshing are done by hand; and considerable time is spent on the collection of animal fodder, litter, fuelwood, and grazing supervision. In the traditional system, households tended to be self-

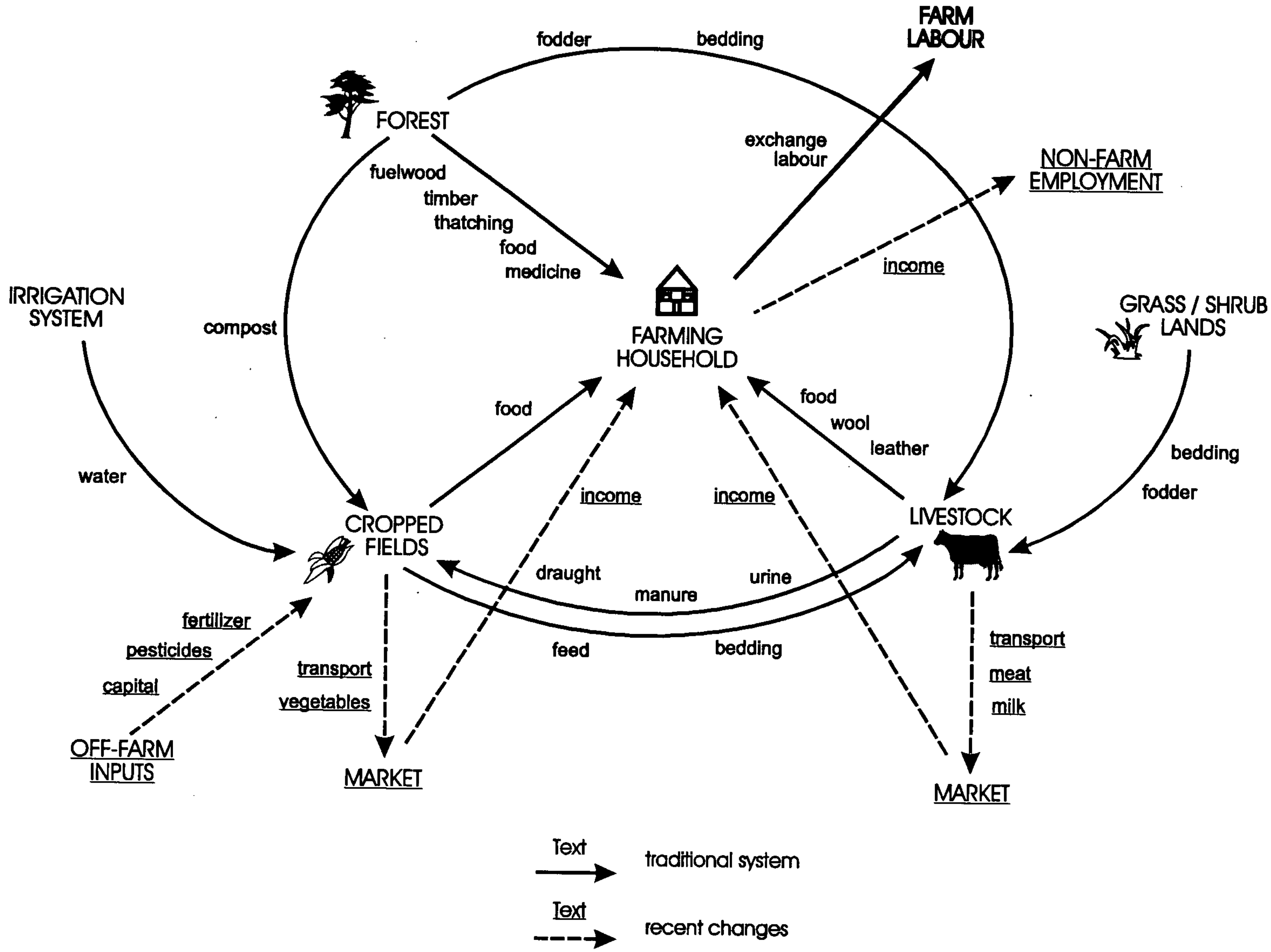


Figure 3.3. Component interactions within farming systems.

supporting for basic requirements, arable land was intensively utilized, and there was a heavy reliance on livestock and forest inputs for crop production. As market oriented production and off-farm employment opportunities developed in the 1980s, the potential for income generation and purchasing outside inputs increased. Cash crops include tomatoes, potatoes, garlic and onions; milk and meat are also marketed; and chemical fertilizers and pesticides are now utilized. However, these intensive agricultural systems are more extractive of both soil and human resources (Pound et al 1992; Panth and Gautam 1990; Yadav 1992, Carson 1992).

3.3.1 Dominant Cropping Systems

The cropping systems determine nutrient requirements and where nutrient inputs are limited, soil nutrients may be depleted through crop uptake. The cropping systems adopted by farmers are influenced by soil tilth, variable rainfall, the temperature regime, available irrigation facilities, labour availability, household food requirements and preferences, and recently, market opportunities (Schreier et al. 1990c, Kennedy and Dunlop 1989, Chitrakar 1990). The prevalent cropping systems on khet and bari land in the Bela-Bhimsenthan region are shown in Figure 3.4. Based on the monsoon climate, the year is divided into three growing seasons: pre-monsoon (February-May), monsoon (June-September) and winter (October-January). Irrigated lowland cultivation (khet) typically includes a premonsoon rice or maize crop followed by monsoon rice and a winter grain or cash crop. Rainfed upland cultivation (bari) commonly involves a fallow pre-monsoon period followed by maize or maize intercropped with beans during the monsoon, and a winter crop of wheat or mustard. With recent increases in market oriented production, a tomato crop may be grown during the winter season if sufficient water is available. Legumes, mainly associated with bari land are grown for home consumption, and are not incorporated into the soil as a green manure. Finger millet which is extensively grown in the Middle Mountains (Chitrakar 1990, Sakya 1986) is not common in the study area due to unfavourable climatic conditions.

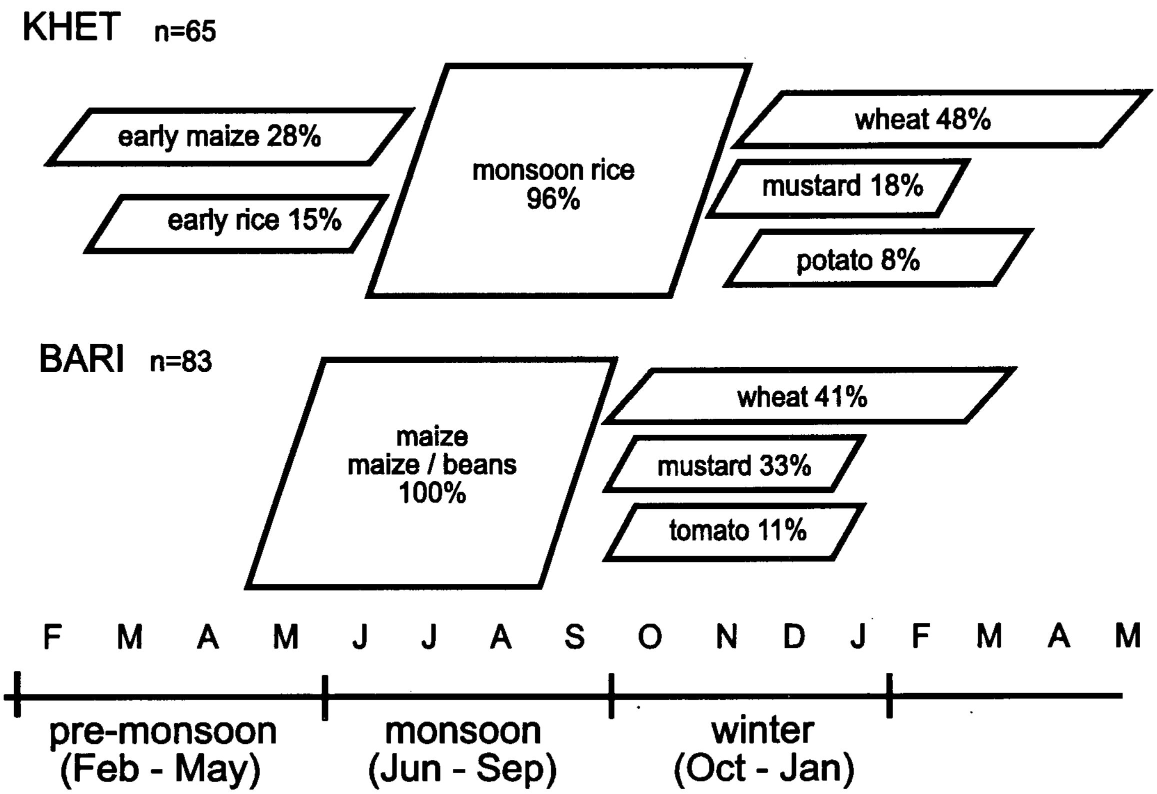


Figure 3.4. Dominant cropping systems
(dataset: 1994 Bela-Bhimsenthan household survey; 1996 key informant questionnaires; Shah 1996).

Of the surveyed households owning khet land (n=65), 63 grew monsoon rice on some or all of their khet land, while 14 grew premonsoon maize and 10 premonsoon rice. The dominant winter crops were wheat grown by 33 households, mustard (13 households) and potatoes (12 households). For the households owning bari land (n=83), during the monsoon period all households planted maize or maize intercropped with beans on some of their bari land. During the winter, 34 households grew wheat, 30 mustard, 21 tomatoes and 9 grew potatoes. Most farmers utilize the same cropping system each year (e.g. maize or rice dominated), but the winter crops are rotated within and between fields to minimise risk within a given year and to maintain crop yields between years.

Compost and Chemical Fertilizer Use

Traditionally, Nepalese hill crop production systems have been sustained by recycling animal manure, and organic residues from crops and forest land. Compost in the region is usually a mixture of livestock manure, waste from the maize crop (cobs and stalks) and livestock bedding materials (pine needles, straw and leaves) (Kennedy and Dunlop 1989, Subedi et al. 1995). While compost and farm yard manure are important sources of nutrient inputs within the traditional farming system, chemical fertilizers are becoming an important nutrient source (Pandey et al. 1995, Chitrakar 1990, Carson 1992). The dominant chemical fertilizers used in the study area are urea (46-0-0), complex© (20-20-0) and ammonium sulphate (21-0-0).

Table 3.3 summarizes reported organic matter and chemical fertilizer inputs and the corresponding N and P_2O_5 inputs to the 130 cultivated fields of the 1993/94 Bela-Bhimsenthan soil survey. The nutrient content of traditional compost measured at the Lumle Agricultural Research Centre (0.6% N and 0.06% P_2O_5 on a dry weight basis) and a 25% moisture content is utilized in the estimation of N and P_2O_5 inputs from organic sources (Subedi et al. 1995). The number of farmers growing crops varies between seasons and a few farmers did not provide input data. In the premonsoon period, 20 farmers grow crops, compared to 127 reporting input data in the monsoon and 91 in winter. Ninety-seven percent of the 85 households surveyed report using chemical fertilizers on some or all of their crops, while 87% apply compost. The median amount of organic matter and chemical fertilizer applications are greatest in the monsoon season and least in the winter. Monsoon inputs account for 86% of the organic matter applied and 58% of the chemical fertilizer application. Twenty-three percent of farmers report using no chemical fertilizer in the winter compared to 5% in the monsoon, and 77% of farmers report applying no organic matter to their winter crops. Nutrient inputs are greater from chemical fertilizer sources, with a median of 100 kg N and 47 kg P_2O_5 applied per year, however, inputs are highly variable between farms. Complex© is the most widely used chemical fertilizer and accounts for 50% of the inorganic N inputs and 100% of the inorganic P_2O_5 inputs.

Table 3.3. Reported nutrient inputs from organic and chemical fertilizer sources.

Source[1]	n	Application[2] (kg ha^{-1})		None Applied[3]	N Input (kg ha^{-1})		P_2O_5 Input (kg ha^{-1})	
		median	range	(% Farmers)	median	range	median	range
Organic Matter								
premonsoon	20	0	0-19,658	60	0	0-88	0	0-9
monsoon	127	8,477	0-98,288	20	38	0-442	4	0-44
winter	91	0	0-49,144	77	0	0-221	0	0-22
P-M-W	127	9,829	0-98,288	13	44	0-442	4	0-44
Chemical Fertilizer								
premonsoon	20	241	0-629	5	49	0-208	37	0-98
monsoon	127	275	0-1,965	4	68	0-403	33	0-197
winter	91	147	0-983	23	31	0-452	20	0-197
P-M-W	127	472	0-2,506	3	100	0-664	47	0-295
Fertilizer Type								
complex©	127	236	0-1,474	6	47	0-295	47	0-295
urea	127	125	0-747	39	57	0-344	-	-
ammonium sulphate	127	0	0-982	82	0	0-206	-	-

[1] dataset: 1993/94 Bela-Bhimsenthan soil survey, n=130; male farmer responses

[2] includes farmers not applying nutrients

[3] % of farmers growing crops who do not apply nutrients

3.3.2 Livestock Operations

Livestock play an integral role in the farming systems of Nepal, and impact soil productivity through manure inputs, biomass removal to meet feed requirements, and compaction by free grazing. The typical livestock mix within the sampled households is shown in Figure 3.5. Fifty to sixty percent of households own a pair of bullock (oxen), a cow and calf, a female buffalo and calf, 4 goats, and 2 chickens. Two Newar households had no livestock as they are largely involved in small business, while the sample high was a Danuwar household with 79 animals (60 chickens).

Livestock is a major contributor to soil fertility maintenance through the production of organic matter from dung and dung / compost mixtures. Traditionally, the majority of farm yard manure / compost was applied to bari land, however compost is currently applied to khet land to meet increasing nutrient requirements due to crop intensification (Carson 1992, Vaidya et al, 1995). The concentration of livestock per unit area of cultivated land impacts the potential compost application to support crop production. To

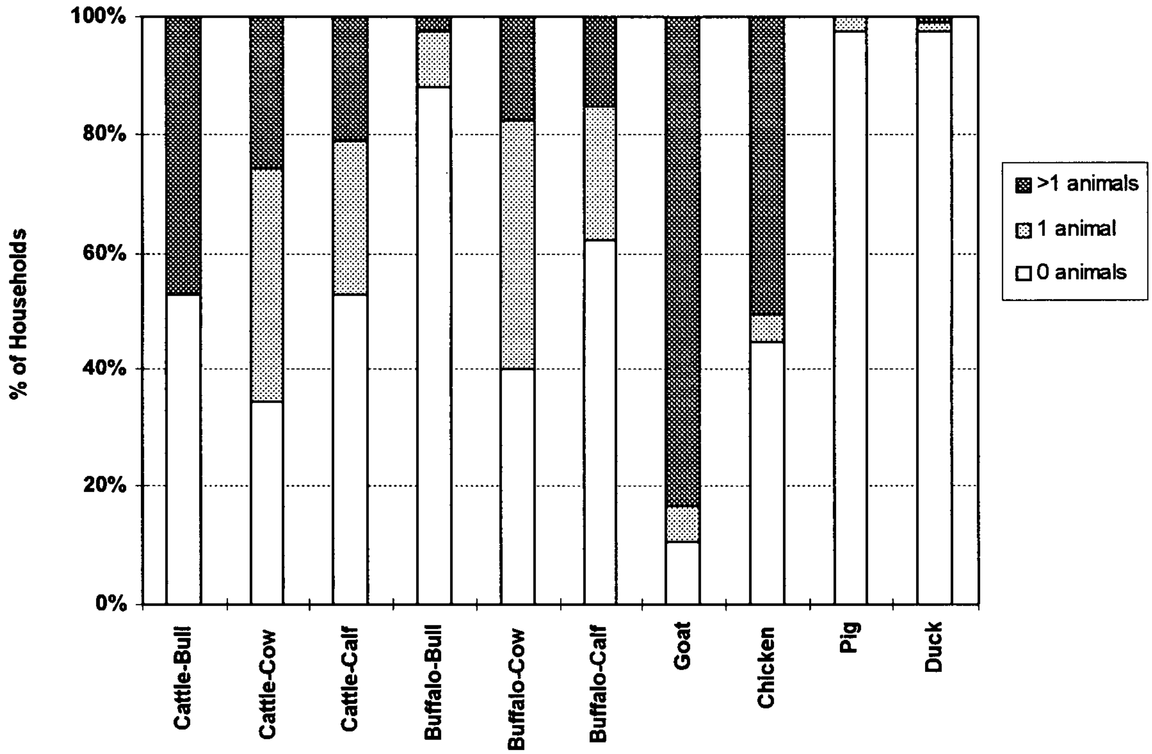


Figure 3.5. Livestock holdings
(dataset: 1994 Bela-Bhimsenthan household survey, n-85, female farmers responses).

determine animal stocking densities, given different types of livestock, tropical livestock units (TLU) were calculated. Livestock units are based on the N content of manure produced by a standard cow, which has a liveweight between 200 and 350 kg in the tropics. The calculations relating cattle to other domesticated species are given in Table 3.4. For example, one bullock is equivalent to 5 swine or 125 chickens (FAO 1975, Williamson and Payne 1978, Ont. MoAF et al. 1976, Brisbin 1995, Fox 1987, Pagot 1992, LRMP 1986a). Livestock concentrations for the surveyed households are presented in Table 3.5. The median TLU per household is 3.9, while the maximum is 9.9 TLU (a Danuwar family with 4 bullock, 1 cow, 1 calf, 1 female buffalo, 5 young buffalo, 7 goats and 60 chickens). The median stocking density, TLU per ha of cultivated land, is 3.8 with a maximum stocking density of 42 TLU per ha (a Danuwar family with 0.15 ha of bari land, 2 bullocks, 1 cow, 1 calf, 1 female buffalo, 4 young buffalo, 2 goats and 3 chickens). These stocking densities are some of the highest in the world and place additional pressure on fodder resources (Joshi 1992, Panth and Gautam 1990, Chitrakar 1990).

Table 3.4. Tropical livestock unit equivalents.

Animal Type	TLU[1]
Cattle - Bullocks	1
Cattle - Cow	0.8
Cattle - Calf	0.4
Buffalo - Bull	1.2
Buffalo - Cow	1
Buffalo - Calf	0.5
Goat	0.1
Pig	0.2
Chicken	0.008
Duck	0.008

[1] sources: FAO 1975, Williamson and Payne 1978, Fox 1987, Brisbin 1995, Ont. MoAF et al. 1987

Table 3.5. Livestock concentration in the Bela-Bhimsenthan region.

Livestock Concentration	Household	
	average	maximum
TLU per household	3.9	9.9
Stocking Density ($TLUha^{-1}$)	3.8	42.0

dataset: 1993/94 Bela-Bhimsenthan household survey, n=85; female farmer responses

Fodder deficiencies are a primary constraint to enhancing livestock production, and the quantity and quality of the manure produced. Buffalo are primarily stall fed, cattle are raised under a semi-extensive system, grazing a few hours per day on the limited grasslands or on cultivated land after crop harvest, while pigs and chickens are raised under a scavenging system. Animal feed levels available in Nepal are estimated to be less than 70% of requirements. In the Bela-Bhimsenthan region, 55% of the female farmers surveyed reported fodder shortages and 98% of those occurred in the winter dry season. Virtually all lands are grazed to some degree at some time during the year, and heavy grazing is responsible for much of the environmental degradation of public lands. Traditionally, forests were heavily relied on to meet fodder needs but farmers have begun to stall feed their livestock for much of the year. Most feed now originates from agriculture but fodder trees are often the only fresh matter available during the dry winter period (Fox 1987, Shepherd 1985, Shrestha 1992, Panday et al. 1991, Jain and Kumar 1995, Joshi 1992, Rasali et al 1995, Panday 1992, Pariyar et al. 1996, Mahat et al. 1987a). In the study region, the majority of fodder comes from crop residues (51%) and terrace risers (26%), while purchasing fodder (11%), private trees (7%) and community or government forests (5%) provide additional sources.

3.3.3 Forest Products

Forests are an integral part of the farming system in the Middle Mountains. Grass and green leaves collected from the forest are used as livestock fodder, and are particularly important for livestock maintenance during the dry season. Litter collected from the forest floor is used as animal bedding, and bedding materials mixed with manure are subsequently applied to crop land (Schmidt 1992). Common species for fodder and litter reported by the female farmers in the study region (n=85) are kaingyo (*Ligustrum confusum*), pithauli (*Rhus parviflora*) and sal (*Shorea robusta*), but 53-62% reported difficulties in collecting these species compared to five years ago.

Fuelwood is a major energy source for cooking and heating in all parts of Nepal (Smith et al. 1993, Chitrakar 1990). Ninety-five percent of the households surveyed (n=85) depend on fuelwood as a major energy source. The main fuelwood sources and their contribution to household fuel supply (Figure 3.6) are private trees (35%), communal or government forests (24%) and purchased fuelwood (4%). Fuel deficits are reported by 62% of households. Scarcity of fuelwood, difficulty in fuelwood collection and labour shortages may promote the use of substitutes but only 8% of the households use any kerosene. The low reliance on forests for fuelwood supplies (24%) and the long trips required to collect fuelwood (3.2 hours per trip) reflect the scarcity of fuelwood sources.

Ninety-six percent of the households surveyed (n=85) report having trees on their private land. Fodder trees are grown by 85% of the households, and are typically grown between terraces on bari land. Ninety-two percent of households report growing fruit trees which provide a supplemental food and/or income source. Fuelwood and timber are mostly grown on non-cultivated land, and are limited to fewer households (52% and 36% respectively). The majority of surveyed households report having the same number of

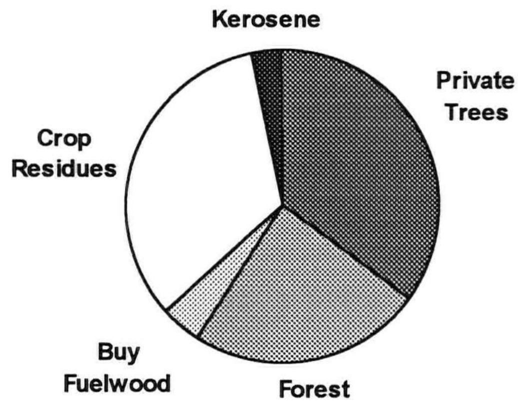


Figure 3.6. Percent supply of household fuel by source
(dataset: 1994 Bela-Bhimsenthan household survey, n=85, combined male and female responses).

fuelwood, fruit and timber trees relative to five years ago, but 60% report having more fodder trees on their own land, indicative of the shortage of fodder sources on common property. Households reporting fodder shortages during the dry season grow an average only 7 fodder trees on their own land, while households reporting no fodder shortages own an average of 17 fodder trees.

3.4 Summary

The biophysical setting reflects inherent soil fertility and anthropogenic processes active within the study region. Topographic conditions indicate a diverse landscape, with elevation ranging from 810 to 1927 metres, dominantly north-south aspect, and slopes from 0 to >30°. Elevation and aspect reflect micro-climatic conditions with high elevation north facing sites being cooler and moister than the hot dry south facing sites. Erosion is highest on cultivated uplands during the premonsoon season prior to the establishment of vegetative cover, and on degraded sites characterised by exposed soil, extensive rills and gullies, and surface crusting. Red soils, which occupy 68% of the study area, are highly weathered, kaolinitic soils with low infiltrability. Under good management, red soils may be highly productive, but some of the most degraded sites occur on red soils. Irrigated (khet) land comprises only 10% of the area, compared to 42% dryland (bari), and 32% forest and shrub.

The cultural setting influences social and economic activities in the study region. Caste and ethnic distinctions are not rigid but reflect household ritual and economic allocation. Brahmins (high caste) are the largest ethnic group in the area and comprise 54% of the study sample. Women are responsible for the day-to-day tasks within the farming system, and constitute 85-95% of the labour requirements for the main crops grown. Due to their traditional role as resource users and managers, women are central in soil fertility maintenance. Religious beliefs and law prohibit the slaughter of cattle and female livestock in Nepal, resulting in the accumulation of low productivity livestock and additional pressure on the limited fodder resources.

Farming systems integrate rainfed and irrigated cultivation, livestock husbandry, forest products and household labour. Maize-wheat and rice-wheat rotations are the dominant cropping systems on bari and khet land respectively, with potatoes and tomatoes the main cash crops grown. Compost is largely applied to the monsoon maize crop, and chemical fertilizer (dominantly complex©) is mainly applied to rice and vegetable crops. Livestock are owned by 98% of the sampled households with a typical holding of four tropical livestock units per household. Crop residues are the main fodder source, but fodder deficiencies are reported during the dry season by 54% of the female farmers surveyed. Grass and green leaves collected from the forest and shrub lands provide an important source of livestock fodder during the dry season. Forest litter is used for animal bedding and subsequently applied to crop land, and fuelwood is used as an energy source by 95% of the surveyed households.

4. SOIL FERTILITY STATUS AND DYNAMICS

The focus of this chapter is to evaluate the current status of soil fertility in the study region and to determine any changes. The components evaluated and their interactions are shown in Figure 4.1. Soil fertility data for agricultural sites in the Bela-Bhimsenthan region are compared to region values and desirable levels for crop production. The dominant factors influencing agricultural soil productivity are discussed, specifically topography, soil type and land use. From these relationships and supplemental data from forest plot studies, a fertility classification is developed to evaluate the spatial extent of fertility problems in the study area. Phosphorus fixation by Fe and Al oxides is a potential concern in relation to chemical fertilizer inputs and is evaluated through P sorption studies and modelling techniques. A classification of P sorption capacity is then developed to assess the spatial extent of P fixation problems in the study area.

Soil fertility dynamics are quantified using nutrient budget modelling and plot study data. Nutrient inputs, their redistribution, losses from the soil-plant nutrient pool and crop nutrient uptake provide indicators of how soil fertility is changing. Insufficient inputs, poor quality compost, inefficient chemical fertilizer use, accelerated erosion and intensive cultivation may all negatively impact soil fertility. The components of nutrient management discussed include compost and chemical fertilizer use, the loss of nutrients via erosion, nutrient recapture through irrigation and sediment deposition, and nutrient losses associated with P fixation, N leaching, denitrification, NH^{3+} volatilization and Ca leaching. Nutrient removal through crop uptake and subsequent harvesting is discussed relative to yield and soil-productivity relationships. A nutrient budget model which incorporates nutrient inputs, crop uptake, erosion and other nutrient losses is developed to estimated surplus / deficit N, P and Ca flows for the dominant cropping systems and to assess how soil fertility may be changing. A sensitivity analysis, best management practices and deficit elimination scenarios are used to identify key model variables and potential options to minimize nutrient deficits. The nutrient budget model is applied to individual fields to evaluate the variability between sites and the direction of change in soil fertility under different land use and management regimes. Rates of change in soil fertility are then determined from plot studies data conducted as part of the Jhikhu Khola Watershed Project (Schreier et al. 1994b).

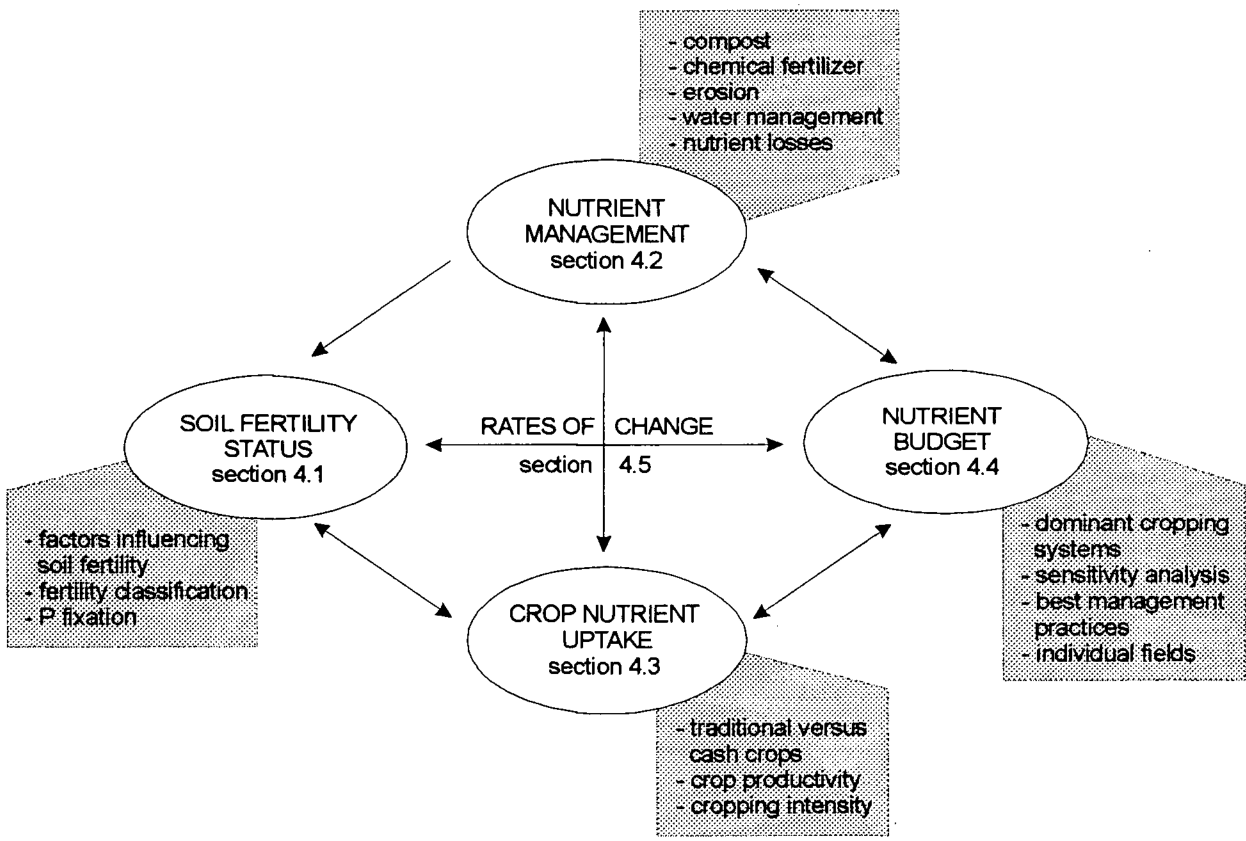


Figure 4.1. Components and characteristics of soil fertility status and dynamics evaluated in chapter 4.

4.1 Soil Fertility Status

The current soil fertility status of the Bela-Bhimsenthan region is summarized in Table 4.1, and compared to data from the Dhulikhel subwatershed (Figure 1.4) located in the headwaters of the Jhikhu Khola (Schmidt 1992, Wymann 1991), data for the entire Jhikhu Khola watershed (Schreier et al. 1991b), and desirable levels for tropical production derived from literature sources. Overall soil nutrient reserves are low. In the Bela-Bhimsenthan region, soil acidity is one pH unit below desirable levels, and carbon and cation exchange capacity are low. Phosphorus, potassium and base saturation are adequate, but values are slightly higher relative to the Dhulikhel and Jhikhu Khola surveys. The Bela-Bhimsenthan survey focuses on agriculture, while the Dhulikhel survey compares forest and agricultural soils, and the Jhikhu Khola survey covers the entire watershed. The Dhulikhel and Jhikhu Khola soil surveys are therefore more representative of the overall soil conditions.

Table 4.1. Current soil fertility status (0-15 cm depth).

Variable (mean values)	**Bela-Bhimsenthan** (n=200)	**Dhulikhel**[1] (n=256)	**Jhikhu Khola**[2] (n=225)	**Desirable Levels**[3]
pH ($CaCl_2$)	4.8 (0.4)	4.4	4.6	5.0 - 6.5
CEC (cmol kg^{-1})	10.8 (4.1)	10.5	10.4	>15
exchangeable Ca (cmol kg^{-1})	3.75 (2.04)	2.18	2.58	>3.0
exchangeable Mg (cmol kg^{-1})	1.40 (0.80)	0.61	0.99	>1.5
exchangeable K (cmol kg^{-1})	0.28 (0.21)	0.27	0.29	>0.25
Base Saturation (%)	51.7 (16.7)	30.9	39.0	>50
available P (mg kg^{-1})	16.6 (18.9)	11.6	2.1	>15
Carbon (%)	0.99 (0.47)	0.68	1.01	1.5-2.0

numbers in parenthesis are one standard deviation

[1] Schmidt 1992, Wymann 1993

[2] Schreier et al. 1991

[3] Landon 1984, Miller and Donahue 1990

Soil pH is an indication of the acidity or alkalinity of the soil and influences the availability of plant nutrients, with a pH range of 5.0-6.5 considered optimum (Foth 1990, Miller and Donahue 1990, Landon 1984). The soils sampled in the Bela-Bhimsenthan data set are strongly acidic with an average pH of 4.8, and 71% of the samples have pH values less than 5.0. The soils in the study region are acidic for a number of reasons: 1) the dominant bedrock is sandstone, siltstone and quartzite which produce acidic soil material; 2) chemical fertilizer use is increasing, ammonium sulphate and urea being the most common, both of which acidify the soils; 3) pine litter used in compost has acidic decomposition products; and 4) no lime is currently applied in the farming system (Schreier et al. 1995). The effect of soil pH on the solubility of minerals is significant, with strongly acidic soils (pH <5) usually having high concentrations of soluble Fe and Al which fix P in a form not readily available to plants (Miller and Donahue 1990, Landon 1984).

The cation exchange capacity (CEC) refers to the sum total of exchangeable cations that a soil can adsorb. The type and amount of clay, and the organic matter content influence CEC. The higher the CEC, the greater the capacity of the soil to retain basic catonic nutrients in an available form against leaching. The average CEC in the sampled sites is 10.8 cmol kg^{-1} and 86% of the samples have CEC values <15 cmol kg^{-1}. The low cation exchange capacity in the study area is related to the inherited bedrock conditions (sandstone, siltstone, and quartzite), extensive weathering leaving kaolinite as the dominant clay mineral in these soils, and low organic matter content. Kaolinite and other highly weathered clays are classified as variable charge clays, where CEC increases with soil pH. The low CEC values are indicative of a limited ability to retain nutrient cations and restricts the effectiveness of fertilizer applications (Willett 1994, Brady and Weil 1996, Miller and Donahue 1990, Sanchez 1976).

The basic cations held on the exchange sites of a soil are Ca, Mg, K and Na. Calcium, Mg and K are essential elements for plant growth (Miller and Donahue 1990). Normally, Ca deficiencies occur only in soils with low CEC at pH values <5.5 (Landon 1984). Calcium levels in the agricultural soils (Bela-Bhimsenthan survey) are adequate but overall (Dhulikhel and Jhikhu Khola surveys) values are low. The presence of a Mg deficiency in a crop is associated with low Mg values and with Ca:Mg ratios above 5:1 as Mg may become less available (Landon 1984). Magnesium values in the region are low, and Ca:Mg ratios are >5 for 86% of the samples. Potassium values appear to be adequate in all three surveys, but the variability of K values is high within the Bela-Bhimsenthan dataset, and sites with K below 0.2 cmol kg^{-1} will likely respond to K fertilizer (Landon 1984).

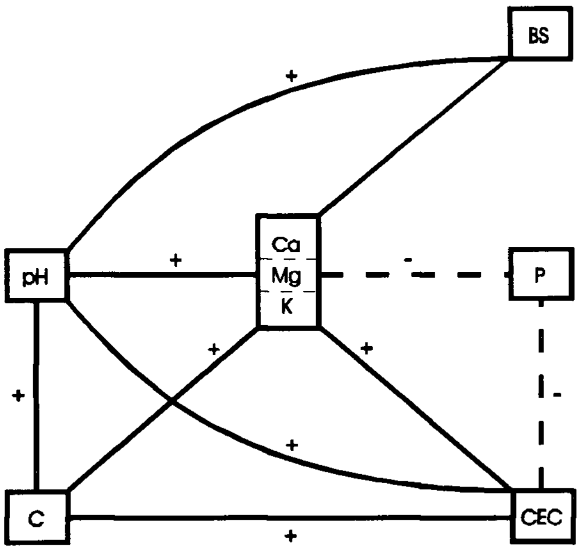
Base saturation is the proportion of the CEC occupied by the bases Ca, Mg, K and Na. In general, as the base saturation of a soil increases, so do the pH and fertility level (Miller and Donahue 1990, Landon 1984). An increase in base saturation results in a quantitative increase in bases in the soil, and an increase in absorption by plants. Base saturation in the agricultural soils (Bela-Bhimsenthan survey) are adequate, but average values from the Dhulikhel and Jhikhu Khola surveys are low.

Phosphorus is one of the limiting nutrients in the soils of the Middle Mountains. The availability of phosphorus depends on soil acidity, organic matter content and microbial activity. Phosphorus is relatively available from pH 5.5 to 6.5, but below pH 5.5 phosphate is fixed by hydrous oxides of Fe and Al (Schreier et al. 1995, Willett 1994, Landon 1984). Phosphorus values for the agricultural soils in the study region are adequate and 32% of available P values are >15 mg kg^{-1}. Overall P concentrations are low (Dhulikhel and Jhikhu Khola surveys), and organic matter and soil acidity are major concerns with regard to P availability.

Organic matter content has many beneficial effects on soil physical, chemical and biological properties, and a low organic matter content is undesirable for plant growth (Tisdale et al. 1985). Soil carbon content is directly proportional to organic matter content. Carbon content in all three surveys is low and only 12% of the Bela-Bhimsenthan samples have C values >1.5%. Low carbon levels are related to historic losses of organic matter due to soil erosion, crop removal and litter collection. Organic matter management is critical to the maintenance of soil fertility within the study region as compost is a major soil additive used by Nepalese farmers (Carson 1992).

To identify relationships between soil fertility parameters, Pearson correlation coefficients were calculated for pairs of variables. Figure 4.2 displays variables with correlation coefficients significant at the 95% confidence level (two tailed). Strong positive correlation coefficients are shown between pH, exchangeable Ca, exchangeable Mg and base saturation. The influence of pH on the availability of plant nutrients is reflected in the relationship between the percentage of base (or H) saturation and pH. When the base saturation is less than 100%, an increase in pH is associated with an increase in the amount of Ca and Mg in the soil solution, since Ca and Mg are the dominant exchangeable bases replaced by H^+ (Miller and Donahue 1990, Foth 1990). No significant relation was found between pH and available P however, and may be related to other factors such as soil type or P inputs through compost.

The spatial distribution of selected soil fertility variables on cultivated sites are shown in Plates 6-8. Exchangeable Ca is indicative of overall soil fertility conditions, while pH and available P are potentially limiting factors. Calcium (Plate 6) is generally adequate with over one-half of the samples having exchangeable Ca >3 cmol kg^{-1}, but low Ca values are prevalent on high elevation, south facing sites. Soil pH (Plate 7) is generally very low with more than one half of the samples having pH <4.8. These acidic sites are distributed throughout the study area. Available P (Plate 8) displays a range of values, but 68% of the samples are below desirable levels (P>15 mg kg^{-1}) and very low P values (available P <5 mg kg^{-1}) are concentrated in the Bhimsenthan region.



Variable	pH ($CaCl_2$)	CEC (cmol kg^{-1})	exch. Ca (cmol kg^{-1})	exch. Mg (cmol kg^{-1})	exch. K (cmol kg^{-1})
CEC (cmol kg^{-1})	0.44				
exch. Ca (cmol kg^{-1})	0.81	0.57			
exch. Mg (cmol kg^{-1})	0.70	0.68	0.52		
exch. K (cmol kg^{-1})		0.54		0.29	
Base Saturation (%)	0.65		0.64	0.25	
avail. P (mg kg^{-1})		-0.26		-0.26	
Carbon (%)	0.42	0.51	0.47	0.49	0.28

Figure 4.2. Significantly correlated soil parameters, r values significance of $\alpha<0.05$ (dataset: 1994 Bela-Bhimsenthan soil survey, n=130).

4.1.1 Factors Influencing Soil Fertility

The current soil fertility status is related to the main factors of soil formation (climate, parent material, soil organisms, topography and time) and modifications by human activity. Topographic conditions influence erosion rates and reflect local variations in temperature and moisture associated with changes in elevation (Plate 1) and aspect (Plate 2). High elevation, north facing sites tend to be cooler and moister, while low elevation, south facing sites are hotter and drier. Soil type, differentiating red and non-red soils (Plate 4), distinguish properties associated with parent material and incorporates the influence of time. Red soils are the oldest soils in Nepal, are highly weathered and kaolinite is the dominant clay mineral. Climatic conditions are generally favourable for soil organisms, but their activity is influenced by land use, particularly organic matter management. Land use (Plate 5a) has a major impact on soil fertility through management activities, particularly nutrient inputs, cropping intensity and water management. Irrigated agricultural land (khet) is intensively managed, dryland agricultural fields (bari) receive the greatest manure inputs, and forest, shrub and grasslands are used to provide animal fodder, litter and fuelwood. Stratifying the 200 agricultural sites surveyed by elevation, aspect, soil type and land use accounts for differences in inherent properties, natural processes and human activities. The influence of these individual factors on soil fertility is summarized in Table 4.2. For each group, mean values are listed and differences between groups determined by Mann Whitney U test are displayed.

Topography

Elevation and aspect classes are related to a number of important soil fertility variables. Statistically significant differences are found between elevation (<1200 m versus $\geq$1200 m) and pH, CEC, exchangeable Ca, exchangeable Mg, base saturation and available P. Higher elevations ($\geq$1200 m) have lower values of all variables with the exception of available P. Increased precipitation, stronger leaching conditions and greater erosional losses associated with higher elevations lead to the removal of bases, while deposition and the lateral movement of bases through surface and groundwater flow may account for the increased pH and bases at lower elevations. The elevated P levels at elevations $\geq$1200 m is probably

Table 4.2. Differences between factors affecting soil fertility (sample mean and Mann Whitney U test).

Factor	**pH** ($CaCl_2$)	**CEC** cmol kg^{-1}	**exch. Ca** cmol kg^{-1}	**exch. Mg** cmol kg^{-1}	**exch. K** cmol kg^{-1}	**Base** **Sat. (%)**	**avail.P** mg kg^{-1}	**Carbon** %
Elevation (m)								
<1200 m (n=120)	4.9	11.2	4.18	1.56	0.28	55.1	14.5	0.98
≥1200 m (n=80)	4.7	10.1	3.10	1.14	0.28	46.7	19.6	1.02
<1200 vs. ≥1200	●	○	●	●		●	○	
Aspect								
north (n=100)	4.8	11.0	4.09	1.19	0.33	53.2	20.9	0.88
south (n=100)	4.9	10.6	3.40	1.60	0.23	50.2	12.2	1.11
north vs. south			●	●	●	○	●	●
Soil Type								
red (n=90)	4.9	13.0	3.97	1.77	0.37	46.8	9.8	0.99
non-red (n=110)	4.8	8.9	3.56	1.09	0.21	55.8	22.1	1.00
red vs. non-red		●		●	●	●	●	
Land Use								
khet (n=50)	5.2	11.2	5.29	1.52	0.23	63.9	21.6	0.89
bari (n=80)	4.8	10.7	3.60	1.47	0.35	52.6	20.6	0.98
grazing (n=70)	4.7	10.6	2.81	1.22	0.24	42.0	8.3	1.09
khet vs. bari	●		●		●	●		
bari vs. grassland	●		●	●	●	●	●	
khet vs. grassland	●		●			●	●	

dataset: 1994 Bela-Bhimsenthan soil survey, n=200

● Significant differences between groups $\alpha<0.05$ ○ Significant differences between groups $\alpha<0.10$

not caused by factors associated with topography, but rather to differences in land use with elevation. More organic residue is traditionally applied to upland bari systems than lowland khet systems, and likely accounts for the greater P values at higher elevations.

Aspect (north versus south facing slopes) shows significant differences between Ca, Mg, K, base saturation, available P and %C. Fertility conditions are generally better on the north facing slopes with the exception of Mg and %C. The north facing slopes are generally cooler, moister and better vegetated than the hotter and drier south facing slopes, and consequently more nutrient recycling occurs. South facing sites have greater %C than north facing sites but differences are small and likely related to land use. In the Bhimsenthan (south-facing) region there is a greater concentration of bari land which receives significant amounts of organic matter via compost.

Red Soils

Soil type is related to a number of important soil fertility variables. Red soils display significantly higher CEC, Mg and K values, while non-red soils have higher base saturation and available P. Non-red soils, developed largely on quartzite and sandstone, have a high silica content and very low clay content accounting for the low CEC. Red soils have a higher exchange capacity due to their higher clay content, and are less sensitive to leaching losses. Available P is significantly greater in the non-red soils. Fifty-two percent of the non-red samples have available P $\geq$15 mg kg^{-1} while 87% of the red soil samples have P levels <15 mg kg^{-1} (P $\geq$15 mg kg^{-1} is desirable for tropical production). No statistically significant differences are noted between compost and chemical fertilizer inputs to red and non-red soils. The low available P in red soils is likely associated with high concentrations of hydrous oxides of Fe and Al which fix P and make it unavailable, particularly at pH < 4.5. Differences in CEC, Mg, K and P are clearly dominated by soil type. The soil fertility of red soils are key to maintaining productivity, and organic matter inputs are vital to maintain soil structure and provide adequate levels of available nutrients. Factors affecting soil pH are also critical as pH must be maintained above 4.5 to limit Fe and Al solubility and P fixation, and as the optimal range for nutrient availability.

Land Use

Land use and its associated management have a considerable impact on soil fertility. Significant differences in pH, Ca, Mg, K, base saturation and available P occur between land uses. The strong influence of land use, particularly khet, is indicated by differences in pH, Ca and base saturation between all three land uses. Overall, khet sites have the highest soil fertility status, followed by bari, while grassland sites have the lowest fertility. Khet land receives nutrient inputs via irrigation waters and sediment deposition while bari and grasslands suffer erosion and leaching losses. In addition to an input of cations, irrigation waters are slightly alkaline (pH 8.7) and impact soil pH (Schreier et al. 1994b). Seventy-four percent of khet soil samples have pH > 4.8, while 63% of bari and grass land soil samples have pH < 4.8. Potassium values for bari samples are significantly higher than khet or grassland sites, and are likely associated with the greater manure and compost inputs to bari land. Available phosphorus levels for bari and khet sites are significantly higher than grasslands, and are related to manure and chemical fertilizer inputs to cultivated fields while biomass is removed from grasslands and nutrient inputs are minimal.

Interactions

Individually, elevation, aspect, soil type and land use have a significant influence on soil fertility, however, these factors may not be independent and interactions between factors may account for some of the variation in soil fertility. Interactions between factors were evaluated using analysis of variance techniques and are displayed in Table 4.3. Overall, land use is most important followed by soil type. However, soil variables are influenced differently by individual factors. For example, CEC is differentiated by soil type, carbon by land use and exchangeable Mg appears to be influenced by all factors. For most variables, factors are independent, with the exception of aspect which shows significant interactions for CEC, exchangeable Mg, available P and % carbon. Only available P shows significant interactions between all four factors, making the interpretation complex.

Table 4.3. Significant factors related to soil fertility (based on analysis of variance).

Variables	**Elevation**	**Aspect**	**Soil Type**	**Land Use**	**Interactions**
pH ($CaCl_2$)	●	●		●	-
CEC (cmol kg^{-1})			●		Aspect - Elevation Aspect - Soil Type
Exch. Ca (cmol kg^{-1})	●	○		●	-
Exch. Mg (cmol kg^{-1})	○	●	●	●	Aspect - Land Use
Exch. K (cmol kg^{-1})		●	●	●	-
Base Saturation (%)	●		●	●	-
Available P (mg kg^{-1})		●	●	●	Aspect - Elevation Aspect - Land Use Elevation - Land Use Land Use - Soil Type
Carbon (%)		○		●	Aspect - Elevation Aspect - Soil Type

dataset: 1994 Bela-Bhimsenthan soil survey, n=200

● Significant differences between groups $\alpha<0.05$ ○ Significant differences between groups $\alpha<0.10$

As soil type and land use were the most significant factors related to soil fertility, the soil samples were stratified by soil type and land use. Using the Bela-Bhimsenthan agricultural soil survey and the forest plot studies (Feigl 1989), differences between khet, bari, grass and forest lands are displayed separately for red and non-red soils (Figure 4.3 a-h). The impact of parent material on soil fertility is illustrated by available P, exchangeable Mg and CEC. In these cases the relationship to land use is limited, but consistent differences occur between soil types. Red soils have greater clay content, higher CEC and greater exchangeable Mg values, with the higher Fe and Al content likely tying up available phosphorus in these soils (Schreier et al. 1994b).

The relationship between land use and soil fertility is exemplified by pH and exchangeable Ca. Khet land displays the best fertility conditions, followed by bari and grassland, while forest soil fertility is the poorest. The highest pH, exchangeable Ca and base saturation are found in khet lands, and may be attributed to the input of cations through sediments and irrigation water. Bari land appears to have slightly higher P values, likely related to greater manure applications in dryland agriculture. Grazing and forest lands, which receive minimal nutrient inputs are the poorest regardless of soil type. These trends are consistent over the entire study area and clearly indicate the influence of land use management on soil fertility.

Overall, nutrient deficiencies are widespread, and are the result of a combination of inherent soil properties and anthropogenic causes. Parent material and the age of soil development determines the inherent soil properties, but within a given soil type, land management is an important factor influencing soil fertility.

4.1.2 Fertility Classification

Summarizing average values for soil fertility variables, comparing differences between individual factors which influence soil fertility, and evaluating the interactions between factors are useful in assessing the current fertility status and determining which factors account for these differences, but the extent of soil

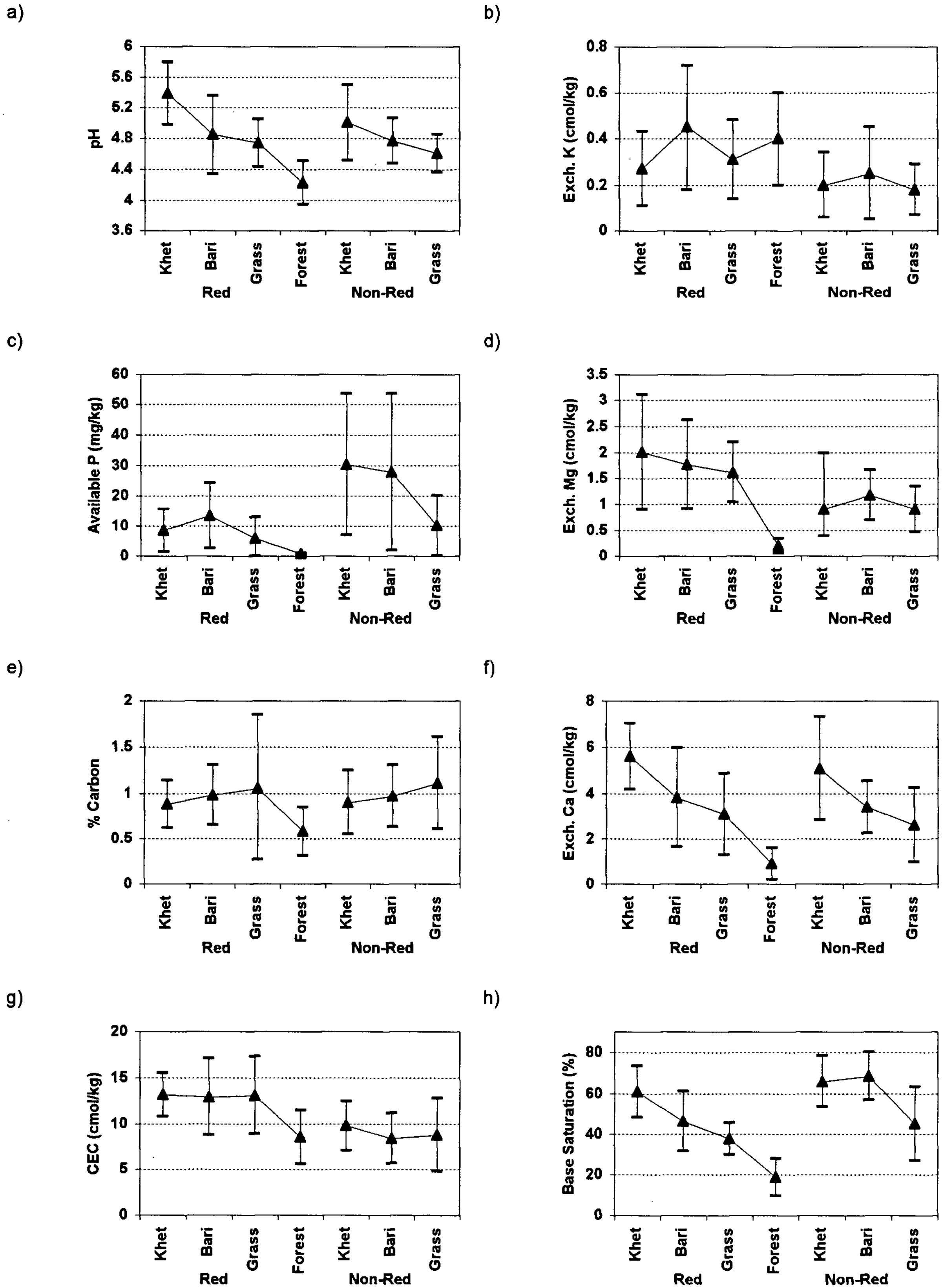


Figure 4.3. Soil fertility variables stratified by soil type and land use; mean, minimum and maximum (dataset: 1993/94 Bela-Bhimsenthan site soil survey, n=200; 1989 Jhikhu Khola forest plot studies, n=7).

fertility problems within the study area is not evaluated using these approaches. To determine the spatial extent of soil fertility problems a site factor approach is employed. From the analysis of variance (Table 4.3) and the stratification of variables by soil type and land use (Figure 4.3), key soil fertility parameters can be identified. Exchangeable Ca, pH and available P are used to summarize overall fertility conditions, and exemplify the affect of soil type and land use on soil fertility conditions.

Key fertility parameters are related to the factors which account for their variability, specifically soil type, land use, elevation and aspect. Relationships established using the 200 site agricultural soil fertility survey and the forest plot studies are then extrapolated to the entire study region utilizing the GIS. Overlay techniques are used to display the relevant combinations of land use (khet, bari, grassland, forest and shrub), soil type (red and non-red), elevation ($\pm$ 1200 m), and aspect (dominantly north versus south facing slopes). Of the 32 possible combinations, only 24 types occur within the study region. For a particular variable the soil fertility data are stratified by the significant factors determined by the analysis of variance and mean values are assigned to each combination of factors (e.g. khet land on red soil at an elevation <1200 m). The results are then grouped into three classes and displayed using the GIS system. Forest / shrub sites were not stratified by soil type or topographic conditions given the limited number of plot studies within the Bela-Bhimsenthan region. Although forest soils in the Dhulikhel subwatershed showed some differences with soil type and topographic conditions (Schmidt 1992), all base saturation, pH and available P values fell into the very low categories.

The main factors accounting for the variability in exchangeable Ca are land use, elevation and aspect (Table 4.3). Samples are stratified by these factors, average exchangeable Ca is determined for each group and the results are lumped into three categories: exchangeable Ca <3 cmol kg^{-1}, 3-4, and >4 cmol kg^{-1}. Land use, elevation and aspect themes are overlain within the GIS and assigned the appropriate exchangeable Ca value. The results displayed in Plate 9 indicate that 57% of the classified area has adequate exchangeable Ca values (>3 cmol kg^{-1}). All khet sites and low elevation, south facing bari fields have moderate levels of exchangeable Ca. Conversely, forest, shrub and high elevation grasslands are classified as very low (exchangeable Ca <3 cmol kg^{-1}).

The main factors accounting for the variability in soil acidity are land use, elevation and aspect (Table 4.3). Soil samples are stratified by these factors, average pH is determined for each group and the results are placed into three categories: pH <4.8, 4.8-5.0, and >5.0. A break in the distribution occurs at pH 4.8 with roughly one-half of the values falling above and below pH 4.8, and pH >5.0 is considered optimum. Land use, elevation and aspect themes are overlain within the GIS and each polygon type is assigned an average pH value. The results displayed in Plate 10 indicate that only 28% of the classified area has adequate pH values (>5.0). The areas classified as adequate correspond to low elevation khet land on both north and south aspects, and low elevation bari land on south facing slopes. Conversely, areas classified as very low (pH <4.8) correspond to forest, shrub and grasslands irrespective of elevation or aspect, and low elevation bari land on north facing slopes.

The variability in available P is accounted for by soil type, land use and aspect (Table 4.3), however no significant differences are found between khet and bari land. Available P is summarized for each significant combination of soil type (red and non-red), land use (khet / bari, grassland and forest / shrub), and aspect (north and south). The results are classified into three categories: available P <5 mg kg^{-1}, 5-15, and >15 mg kg^{-1}. The relevant soil type, land use and aspect classes are overlain within the GIS and assigned the appropriate available P values. The results displayed in Plate 11 indicate that 38% of the classified area has adequate P levels (available P >15 mg kg^{-1}). The areas classified as adequate correspond to khet or bari land on non-red soils, and khet or bari land on north facing red soils. Areas classified as very low (available P <5 mg kg^{-1}) correspond to all forest and shrub sites, and grasslands on north facing red soils.

A composite soil fertility map was produced by combining the exchangeable Ca, pH and available P maps using GIS overlay techniques. Of the 27 possible combinations, only 11 occurred within the study region. The results displayed in Plate 12 are grouped into 4 categories: low in all three variables, low in at least one variable, moderate or adequate, and adequate in all three variables. Only 14% of the classified regions have adequate levels of exchangeable Ca, pH and available P, while 35% are very low in all three variables, and 61% have at least one limiting variable. The best fertility conditions are found on low elevation khet and bari lands on non-red soils. This is related to the higher nutrient inputs to cultivated lands, their proximity to water resources (low elevation) and the prevalence of non-red soils near the Jhikhu Khola river. The poorest composite fertility is found on forest and shrub lands, and is likely related to the human removal of biomass (nutrients) from these areas to support agriculture. Overall, soil fertility conditions are poor and the production potential may be limited in many regions.

4.1.3 Phosphorus Fixation

Available phosphorus is generally low in the study area, and P fixation by Fe and Al oxides is of concern particularly in relation to P additions on red soils. To evaluate the P fixation capacity of soils in the study region, P sorption studies were conducted, and relationships with Fe and Al are used to model the P fixation capacity under different land uses. Selected P sorption curves for red soil samples are shown in Figure 4.4. P sorption ranged from 2-4 g P_2O_5 per kg soil for the 16 red soil sites measured. These values are below the 8-15 g P_2O_5 fixation per kg soil noted for imogolite and allophane complexes in Andosols which possess the highest P fixation capacity (Dabin 1980), but are comparable to the P sorption of 1-6 g P_2O_5 per kg soil determined for forest soils in British Columbia by Yuan and Lavkulich (1994).

Phosphate sorption in many acid soils is predominantly influenced by oxides and hydroxides of Fe and Al, and has been related to AAO and CBD extractable Al and Fe in many studies (Yuan and Lavkulich 1994, Borggaard et al. 1990, van der Zee and Riemsdijk 1988, Nagpal 1981). Relationships between P sorption, Fe and Al are shown in Figures 4. 5a-c. AAO extractable Al shows the best relationship (r^2=0.80), but many models relate P sorption to a linear combination of AAO extractable Fe and Al, and may include CBD extractable Fe. Phosphate sorption calculated using Borggaard's model, which includes CBD extractable Fe, shows good agreement (r^2=0.85) with measured P sorption (Figure 4.6).

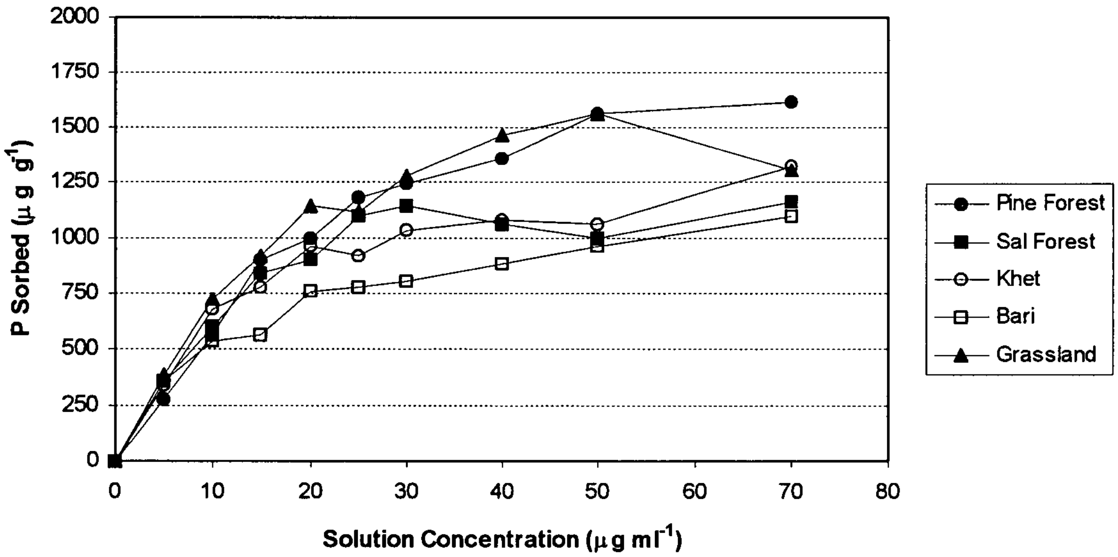
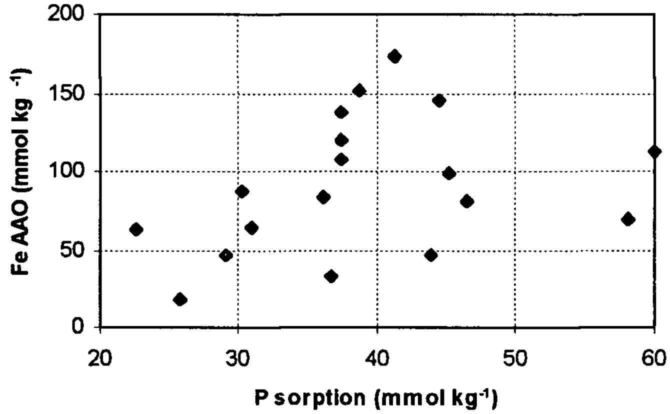


Figure 4.4. Selected P sorption curves
(dataset: 1994 Jhikhu Khola nutrient cycling plot studies; 1989 Jhikhu Khola forest plot studies).

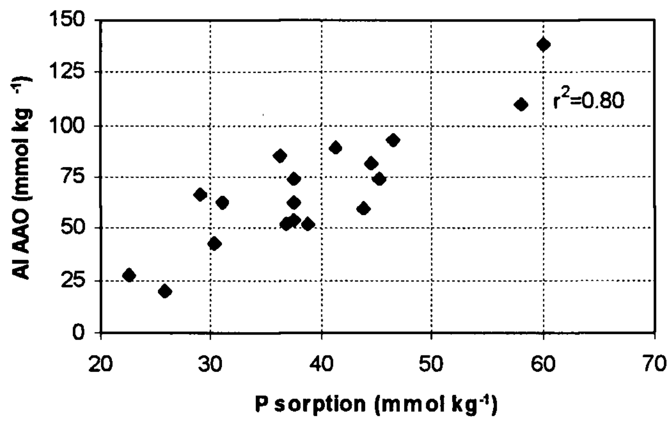
Given the good fit of Borggaard's model and measured P sorption, the model is used to calculate P sorption under different land uses. Figures 4.7a and 4.7b show mean, minimum and maximum calculated P sorption on red and non-red soils (n=60). Phosphate sorption capacity on red soils ranged from 0.7-2.3 g per kg of soil, and is nearly one order of magnitude greater than P sorption calculated for non-red soils (0.06-0.56 g kg^{-1}). Within the red soils, forest sites sorbed an average of 1.7 g kg^{-1} which is significantly greater ($\alpha<0.05$) than P sorption on the agricultural sites (1.2 g kg^{-1}). Using the site factor approach outlined in section 4.1.2, a classified map of P sorption was developed. Samples were stratified by soil type and land use, the average P sorption capacity assigned to each group, and the results were classified into three categories: >1.5 g kg^{-1}, 0.5-1.5, and <0.5 g kg^{-1}. The results, shown in Plate 13, indicate that 29% of the classified area has high P fixation capacity (>1.5 g kg^{-1}) and 61% has a P fixation capacity

>0.5 g kg^{-1}. The high P fixation capacity of these soils has significant implications for phosphorus management as P applied in water soluble forms will be quickly converted to insoluble or complex forms (Stevenson 1986).

a)



b)



c)

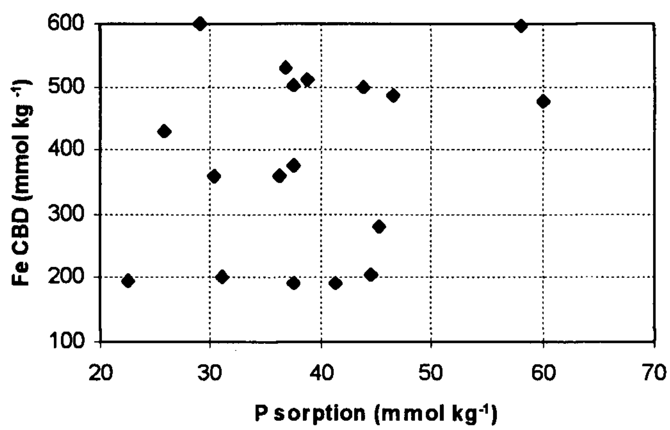


Figure 4.5. Relationships between P sorption, Fe and Al
(dataset: 1994 Jhikhu Khola nutrient cycling plot studies; 1989 Jhikhu Khola forest plot studies).

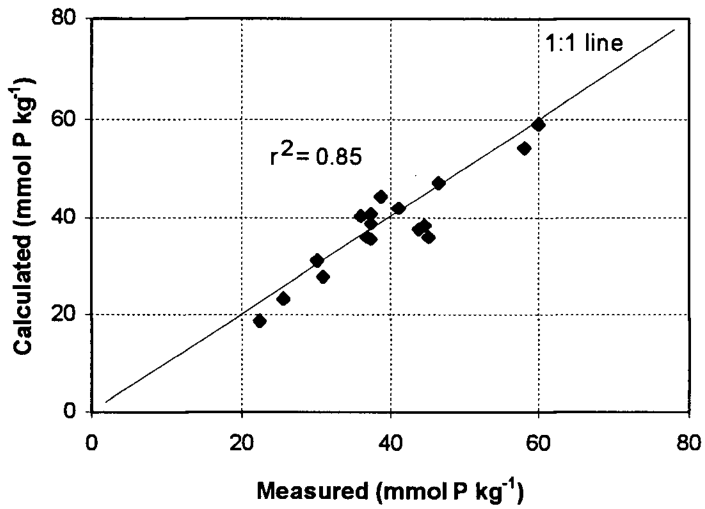
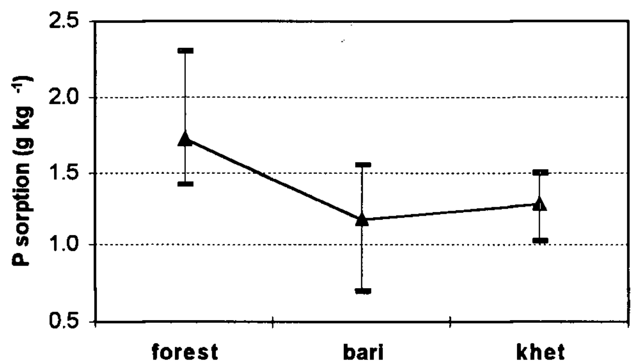


Figure 4.6. Comparison of measured P sorption capacity with calculated values from Borggaard's model (dataset: 1994 Jhikhu Khola nutrient cycling plot studies; 1989 Jhikhu Khola forest plot studies).

a) red soils



b) non-red soils

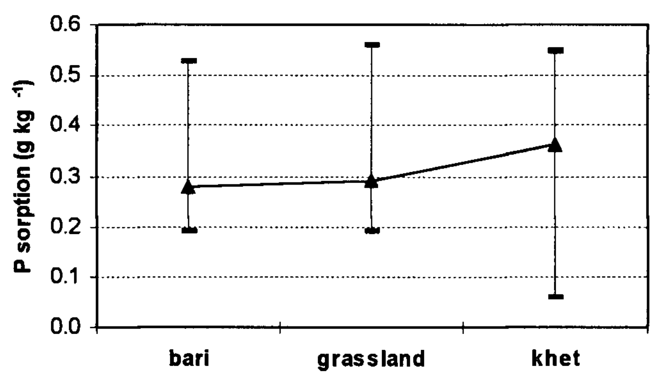


Figure 4.7. Calculated P sorption under different land uses on red and non-red soils; mean, minimum and maximum values (dataset: 1994 Jhikhu Khola nutrient cycling plot studies; 1989 Jhikhu Khola forest plot studies).

4.2 The Management of Soil Nutrients

The current soil fertility status and how it is changing will be strongly influenced by nutrient management. Within the study region, N, P and Ca are critical macronutrients which are potentially limiting to plant growth and may be significantly influenced by management. The dominant sources of nutrients in the study region are manure, compost and chemical fertilizers. Erosional losses of nutrients from upland sites, and nutrient inputs to irrigated lowland agriculture associated with water management and sedimentation are important redistributional processes. Available nutrients are lost from the rooting zone through crop uptake (discussed in section 4.3), P fixation, N leaching, denitrification, NH_3 volatilization and Ca leaching.

4.2.1 Initial Soil Nutrient Pool

The initial pool of soil nutrients may be calculated from the current soil fertility status for each land use category. Given the measured soil nutrient concentration, and assuming a soil bulk density of 1400 kg m^{-3} and a 15 cm rooting depth, the potentially available soil nutrient pool for N, P_2O_5 and Ca are show in Table 4.4. For each land use category, nutrient additions and/or losses will apply.

Table 4.4. Initial soil nutrient pool (mean values).

Land Use	Soil Nutrient Concentration (mg/kg)			Soil Nutrient Pool[1] (kg ha^{-1} furrow slice)		
	N	P_2O_5	Ca	N	P_2O_5	Ca
khet	854	49	2120	1793	103	4452
bari	941	47	1443	1976	99	3030
grass/shrub	1046	19	1126	2197	40	2365
forest	557	2	361	1170	4	759

dataset: 1993/94 Bela-Bhimsenthan soil survey; 1989 Jhikhu Khola forest plot studies
[1] assuming ρ_B= 1400 kg m^{-3} and a 15 cm soil depth

4.2.2 Compost and Chemical Fertilizer Use

Most Middle Mountain farmers' apply dry manure and compost to the fields to reduce pest problems and the labour required for transportation. Compost preparation and storage commonly utilizes a heaping method, where dung, forest litter and crop residues are piled. However, the piles are not turned and undecomposed or semi-decomposed compost is often applied to the fields. Compost heaps are often left exposed to intense sunlight and monsoonal rains, resulting in nutrient loss through denitrification, volatilization, and leaching (Sherchan and Baniya 1991, Suwal et al. 1991, Sthapit et al. 1988). Research at the Lumle Agriculture Research Centre indicates that the resulting compost has a low nutrient content averaging 0.6% N, 0.06% P_2O_5 , and 0.6% K_2O (Subedi et al. 1995). While these values are low in comparison to literature sources (Table 6 Appendix B), they are representative of current composting practices in the Middle Mountains. Pit composting is representative of best management practices (BMP) and provides an estimate of potential nutrient inputs from compost (Table 4.5). The Ca content of compost was estimated from average values for forest litter in the Jhikhu Khola Watershed (Table 7 Appendix B) and the Ca content of cattle dung derived from literature sources (Table 6 Appendix B). A typical compost comprised of 80% litter and 20% manure was used, and leaching losses during storage and handling of 20-40% were assumed. Nutrient inputs were then calculated for traditional compost and best management practices assuming a 25% moisture content.

Table 4.5. Nutrient content of compost (dry weight basis).

Nutrient Source	**N (%)**	**P_2O_5 (%)**	**K_2O (%)**	**Ca (%)**	**Source**
Middle Mountains					
Traditional Compost	0.6	0.06	0.6		Suwal et al. 1991
Pit Compost (BMP)	1.1	0.11	1.4		Suwal et al. 1991
Forest Litter & Manure				0.8-1.0	estimated

Nutrient inputs to rice, maize and wheat crops from organic matter and chemical fertilizer sources are summarized in Table 4.6. The greatest amount of organic matter inputs are applied to maize grown on bari lands during the monsoon. Farmers apply 12 t ha^{-1} of organic fertilizer to bari lands during the monsoon season on average, and up to 50 t ha^{-1} may be applied. While these levels are high by North American standards, they are within rates of compost use reported by other researchers in Nepal (Carson 1992, Pandey et al. 1995, Sherchan and Gurung 1995, Suwal et al. 1991, Rasali et al. 1995). During the winter, only 18% of farmers apply organic matter to bari fields. Organic matter inputs to khet fields are lower, roughly 4 t ha^{-1} in total, but are distributed over the premonsoon and monsoon periods. Note that organic inputs are highly variable between fields (Table 3.3). The resultant inputs show the relatively small N and P_2O_5 contributions made by organic matter with the exception of maize grown during the monsoon. In contrast organic matter is the main source of Ca on bari fields.

The dominant chemical fertilizers used are urea (46-0-0), complex© (20-20-0) and ammonium sulphate (21-0-0), and mainly supply inorganic N. Chemical fertilizer inputs are applied throughout the year, with early and monsoon rice receiving the largest N and P_2O_5 inputs. Inputs to rice typically meet fertilizer N recommendations for Nepal (100 kg ha^{-1} N and 70 kg ha^{-1} P_2O_5). However, fertilizer applied to maize and wheat are well below the locally recommended application rates of 120 kg/ha N and 70 kg ha^{-1} P_2O_5 for maize, and 100 kg ha^{-1} N and 115 kg ha^{-1} P_2O_5 for wheat (Chitrakar 1990, Thapa 1995). Nutrient inputs from chemical fertilizer are significantly greater than organic inputs (Table 4.6), with the exception of maize grown during the monsoon which receives 52% of N inputs and 20% of P_2O_5 inputs from organic sources. At the other extreme, winter wheat typically receives all N and P_2O_5 inputs from inorganic sources.

Table 4.6. Reported nutrient inputs from organic and chemical fertilizer sources.

System	n	Median Organic Matter Inputs[1]				Median Chemical Fertilizer Inputs		
		Amount[1] (kg ha^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	Ca (kg ha^{-1})	Amount[1] (kg ha^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})
premonsoon								
early rice (khet)	5	1,622	7	1	10	491	143	39
early maize (khet)	12	0	0	0	0	197	43	35
monsoon								
rice (khet)	49	2,457	11	1	15	334	90	39
maize (bari)	65	11,795	53	5	71	236	65	28
winter								
wheat (khet)	30	0	0	0	0	197	49	31
wheat(bari)	21	0	0	0	0	139	38	28

dataset: 1994 Bela-Bhimsenthan soil survey, n=200, male farmer responses

[1] Nutrient content based on farmers' practice

4.2.3 Erosion

Nutrient losses through erosion are estimated from erosion rates determined from plot studies and sediment budgets (Carver 1997), and nutrient losses measured from the erosion plots. Erosion rates, shown in Table 4.7, range from 26±5 t ha^{-1} on bari sites to zero on well managed grasslands, and 62±44 t ha^{-1} on degraded lands. Degraded lands are defined as shrub, grass or barren lands with greater than 50% soil exposure and visible rills or gullies. Average erosion rates are used to estimate nutrient losses under farmers' practice and lower estimates of erosion rates are used to simulate best management practices. For bari lands, the nutrient content of sediments eroded from the plots are used to estimate annual losses. For other land uses, the current soil fertility conditions are used to estimate potential nutrient losses. Eroded sediments commonly contain a higher nutrient content than the topsoil from which they are derived due to selective erosion of organic matter and surface soil high in nutrients. Enrichment factors commonly range from 2-4 (Young 1989, Sharpley et al. 1994), but given the low nutrient status of forest and shrub sites a conservative enrichment factor of 2 is used in the estimation of annual losses. Nutrient losses through erosion from bari fields result in an average annual loss of 25 kg N ha^{-1} and 13 kg Ca ha^{-1}. Available P losses are small, but organic P losses may be high, particularly if a high intensity rainfall event occurs before compost and manure are incorporated into the soil. Best management practices reduce erosion 25% from upland fields and result in a corresponding reduction in nutrient losses. Losses from well managed forests and grasslands are minimal, but shrub and degraded lands loose significant quantities of N and Ca annually (34 and 23 kg ha^{-1} respectively).

4.2.4 Water Management and Sedimentation

The diversion of stream floodwaters which carry large amounts of suspended sediments (Carver and Nakarmi 1995) onto fields through the irrigation system may result in considerable sediment deposition. Carver (1997) measured sediment deposition on 23 khet fields using accumulation pins. Sediment accumulation was measured on 76% of the khet fields and 40% of the fields had more than 5 mm of accumulated sediment.

Table 4.7. Erosion and associated annual nutrient losses from bari, forest, shrub and degraded lands.

	Nutrient Content ($mg\ kg^{-1}$)		Erosion[1]		Depth Integrated Losses ($kg\ ha^{-1}$ per soil loss depth)		
	Eroded	Residual	Rate $t\ ha^{-1}$	Soil loss mm	Eroded	Residual	Losses
Bari			26 ± 5	2			
N	1882	941			49	24	25
avail. P_2O_5	64	47			1.7	1.2	0.5
Ca	1980	1443			51	28	13
total bases	2777	1937			72	50	22
Shrub			10 ± 2	1			
N	2092	1046			21	11	10
avail. P_2O_5	38	19			0.4	0.2	0.2
Ca	2252	1126			23	11	12
total bases	3034	1517			30	15	15
Forest			2 ± 0.2	0.1	negligible		
N		557					
avail. P_2O_5		2					
Ca		361					
total bases		566					
Grassland			0	0	negligible		
Degraded			62 ± 44	4			
N	1114	557			69	35	34
avail. P_2O_5	4	2			0.2	0.1	0.1
Ca	722	361			45	22	23
total bases	1132	566			70	35	35

[1] Erosion rates from Carver 1997

Nutrients losses based on: erosion plot data and current soil conditions with an enrichment factor=2

N losses estimated from %C based on correlation

Nutrient analysis of the newly accumulated sediments and the underlying residual soils indicate significant nutrient enrichment. Figures 4.8 a-c illustrate the higher fertility levels of the newly accumulated sediments. Points below the 45° line represent enriched conditions between residual and accumulated soils in the 23 khet fields. In all but two fields, the newly accumulated material was higher in Ca, P and %C than the residual soils. The average rate of nutrient enrichment ranges from 1.3 for exchangeable Ca to 2.7 for available P. Nutrient enrichment of low lying khet lands associated with irrigation and sediment deposition were also noted by Wymann (1991) in the Dhulikhel subwatershed.

Annual nutrient inputs to lowland khet fields can be calculated based on the amount of sediment accumulated and the nutrient content of those sediments. Given a median annual sediment accumulation of

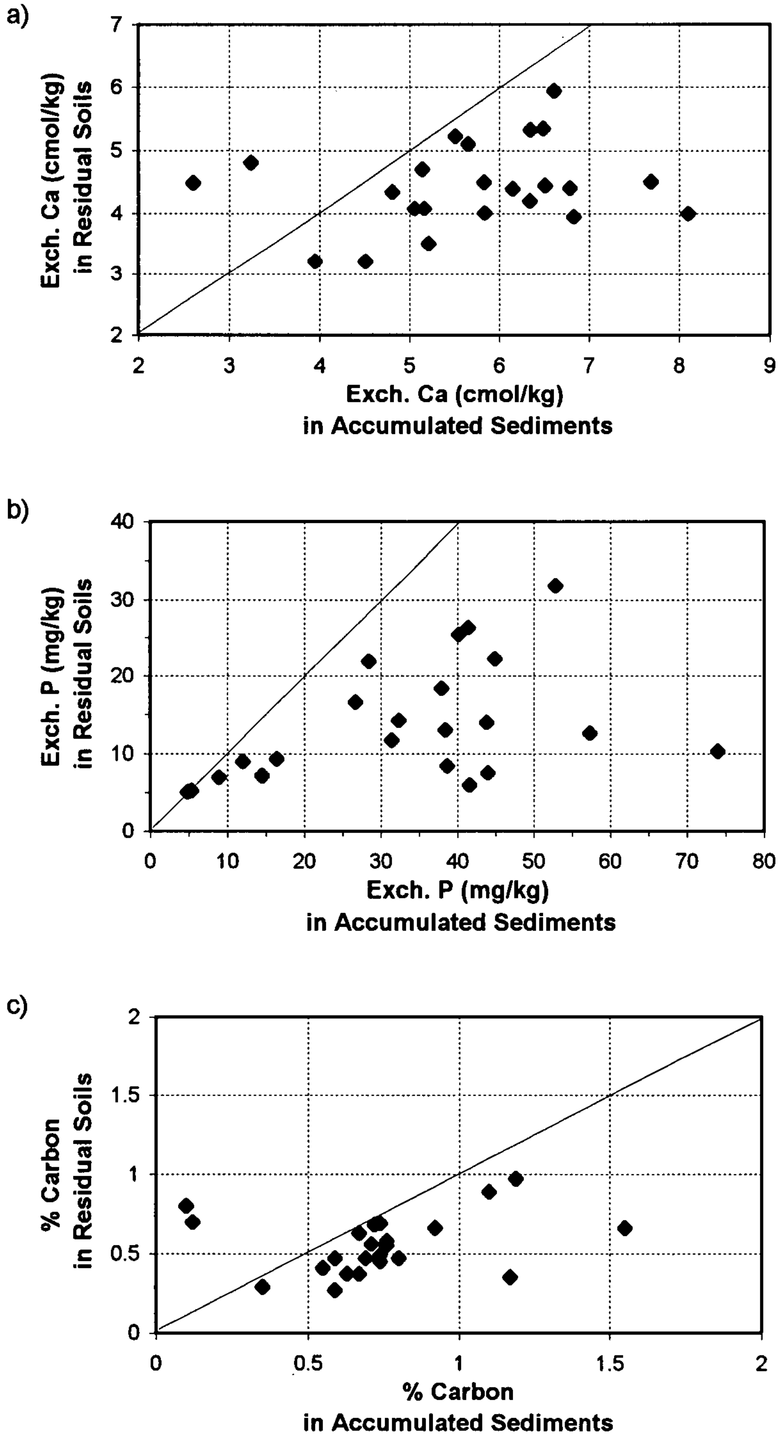


Figure 4.8. Nutrient enrichment in khet fields a) exchangeable Ca;
b) exchangeable P; and c) % carbon (data source: Shah and Schreier 1995b).

4 mm and assuming a soil bulk density of 1400 kg m^{-3}, the annual nutrient enrichment is listed in Table 4.8. An additional 11 kg N ha^{-1} and 28 kg Ca ha^{-1} are potentially available for plant uptake.

Nutrients may also be input to khet fields through irrigation water. Spring and stream water samples taken during the dry season of 1990 (Schreier et al. 1994b) indicate that the water is alkaline and contains moderate quantities of Ca, Mg, NO_3 and PO_4 (Table 4.9). Assuming a 0.5 metre depth of water applied three times per rice crop, irrigation water may contribute an additional 6 kg N ha^{-1} and 300 kg Ca ha^{-1}.

Table 4.8. Estimated rates of annual nutrient enrichment on khet fields from newly accumulated sediments.

Variable		**Median Nutrient Concentration**[1]		**Estimated Annual Inputs ($kg\ ha^{-1}$ for a 4 mm soil depth)**		
	Units	**Accumulated**	**Residual**	**Accumulated**	**Residual**	**Enrichment**
C	%	0.73	0.56			
N[2]	%	0.07	0.05	39	28	11
available P_2O_5	mg kg^{-1}	74.7	30.9	4.2	1.7	2.5
pH	pH	4.9	4.8			
Base Saturation	%	66.0	58.9			
CEC	cmol kg^{-1}	10.9	9.3			
Ca	mg kg^{-1}	2273	1776	127	99	28
Total Bases	mg kg^{-1}	2564	1975	144	111	33

[1]data source: Shah and Schreier 1995b

[2] %N calculated from correlation with %C from nutrient dynamic plot study data

Table 4.9. Chemical composition of irrigation waters.

Variable	**Spring**[1]	**Stream**[1]	**Annual Inputs**	
			Nutrient	kg ha^{-1}
pH	8.2	8.7		
NO_3 (mg l^{-1})	1.7	1.9	**N**	6.1
PO_4 (mg l^{-1})	0.25	0.26	**P_2O_5**	0.3
Ca (mg l^{-1})	20.1	20.0	**Ca**	300
Mg (mg l^{-1})	3.3	1.4		
K (mg l^{-1})	1.9	1.8		
			total bases	509

data source: Schreier et al. 1994b

[1] based on standard methods (Inland Waters Directorate, 1979)

Flooding and Nutrient Availability

Nutrient availability is impacted by flooding. The overall effect of flooding is to increase the pH in acid soils as OH^- ions are released when $Fe(OH)_3$ and similar compounds are reduced. Most paddy soils reach pH values of 6.5 to 7 within one month after flooding and remain at that level until drained. The concentration of phosphorus in the soil solution increases upon flooding due to the reduction of ferric phosphates to more soluble ferrous phosphate, the hydrolysis of Fe and Al bonded phosphates and increased mineralization associated with the rise in pH. As K^+, Ca^{2+} and Mg^{2+} are already in a reduced state they are not directly affected by flooding, but NH_4^+, Fe^{2+} and Mn^{2+} released upon flooding may displace K^+, Ca^{2+}, Mg^{2+} from exchange sites into the soil solution (Sanchez 1976, Patrick 1982, Legg and Meisinger 1982).

Blue-green Algae

Cyanobacteria (blue-green algae) provide supplemental N in rice production. Nitrogen fixation by blue-green algae in the water column and on the surface of submerged soils is an important N source in rice production. Blue-green algae fix atmospheric N_2 and produce soluble NH_4^+, generally fixing 20-65 kg NH_4^+ ha^{-1}. In addition to free-living blue-green algae, *Anabaena azollae* fix N in symbiotic association with the freshwater fern *Azolla*. The algae are able to assimilate N dissolved in the water and in exchange receive photosynthate from the *Azolla* roots. This fixed N is used by the rice when the *Azolla* die and the organic N is mineralized (Buresh and DeDatta 1991, Patrick 1982, Khan 1983, Eskew 1987, Grist 1986, App et al. 1980). Nutrient analysis of green manuring plants conducted at the Lumle Agricultural Research Centre (Suwal et al. 1991) indicates *Azolla* contains 4.5% N by dry weight, but the distribution of *Azolla* in the study region is limited. Blue-green algae are naturally occurring in the ponded water of roughly one-third of rice fields in the study area, and likely supply 10-20 kg N ha^{-1} to the rice crop.

4.2.5 Phosphate Fixation

The high phosphate fixation capacity of soils in the study region described in section 4.1.3 has important ramifications for P management. The P sorption potential for these soils is given in Table 4.10 and compared to values from literature sources. The P sorption capacity averages 6,700 kg P_2O_5 ha^{-1} for red soils and 1,500 kg P_2O_5 ha^{-1} for non-red soils, and are comparable to tropical soils high in kaolinite. Given the high potential for fixation, P released to the soil solution will be governed by the chemical equilibria between soluble and insoluble mineral forms of P, the slow release of inorganic P by mycorrhizal fungi and other micro-organisms, and by mineralization and immobilisation of organic P.

Table 4.10. Phosphate sorption potential.

Soil	**Description**	**P sorption capacity**		**Source**
		g P (kg soil)$^{-1}$	kg P_2O_5 ha^{-1}	
Red Soils	Forest	1.7	8200	Plot studies, n=10
	Khet-Bari	1.2	5900	Plot studies, n=20
Non-red Soils	Khet-Bari-Grass	0.3	1500	Soil Survey, n=26
Andosols	Imogolite, Allophane	8-15	17,000-31,000	Dabin 1980
Spodosols	B.C. Forest	1-6	2,500-17,000	Yuan and Lavkulich 1994
Oxisols, Ultisols	Kaolinite clay	0.5-1	2,300-4,800	Sanchez 1976
Andepts	Allophane	>1	>5,000	Sanchez 1976

The proportion of applied fertilizer P which remains available to plants, decreases with the degree of soil weathering. The higher Fe and Al oxide content typical of older soils results in a larger P fixation capacity. On moderately to highly weathered soils the portion of fertilizer P remaining as available P after six months is low, ranging from 53-73% (Sharpley and Halvorson 1994). Mineralization of organic matter additions may provide an important source of available P. In the tropics net P mineralization commonly ranges from 16-157 kg ha^{-1} yr^{-1} (15-20% of total soil organic P) and crops may recover 20-40% of P applied in organic inputs annually (Sharpley and Halvorson 1994, Sommers and Sutton 1980).

4.2.6 Nitrogen Dynamics

Nitrogen is the most mobile of the nutrients required for plant growth and subject to the greatest losses from the soil-plant system. Gaseous losses through NH^{3+} volatilization are particularly high with the surface application of urea, other ammonia based fertilizers and manure. Denitrification, the reduction of NO_3^- to gaseous forms of N by chemoautotrophic bacteria, is regulated by the availability of NO_3^- and C compounds, and low O_2. As NO_3^- originates by nitrification, an aerobic process, alternating aerobic and anaerobic conditions such as heavy rain or intermittent flooding are conducive to denitrification. Losses of N by leaching occurs mainly as NO_3^- because of the low capacity of most soils to retain anions (Pierzynski et al. 1994, Miller and Donahue 1990, Stevenson 1986).

Fertilizer N Efficiency

The efficiency for the recovery of applied N from chemical fertilizers in cropping systems rarely exceeds 60% and commonly ranges from 30-50%. Up to 50% of N applied as urea and ammonium sulphate fertilizers may be lost by volatilization within 1-4 days of application. Leaching losses of N commonly average 25-50% and a large nitrate flush is associated with the beginning of the rainy season (Pierzynski et al. 1994, McNeal and Pratt 1978, Sanchez 1976, Rolston 1978, Broadbent 1978, Stevenson 1986).

Organic Matter Application and Nutrient Availability

Nitrogen losses from organic matter are strongly influenced by handling, storage and application procedures. Within the study region, compost heaps are often left exposed to rain and sun, manure is typically dried prior to transport, and organic matter may be placed on the fields 2-3 weeks prior to ploughing, depending on the availability of labour (Joshi et al. 1995, Rasali et al. 1995). Nitrogen losses prior to incorporation into the soil may be as high as 40 or 50% (Kirchman 1994, Legg and Meisinger 1982, DeDatta and Buresh 1989, Muchovej and Rechcigl 1994). Once incorporated, compost and manure provide a slowly available N source. Organic matter mineralization in the first year generally ranges from 35-40%, with 15-25% mineralized in the second year (Broadbent 1978, Kirchman 1994). With application rates of 20-30 t ha^{-1} leaching losses are generally small. Denitrification of applied organic matter is maximum within the first week and losses of 5 kg ha^{-1} day^{-1} are common during wet periods, but annual losses are typically only 5-8% (Rolston 1978). The recovery of organic N by crops is commonly 15-30%, but 15-45% remains in the soil and is potentially available to subsequent crops (Legg and Meisinger 1982, Kirkmann 1994).

Rice Production Systems

Rice production provides a unique set of chemical (oxidation - reduction), physical (puddled soil) and microbial (aerobic versus anaerobic) conditions which influence N transformations within the soil. When a soil is flooded, reducing conditions become prevalent in less than one day. Nitrates present in the soil are then denitrified and lost to the atmosphere. Under flooded soils, organic matter is decomposed to NH_4^+, which is stable in anaerobic conditions and therefore accumulates. The presence of a thin oxidized layer over the reduced topsoil leads to nitrification of surface applications of organic matter or ammonium fertilizers. The resulting nitrate ions may move downward by diffusion or leaching into the reduced layer where denitrification quickly occurs and the N_2 gases produced escape to the atmosphere. Intermittent flooding results in alternating oxidation / reduction conditions and large N losses. Right after flooding, nitrates quickly disappear and the NH_4^+ content increases. When the soil dries, a portion of the NH_4^+ is nitrified into NO_3^-. In the next flooding these NO_3^- ions are lost by denitrification or leaching. The recovery of applied N may be lower under flooded rice and is typically 20-50% (Legg and Meisinger 1982, Patrick 1982, Stevenson 1986, Sanchez 1976, DeDatta and Buresh 1989, Buresh and DeDatta 1991).

Grasslands

Within the study region, grasslands are low management, low productivity sites and have a minimum potential for N losses. Grasslands are N deficient and therefore limited NO_3^- is available for leaching. Urine and dung patches result in high localized N concentrations and may be subject to high gaseous N losses, but leaching losses from unmanaged grasslands are typically <1% (Muchovej and Rechcigl 1994, Owens 1994, Kirchmann 1994).

4.2.7 Calcium Availability

High H^+ activity impedes Ca uptake by plants and in acid mineral soils Ca is not readily available to plants at low base saturation. Soils with kaolinitic clays are able to satisfy the Ca^{2+} requirements of most agricultural crops at 40-50% Ca saturation (Tisdale et al. 1985). The Ca saturation for soils in the study region is shown in Figure 4.9. Values are generally satisfactory for khet sites (average 48%), but below optimum for bari and grassland sites, and very low for forest sites.

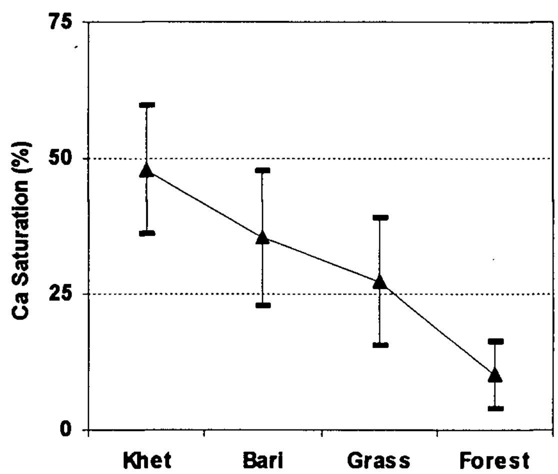


Figure 4.9. Calcium saturation % (mean + 1 standard deviation)
(dataset: 1993/94 Bela-Bhimsenthan soil survey, n=200; 1989 Jhikhu Khola forest plot studies, n=7).

Calcium losses by leaching depend on the amount of rainfall, the Ca supply in the soil and soil texture. The Ca concentrations of stream and spring waters (20 mg l^{-1}) in the study area (Table 4.9) are evidence of Ca leaching. If 100 mm of drainage water passes through the soil, 20 mg l^{-1} Ca in the water represents leaching losses of 20 kg ha^{-1}. Leaching losses from limed tropical soils may be as high as 40-75% but losses from the study area are likely near the lower range of these values. Under rice production considerable quantities of exchangeable Ca are added by flood waters and the increase in pH associated with reducing conditions will likely result in Ca fixation (Bohn et al. 1979, Cooke 1981, Bohan et al. 1997, Bolton 1972, Cahn et al. 1993, Wong et al. 1992, van der Pol and Traore 1993, Brady and Weil 1996).

Available Ca is also impacted by the use of N fertilizers. Ammonium based fertilizers are oxidized by bacteria to form NO^{3-} and H^+, and unless sufficient liming material is present a reduction in pH will result (Brady and Weil 1996, Foth 1990). Acidification due to fertilizers and the Ca required to neutralize their acidifying effects are given in Tables 4.11 and 4.12. Urea and complex© are widely utilized and moderately acidifying, while ammonium sulphate is highly acidifying. Median fertilizer inputs require only moderate Ca to neutralise the acid formed, but high maximum values are indicative of isolated problems and the potential impact of future increases in fertilizer use.

Table 4.11. Acidification due to fertilizers.

Fertilizer	**Acidifying Effect** (kg CaO per kg N applied)
Urea	-1
Complex©	-1
Ammonium Sulphate	-3

source: Landon 1984

Table 4.12. Chemical fertilizer application and equivalent acidity.

Land Use		**Fertilizer Applied (kg ha^{-1})**			**Equivalent Acidity (kg Ca)**	
		complex©	**urea**	**ammonium sulphate**	**median**	**range**
Bari	**maize**	0-786	0-491	0-491	7	0-237
	wheat	0-491	0-200	0-59	3	0-28
Khet	**early maize**	0-315	0-265	0-118	6	4-62
	rice	0-982	0-491	0-982	12	0-474
	wheat	0-393	0-295	0	5	0-17

dataset: 1993/94 Bela-Bhimsenthan soil survey, n=130, male farmer responses

4.3 Crop Nutrient Uptake

Soil nutrients are essential to the growth and development of plants, but the collection of forest products and the intensive cultivation of crops may deplete the soil nutrient pool if organic and chemical fertilizer inputs are not sufficient. Nutrients removed from the soil by plant growth vary with the variety of plant and its yield (Miller and Donahue 1990). Nutrient uptake by the main staple crops grown in the region is calculated from reported yield data and average values of N, P_2O_5 and Ca uptake derived from literature sources. Reported yields for rice, maize and wheat are compared to regional values and locally measured yields to assess the validity and variability of yields reported by farmers.

Rice, maize and wheat yields reported by farmers for individual fields are summarized in Table 4.13 and compared to locally measured yields and regional averages. Locally measured yields were determined for rice, maize and wheat samples collected from 1 m^2 quadrats immediately prior to harvesting, and dry matter was determined for grain and total biomass. While measured yields are representative of site specific conditions, the spatial and temporal variability of yield data is high and the low sample size (n=62) may not be representative. Reported rice yields average 5368 $\pm$ 2207 kg ha^{-1} for premonsoon rice and 3470 $\pm$ 1706 kg ha^{-1} monsoon rice. Reported premonsoon rice yields are substantially higher than monsoon yields but the small sample size (n=5) makes comparison difficult. Monsoon rice yields reported by farmers are considerably lower than values measured locally by MRM project staff, however, they are within the range of regional yields (800-7000 kg ha^{-1}) reported by literature sources. Reported maize yields are typically 3123 $\pm$ 1800 for early maize and 4123 $\pm$ 1772 kg ha^{-1} for monsoon maize, and correspond well with locally measured values. Wheat yields reported by farmers are typically 1541 $\pm$ 1085 kg ha^{-1} and are slightly lower than locally measured and regional values. Wheat yields reported for khet land correspond well to measured values, while average yields on bari land are lower as anticipated. Overall, yields reported by farmers are highly variable but within reasonable limits.

Table 4.13. Reported, locally measured and regional yields for dominant crops.

System	Reported Farm Yield[1] (kg ha^{-1})			Local Measured Yield (kg ha^{-1})			Regional Yield (kg ha^{-1})	
	mean	std dev	n	mean	std dev	n	range	source
premonsoon								
early rice (khet)	5368	2207	5					
early maize (khet)	3123	1800	12					
monsoon								
rice (khet)	3470	1706	49	6037	2194	27	800-7000	Carson 1992
							2488	LRMP 1986
							1560-4943	Suwal et al. 1991
							1179-5050	Sherchan et al. 1991a
							1112-1478	Shah et al. 1987
maize (bari)	4123	1786	65	4561	1436	19	1599	Carson 1992
							980	LRMP 1986
							1323-2838	Suwal et al. 1991
							837-3288	Sherchan et al. 1991a
							803-1003	Shah et al. 1987
winter								
wheat (khet/bari)	1563	1099	51	2512	1159	16	1415	Carson 1992
							899	LRMP 1986
							2310	Suwal et al. 1991
							1675-5984	Sherchan et al. 1991a
wheat (khet)	1854	1293	30	2025	1048	8	521	Shah et al. 1987
wheat(bari)	1147	535	21	3000	1112	8	512	Shah et al. 1987

[1] dataset: 1993/94 Bela-Bhimsenthan soil survey, n=130, male farmer responses

Nutrient removal by rice, maize and wheat is summarized in Table 4.14 and supplemental data listing nutrient uptake from individual references is provided in Tables1-3 of Appendix B. The percent nutrient composition by weight refers to the entire above ground portion of the crop. Nutrient uptake by the total biomass is utilized as crop residues are harvested and used for animal feed. Reported yield values are used to estimate total dry matter based on the ratio of grain to total biomass. For rice, maize and wheat, grain comprises roughly 45% of total dry matter (Grist 1986, Olson and Kurtz 1982, Cox et al. 1985, LRMP 1986a, Aldrich et al. 1975, Stoskopt 1985). The total estimated dry matter on a kg/ha basis is then multiplied by the percent nutrient composition to calculate N, P_2O_5 and Ca uptake.

Table 4.14. Nutrient removal by the dominant staple crops (median values).

System	Reported Yield[1] (kg/ha)	n	Average Composition[2]			Nutrient Uptake (kg/ha)		
			% N	% P_2O_5	% Ca	N	P_2O_5	Ca
premonsoon								
early rice (khet)	2876-7669	5	1.0	0.4	0.1	108	43	11
early maize (khet)	1054-6389	12	1.4	0.6	0.3	79	34	17
monsoon								
rice (khet)	959-7669	49	1.0	0.4	0.1	74	30	7
maize (bari)	688-8256	66	1.4	0.6	0.3	128	55	27
winter								
wheat (khet/bari)	334-5351	53	1.2	0.5	0.1	36	15	3
wheat (khet)	669-5351	31	1.2	0.5	0.1	45	19	4
wheat(bari)	334-2675	22	1.2	0.5	0.1	36	15	3

[1] dataset: 1994 Bela-Bhimsenthan household survey, n=85 male farmer responses

[2] composition by weight, supporting data provided in Tables 1-3, Appendix B

Nutrient uptake is greatest for maize grown during the monsoon with a median of 128 kg N, 55 kg P_2O_5 and 27 kg Ca removed per ha. Monsoon rice removes roughly 74 kg N, 30 kg P_2O_5 and 7 kg Ca per ha, while premonsoon maize and rice remove intermediate levels of N, P_2O_5 and Ca. Wheat, the main crop grown during the winter, removes the least nutrients with a median uptake for khet and bari sites of 36 kg N and 15 kg P_2O_5 per ha. These values cannot be taken as precise since the nutrient composition of crops vary substantially with differences in soil nutrient availability, plant genotype and local environmental conditions. However, these estimates of nutrient uptake for specific fields provide an indication of the level of nutrient inputs required to maintain the soil nutrient pool (Olson 1978, Western Canadian Fertilizer Association 1992).

4.3.1 Soil - Productivity Relationships

Nutrients removed from the soil pool by crop uptake and harvesting are dependent on crop productivity which in itself is a function of available soil nutrients. To evaluate relationships between soil fertility and crop productivity, reported yields are correlated with soil chemical properties for the main staple crops grown in the study area, and differences in soil chemistry between high, medium and low productivity sites are examined.

Correlations between yield and soil chemistry are weak and likely reflect differences in management, but differences in soil chemistry are noted between productivity classes. Maize, wheat and rice productivity classes (low, moderate and high) are defined from the histograms of reported yields for the 130 agricultural sites. Tables 4.15 summarizes the significant soil factors influencing maize and wheat productivity within the study region. Low maize productivity sites (yield <3,000 kg ha^{-1}) display significantly lower pH, Ca, Mg, base saturation and %C than moderate or high productivity sites. Similarly low productivity wheat sites (yield <1,500 kg ha^{-1}) have significantly lower pH, Ca and base saturation than moderate or high productivity sites. No significant differences in yield were noted with soil P, as soil P is likely compensated by P additions through management. Low, moderate and high rice productivity sites did not show any significant differences in soil fertility. Given the intensive management on rice fields, inherent soil fertility likely has a low impact on rice productivity.

Table 4.15 Soil parameters influencing maize and wheat yields (based on Mann Whitney U test)

Soil Parameter (mean values)	**Maize Yield (kg ha^{-1}) n=65**			**Significant Factors**	
	<3000 low	3000-5000 moderate	>5000 high	<3000 vs. 3000-5000	<3000 vs. >5000
pH	4.6	4.9	4.8	●	+
Ca (cmol kg^{-1})	2.85	4.01	3.74	●	+
Mg (cmol kg^{-1})	1.13	1.63	1.37	●	+
Base Saturation (%)	46.4	54.8	57.2	●	●
C (%)	0.89	1.01	1.00	●	●
Soil Parameter	**Wheat Yield (kg ha^{-1}) n=51**			**Significant Factors**	
	<1500 low	1500-2500 moderate	>2500 high	<1500 vs. 1500-2500	<1500 vs. >2500
pH	4.9	5.1	5.1	+	●
Ca (cmol kg^{-1})	4.13	5.05	4.97	+	+
Base Saturation (%)	5.83	63.99	61.85	+	

dataset: 1993/94 Bela-Bhimsenthan soil survey, male responses

● Significance of $\alpha<0.05$ + Significance of $\alpha<0.15$

4.4 Nutrient Budget Model

The impact of management practices on soil fertility for the dominant land uses in the study region is quantified by modelling nutrient inputs, redistribution and losses. Nutrient inputs are associated with compost, fertilizer, sediment, water and biota; redistribution processes include erosion-sedimentation, mineralization-immobilisation, and adsorption-desorption; and losses include leaching, denitrification, volatilization, chemical fixation, erosion and plant uptake. As nutrient inputs to forest, shrub and grass lands are limited, a more detailed assessment is conducted for cultivated lands. Estimates of nutrient dynamics on forest and grass / shrub lands are presented in sections 5.2 and 5.5 respectively. Only nutrient budgets for cultivated lands will be discussed in this section.

The approach and assumptions used to model soil N, P_2O_5 and Ca is shown diagramatically in Figures 4.10-4.12. Nutrient flows are integrated over a 15 cm soil depth. Inputs from compost and chemical fertilizer sources to cultivated lands are based on responses from surveyed farmers (Table 4.6). Compost additions to maize fields typically supply 53 kg N, 5 kg P_2O_5 and 71 kg Ca per ha, and additions to rice fields supply a median of 11 kg N, 1 kg P_2O_5 and 15 kg Ca per ha. Compost additions are subjected to mineralization and retention, and provide nutrients to subsequent crops through organic residues. Organic matter mineralization is assumed to be 40% in the first year, 25% in the second year and 15% in the third year (Broadbent 1978, Kirchman 1994). Inputs from traditional compost are subjected to storage and handling losses prior to incorporation and further N losses under crops will likely be small, however N losses under fallow may be substantial and are assumed to be 70% (McNeal and Pratt 1978, Kirchman 1994). Chemical fertilizer additions to rice fields typically supply 90 kg N and 39 kg P_2O_5 per ha, and additions to maize fields supply a median of 65 kg N and 28 kg P_2O_5 per ha. Crop recovery of applied fertilizer N is taken at 40%, that is 60% losses are assumed due to leaching, volatilization and denitrification (Pierzynski 1994, Cooke 1981, Stevenson 1986, McNeal and Pratt 1978). Phosphate fixation by Fe and Al oxides is assumed to be 73% of applied fertilizer P and 10% of mineralized organic P on red soils, and 53% of applied fertilizer P on non-red soils, with a subsequent slow release of 15% per

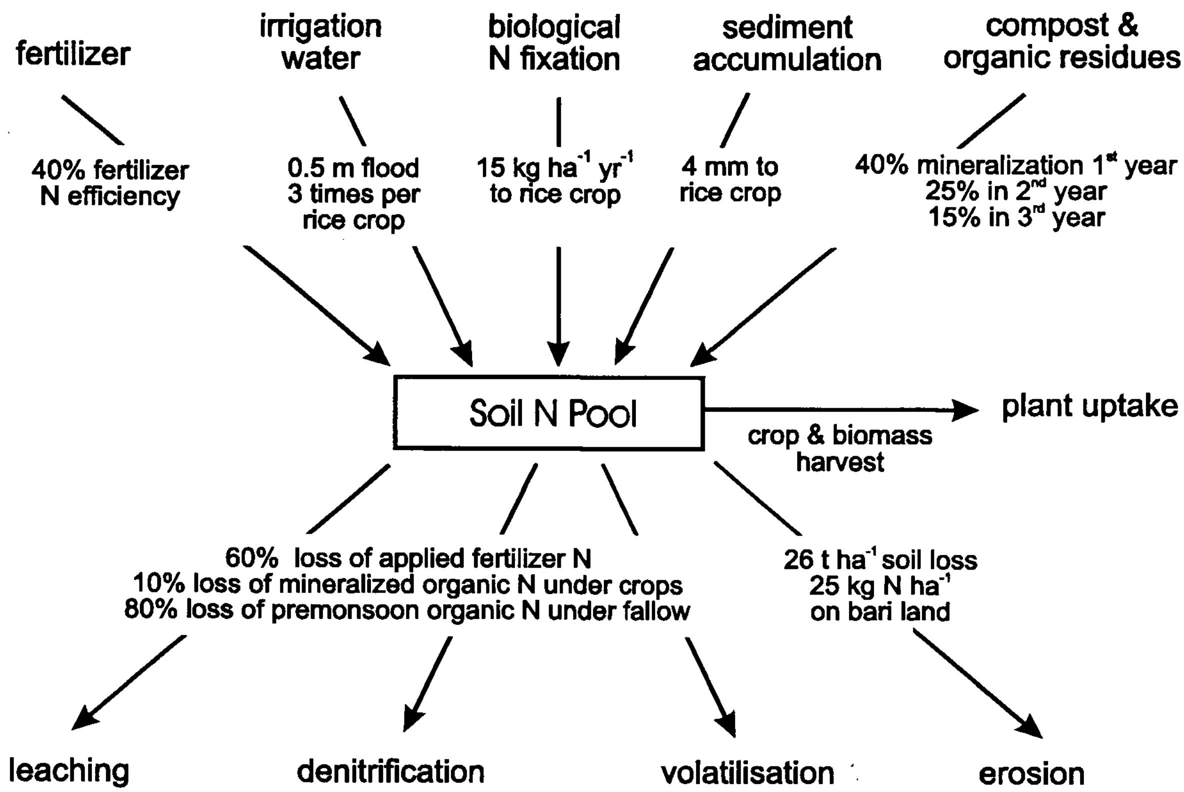


Figure 4.10. Approach for modelling soil N dynamics.

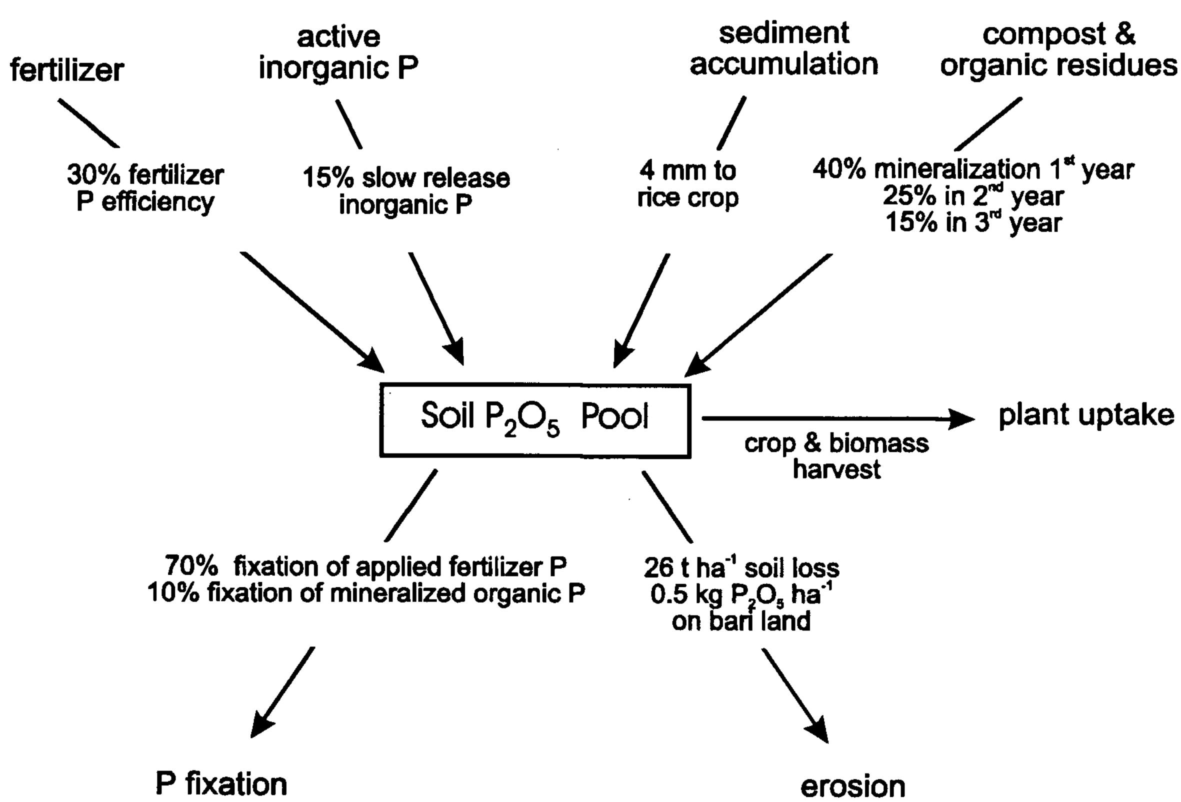


Figure 4.11. Approach for modelling soil P dyanmics.

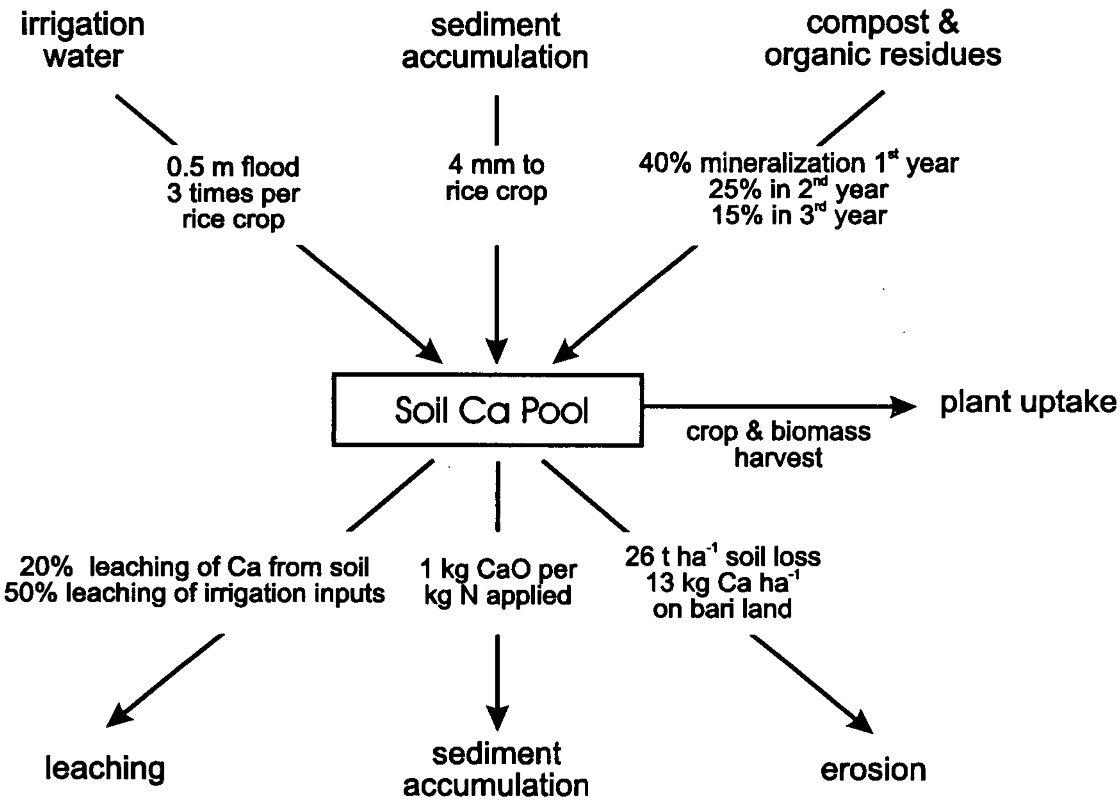


Figure 4.12. Approach for modelling soil Ca dynamics.

annum by chemical and microbial processes (Sharpley and Halvorson 1994). Nutrient losses through erosion are based on erosion plot data and catchment studies (Table 4.7) Losses from bari fields by erosion are typically 25 kg N, 0.5 kg P_2O_5, and 13 kg Ca per ha. Nutrient additions through sediment trapping on rice fields are estimated from annual enrichment rates (Table 4.8), and potential inputs from irrigation water are listed in Table 4.9. Sediment trapping on rice fields typically supplies 11 kg N, 2.5 kg P_2O_5, and 28 kg Ca per ha. Irrigation waters supply moderate levels of N (6.1 kg N ha^{-1}) and significant Ca (300 kg ha^{-1}). Ca losses by leaching are taken at 40% for all sources, and 30% Ca fixation is assumed under rice production (Bohn et al. 1979, Cooke 1981). The Ca required to neutralize the acidifying effects of chemical fertilizers (dominantly urea) is taken at 1 kg CaO per kg N applied (Table 4.11). Nutrient removal by the dominant staple crops are based on reported yields (Table 4.14). Monsoon maize removes a median of 128 kg N, 55 P_2O_5, and 27 kg Ca per ha, and monsoon rice typically removes 74 kg N, 30 P_2O_5, and 7 kg Ca per ha.

4.4.1 Nutrient Budgets for the Dominant Cropping Systems

Nutrient budgets for a dryland maize-wheat rotation and an irrigated early maize-rice-wheat rotation are shown in Figures 4.13-4.20. Calculated N, P_2O_5 and Ca inputs and withdrawals are shown for individual crops and a seasonal budget. Inputs from compost indicate the total nutrients contained in organic matter applied to a crop, while organic residues supply nutrients from prior compost applications, and organic retention refers to compost which is not decomposed during the growing season. Phosphorus fixation indicates the absorption of P by Al and Fe oxides, and active inorganic P refers to slow release of inorganic P from prior inputs. Median values of compost, fertilizer and crop uptake for households growing each crop are used, regardless of the actual cropping sequence.

Under dryland agriculture two crops are typically grown, the most common rotation involving a premonsoon fallow period, monsoon maize and winter wheat. The overall nutrient budget shows significant deficits in N and P (Figure 4.15), largely related to maize production (Figure 4.13). While the addition of compost to maize fields is typically 12 t ha^{-1}, mineralization only supplies 13 kg N and 1 kg P_2O_5 per ha furrow slice, and the high nutrient requirements of the maize crop result in deficits. Dryland wheat (Figure 4.14), which has relatively low yields, removes significantly less nutrients from the soil, and receives nutrients through fertilizers and organic matter applied to the previous maize crop.

On khet lands, up to three crops may be grown, typically involving a premonsoon maize crop, monsoon rice and winter wheat. Under paddy rice cultivation (Figure 4.17), chemical fertilizers provide the main source of N and P, but additional inputs are associated with the trapping of sediments, biological N fixation and irrigation waters. Small deficits are noted for N and P, and surplus Ca is associated with inputs through irrigation. Winter wheat (Figure 4.18) and early maize (Figure 4.16) are nutrient deficient, resulting in a negative overall budget for N and P when three crops are grown (Figure 4.19). If only two crops are produced (Figure 4.20), N and P deficits are significantly reduced.

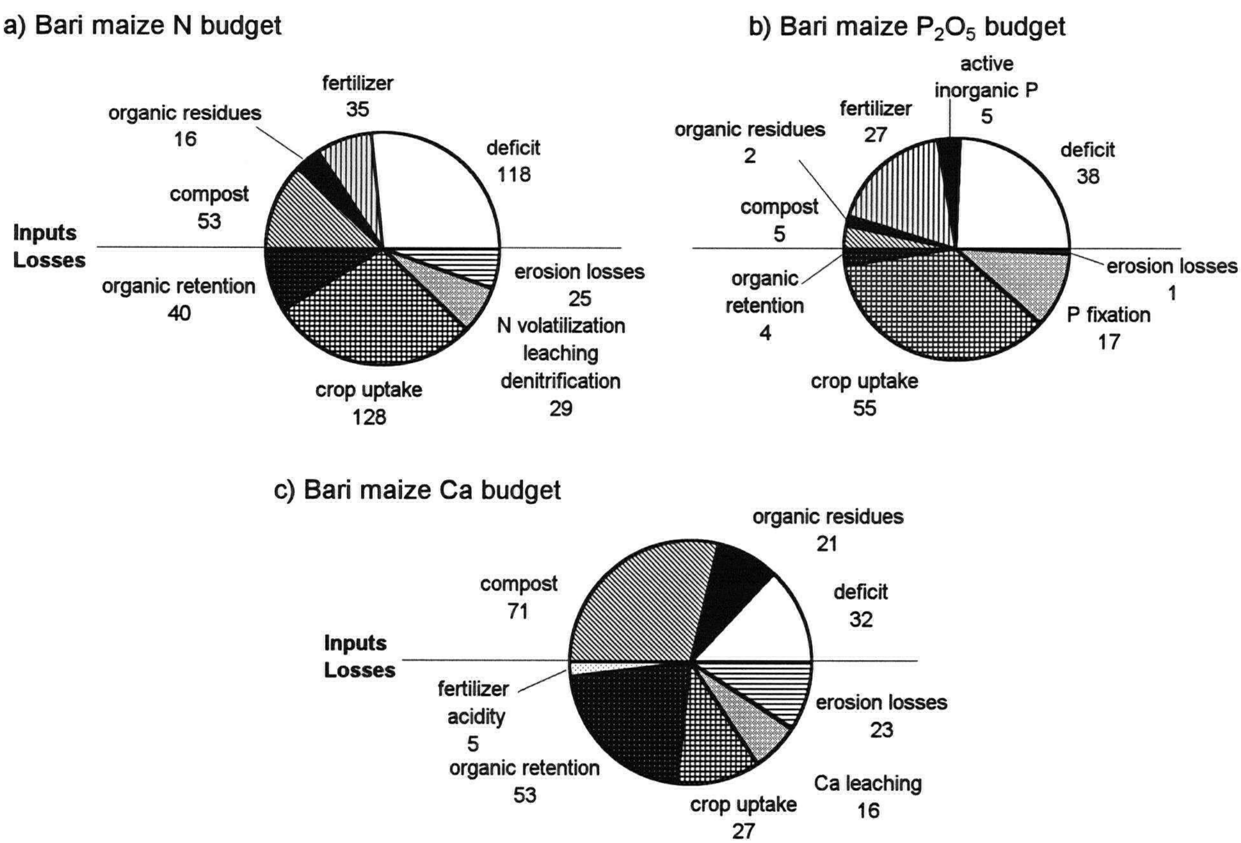


Figure 4.13. Nutrient budget for maize on bari (kg ha^{-1} furrow slice).

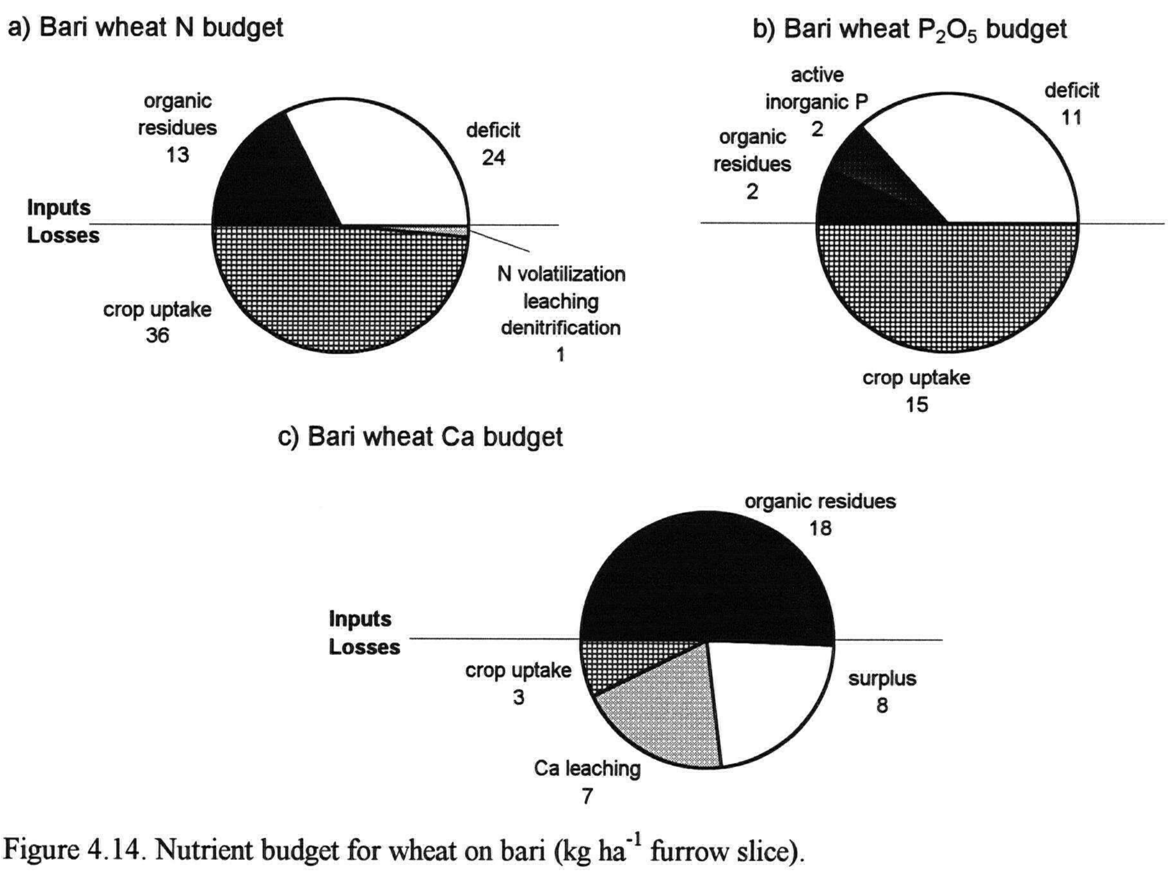


Figure 4.14. Nutrient budget for wheat on bari (kg ha^{-1} furrow slice).

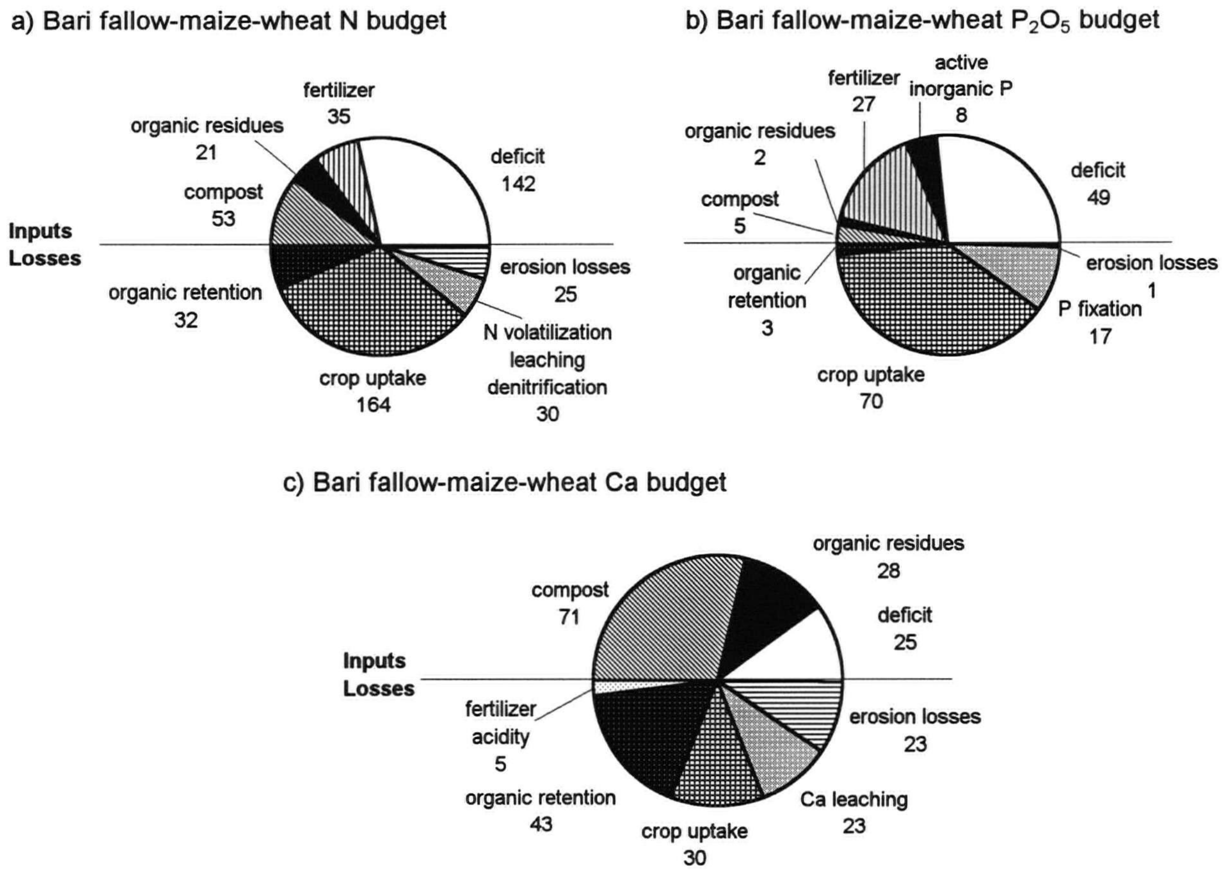


Figure 4.15. Nutrient budget for the dominant cropping sequence on bari (kg ha^{-1} furrow slice).

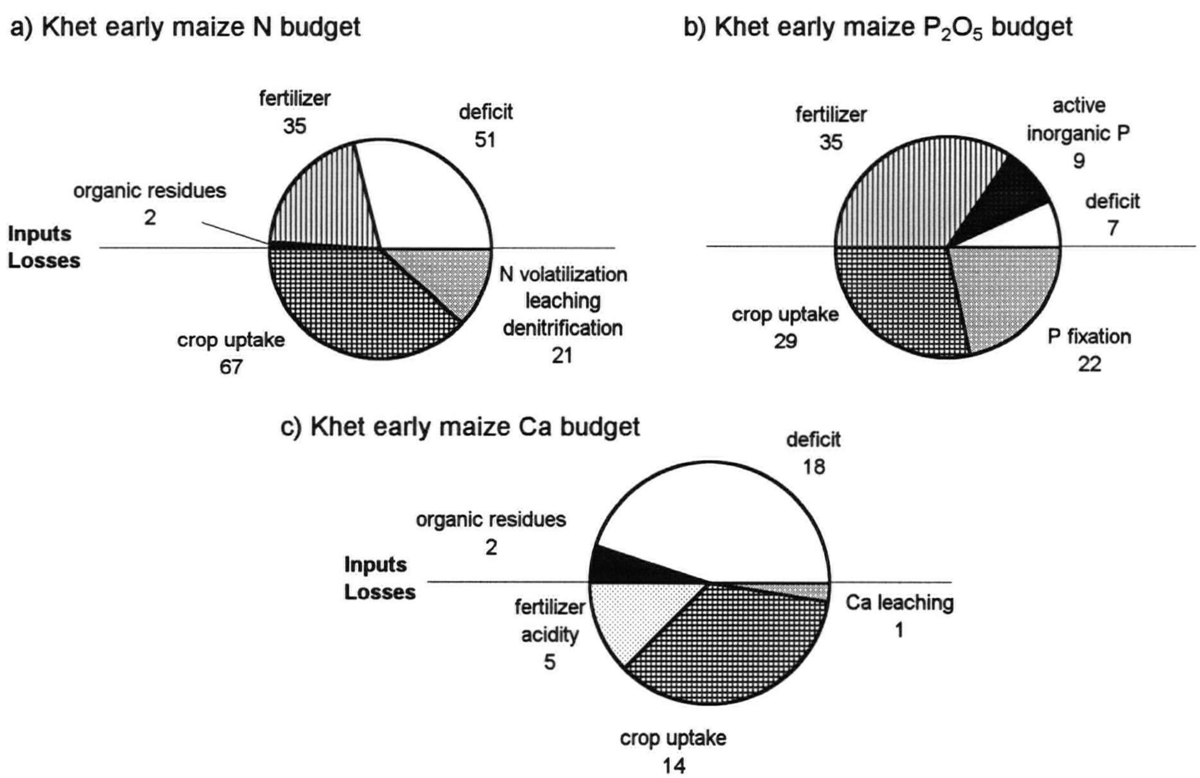


Figure 4.16. Nutrient budget' for early maize on khet (kg ha^{-1} furrow slice).

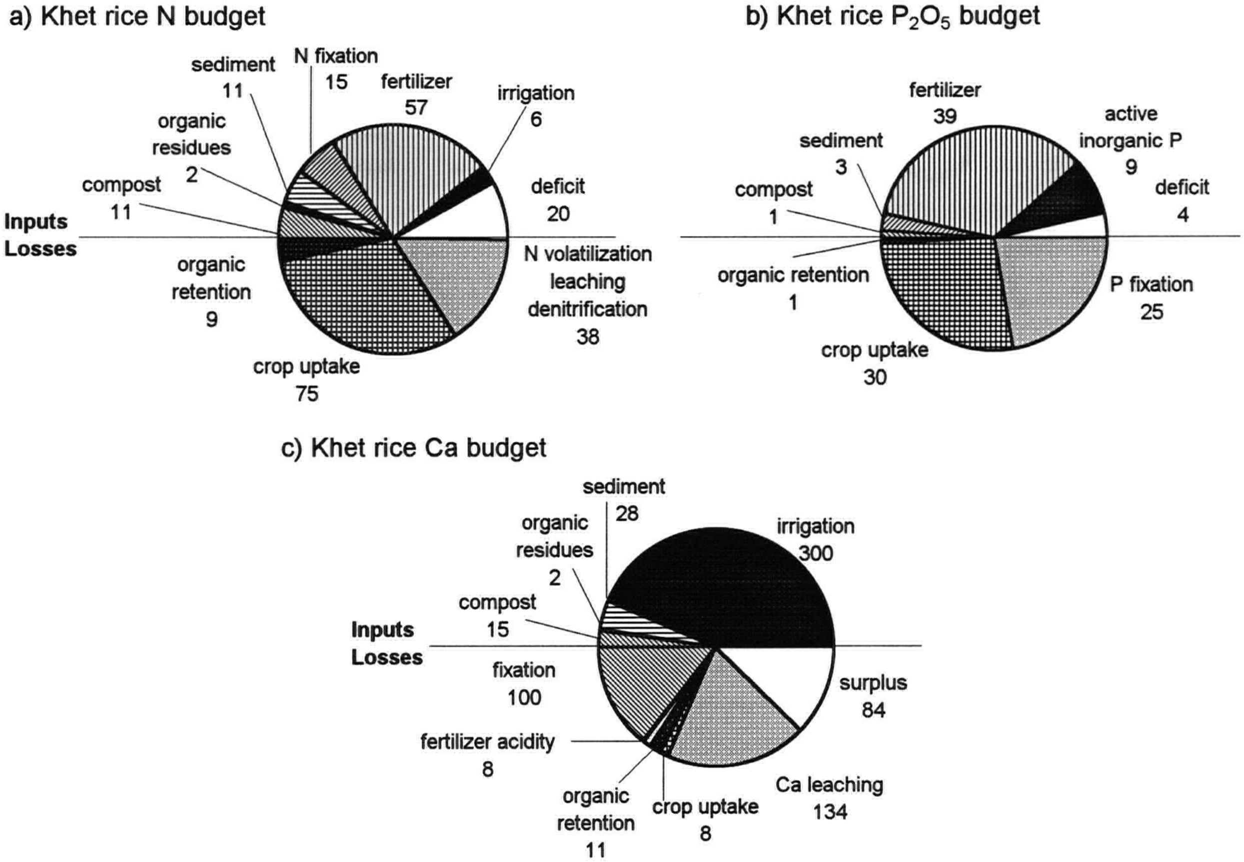


Figure 4.17. Nutrient budget for rice on khet (kg ha^{-1} furrow slice).

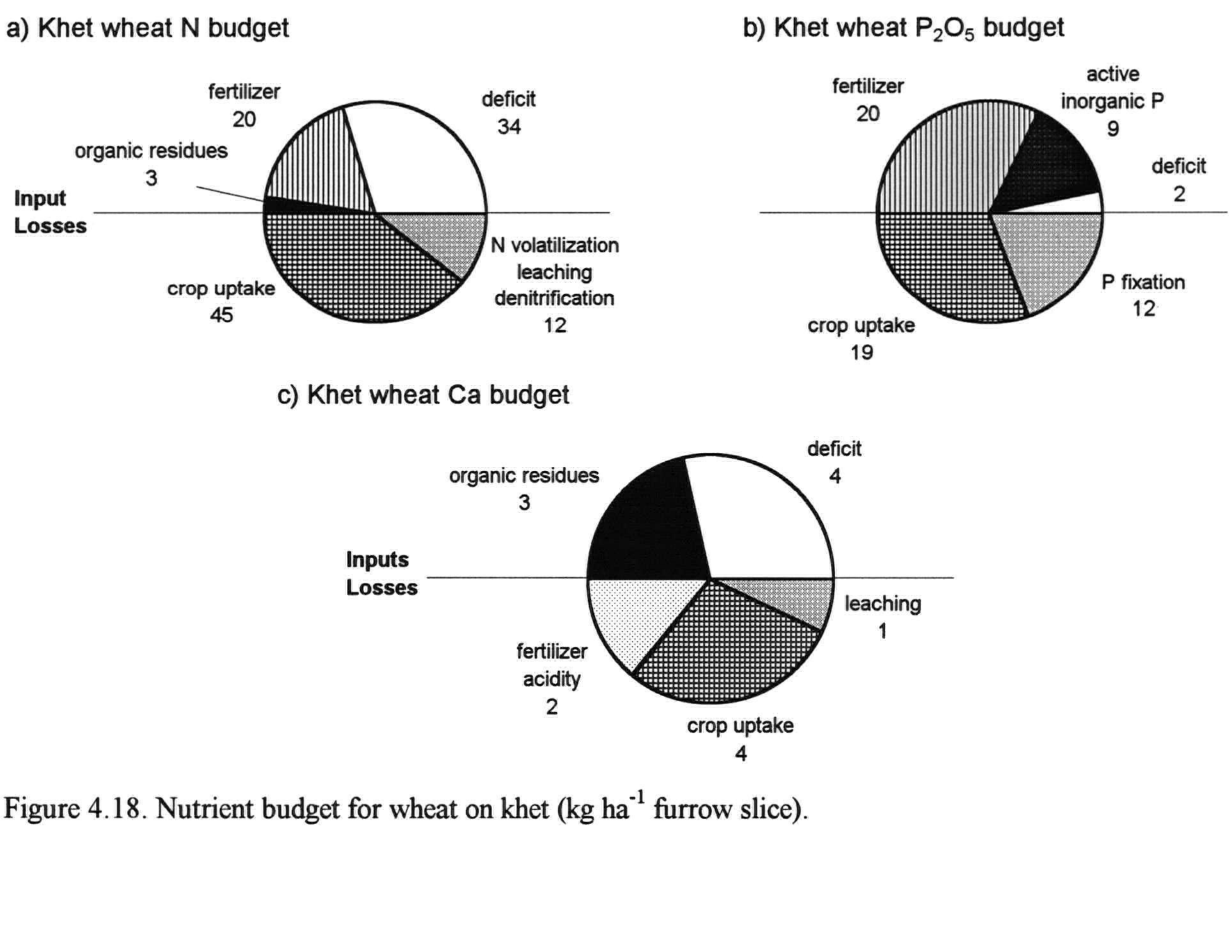


Figure 4.18. Nutrient budget for wheat on khet (kg ha^{-1} furrow slice).

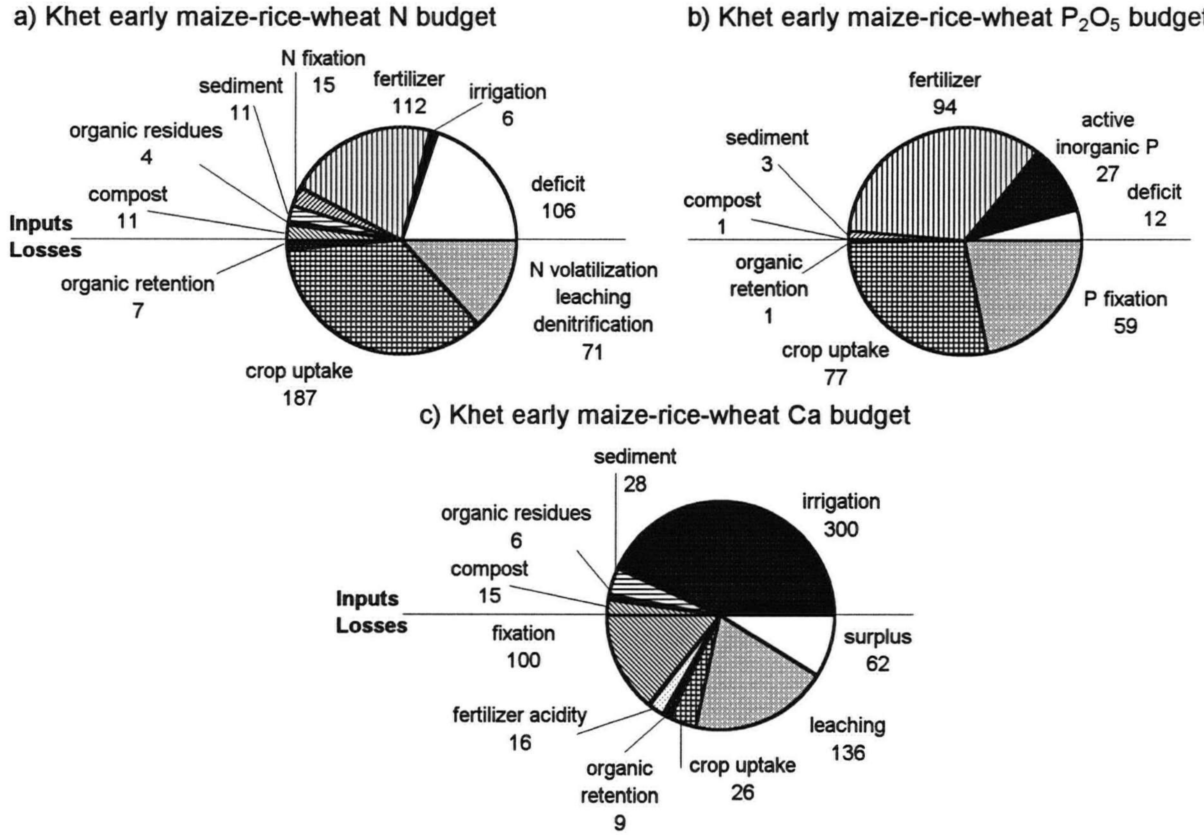


Figure 4.19. Nutrient budget for a three crop sequence on khet (kg ha^{-1} furrow slice).

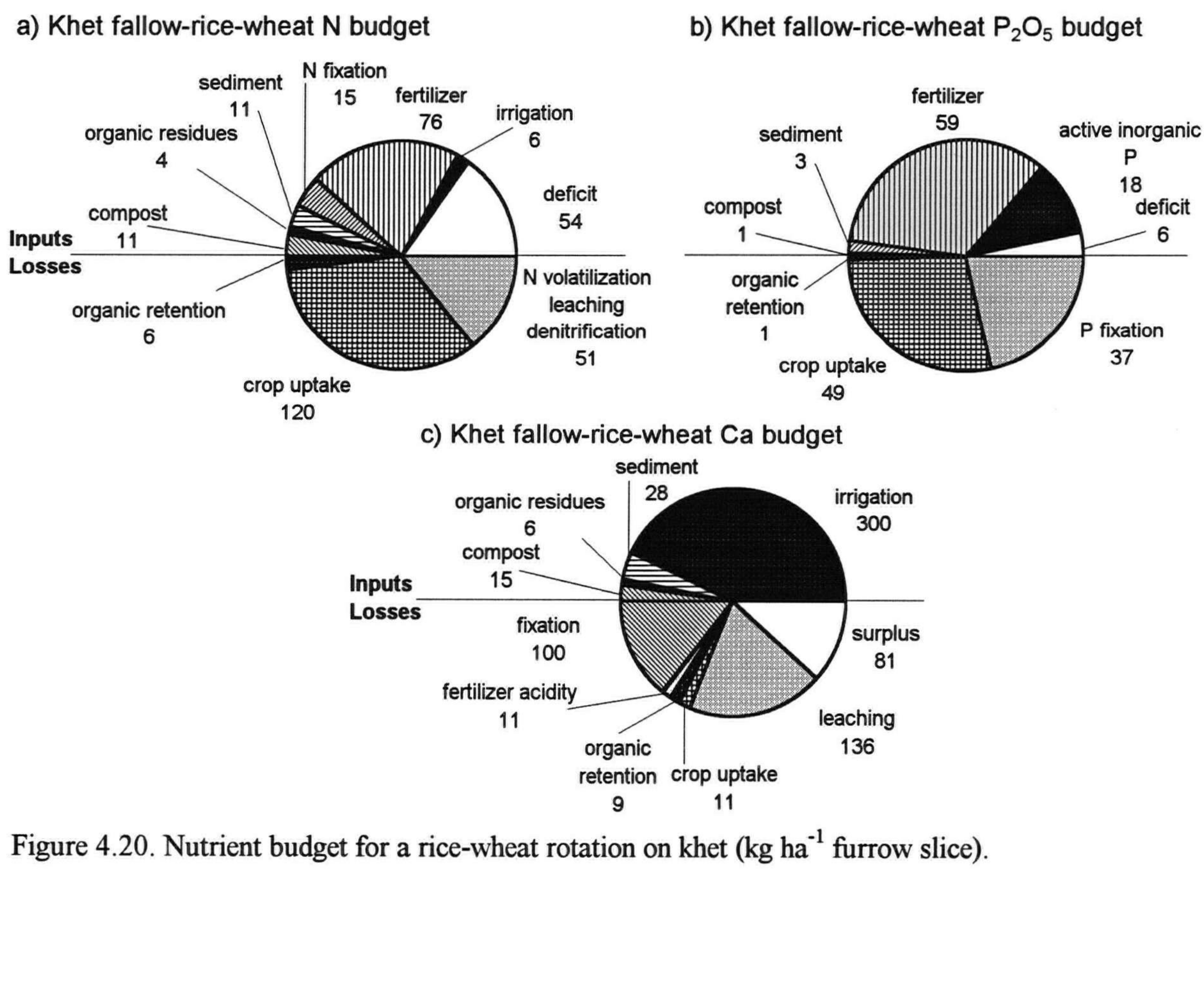


Figure 4.20. Nutrient budget for a rice-wheat rotation on khet (kg ha^{-1} furrow slice).

4.4.2 Sensitivity Analysis

A sensitivity analysis was conducted by varying each factor in the model by 10% and recalculating the nutrient budget. Results for the dominant cropping systems on bari and khet are shown in Figure 4.21a and 4.21b. The nutrient budgets are relatively insensitive to changes in model factors with the exception of crop uptake, leaching, volatilization and denitrification, and Ca inputs in irrigation water. Khet systems display greater sensitivity than bari systems due to the higher yields and a greater nutrient flux, but small changes in most variables will not significantly alter the nutrient budget. Estimates of nutrient inputs associated with irrigation water could be improved through water quality analysis and would enhance the nutrient budget calculations for paddy production. Leaching, denitrification and volatilization losses are difficult to quantify and estimates of fertilizer efficiency are well documented in the literature. Crop productivity is an important factor in the nutrient budgets but yield estimates are inaccurate and relationships between productivity and nutrient uptake are difficult to quantify (Dent and Young 1981, Davidson 1992, Schreier and Zulkifl 1986, Singer 1986). While the model is less sensitive to changes in nutrient inputs it provides a good index of the variability in management practices which may affect soil fertility.

4.4.3 Best Management Practices

The potential impact of best management practices is assessed by comparing farmers' practice and best management practices (BMP) for selected components of the model. The best management practices evaluated are pit composting (Table 4.5), increased sediment accumulation on rice fields (median + 1 stdev, i.e. 7 mm), increased biological N fixation by blue-green algae (45 kg ha^{-1}), reduced erosion (median - 1 stdev, i.e. 21 t ha^{-1} on bari), and increased fertilizer efficiency (50%) through incorporation and improved timing of application. The results shown in Figure 4.22 indicate that moderate reductions in N deficits may be obtained through best management practices. On bari fields, improved composting reduced N deficits 17%, while on khet fields increased biological N fixation was the most effective practice.

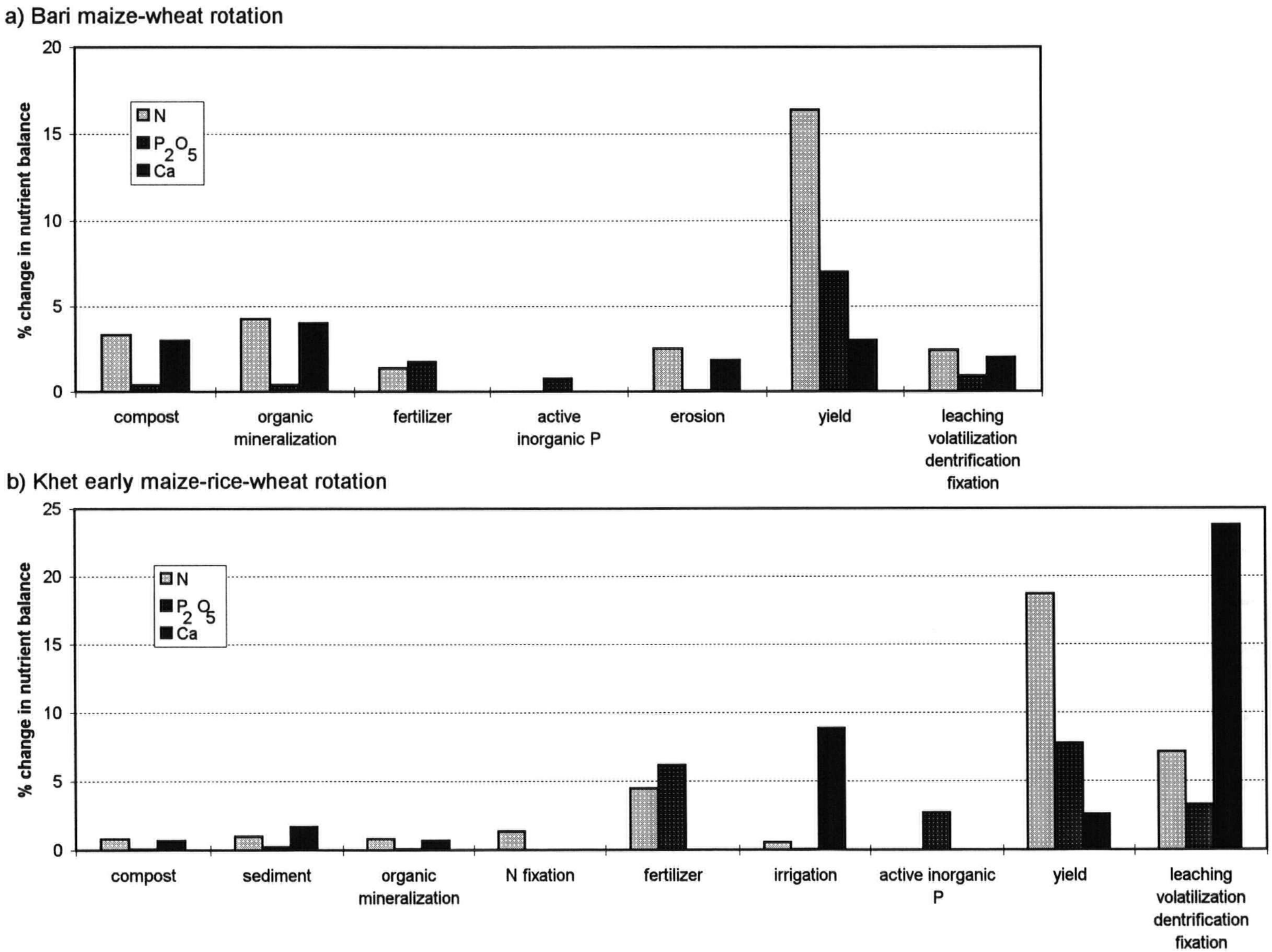


Figure 4.21. Sensitivity analysis of seasonal nutrient budgets for bari and khet.

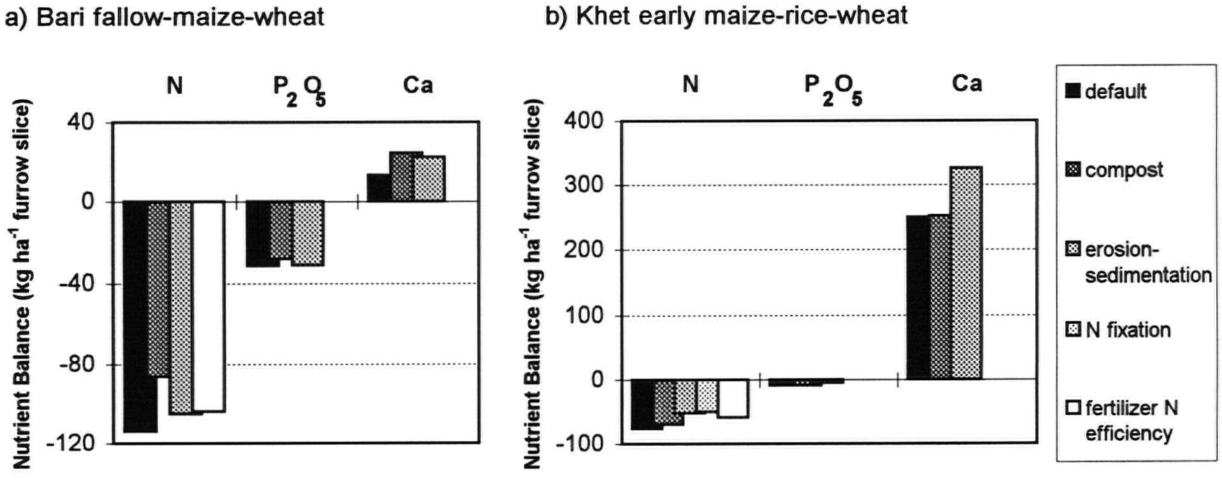


Figure 4.22. Impact of best management practices on nutrient budgets.

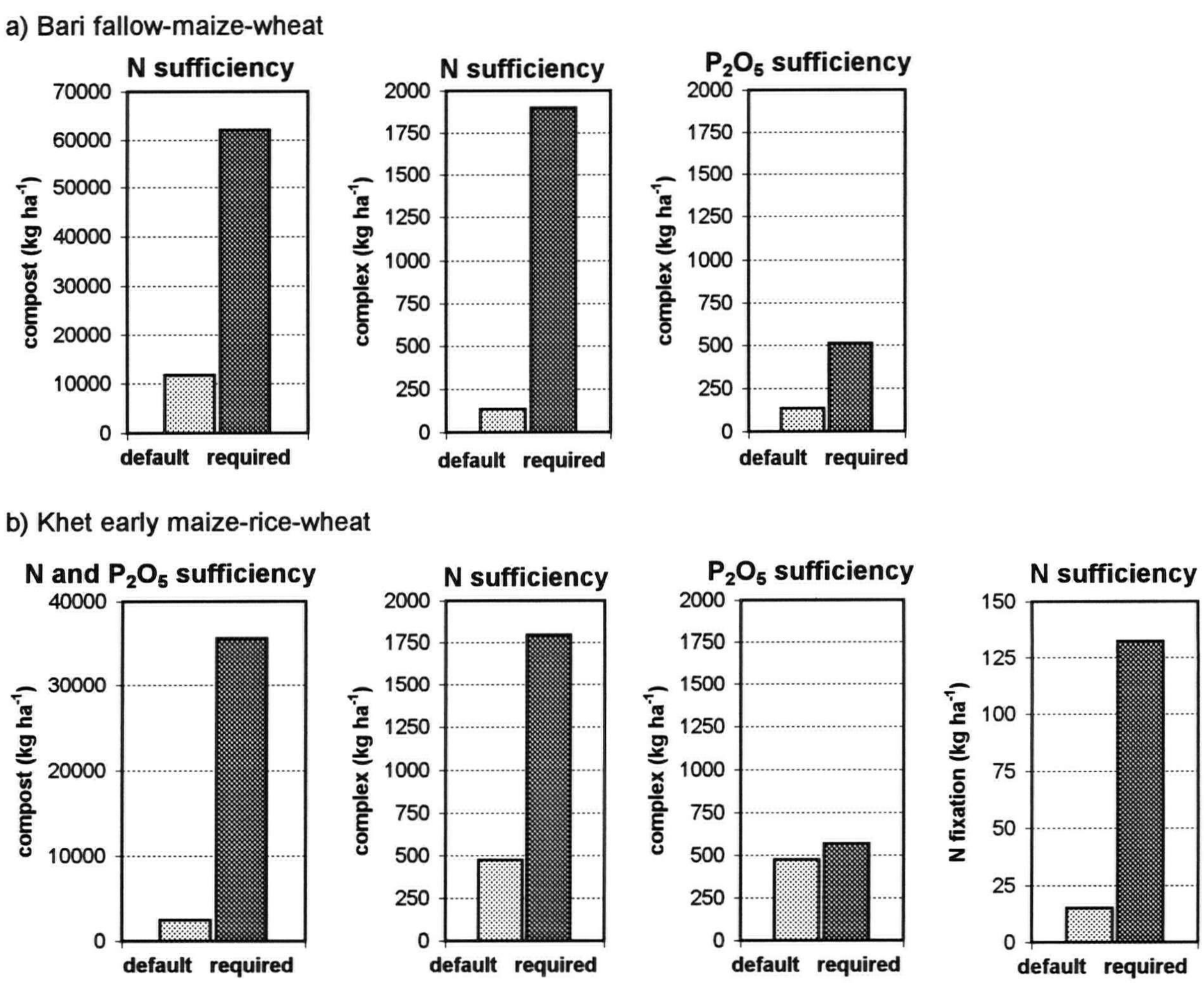


Figure 4.23. Deficit elimination scenarios.

Deficit elimination scenarios were run for compost, fertilizer and biological N fixation. The results shown in Figures 4.23a and 4.23b indicate that 3-10 fold increases in inputs are required. On bari fields, increasing compost to levels near the current maximum would meet crop N demands. On khet fields, complex© fertilizer application would need to be quadrupled to eliminate N deficits. Alternatively, increasing N fixation by blue-green algae and *Azolla* is a viable management option. Inoculation of *Azolla* may produce 15-20 t ha^{-1} of green manure within 15-20 days, and 20-40% of *Azolla* N incorporated into the soil is typically taken up by the first rice crop (Khan 1983, Eskew 1987, Buresh and DeDatta 1991, Singh et al. 1991).

4.4.4 Nutrient Budgets for Individual Fields

To assess between site variability, nutrient budgets for the main crops and cropping rotations were calculated for individual fields. Figures 4.24 and 4.25 display median, maximum and minimum values for N, P_2O_5 and Ca budgets on khet and bari fields. The variability is high with both negative and positive budgets noted for most crops. The variability in N budgets for dryland maize and irrigated rice are shown in Figures 4.26 a and 4.26b. The N budget is negative for 94 % of the sites growing maize while 57% of the sites growing rice receive sufficient inputs. A similar pattern is noted for maize-wheat and rice-wheat rotations with a negative N budget for most dryland sites and 71% of irrigated sites receiving sufficient N. Phosphorus budgets are slightly negative for both bari (Figure 4.24c) and khet (Figure 4.25d) cropping systems, while Ca is negative for 71% of bari sites under maize-wheat production and positive for most rice fields (Figure 4.25b). Large negative Ca budgets are associated with high ammonium sulphate fertilizer use, while high positive budgets are related to high organic matter inputs.

Generally, the median nutrient budgets determined from field budget calculations are less deficient than budgets calculated for a 'typical' maize-wheat or rice-wheat sequence. The nutrient budgets for the dominant cropping systems (section 4.4.1) use median fluxes determined for each crop, while the field specific calculations are influenced by inputs from other cropping sequences. For example, compost is

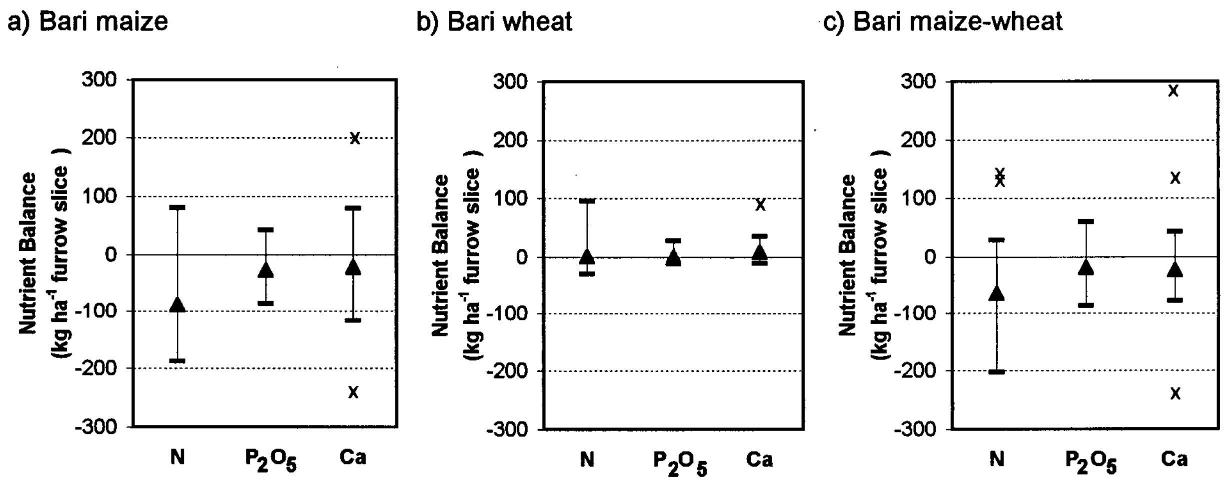


Figure 4.24. Field nutrient budgets for bari; median, minimum, maximum and outliers (n=85).

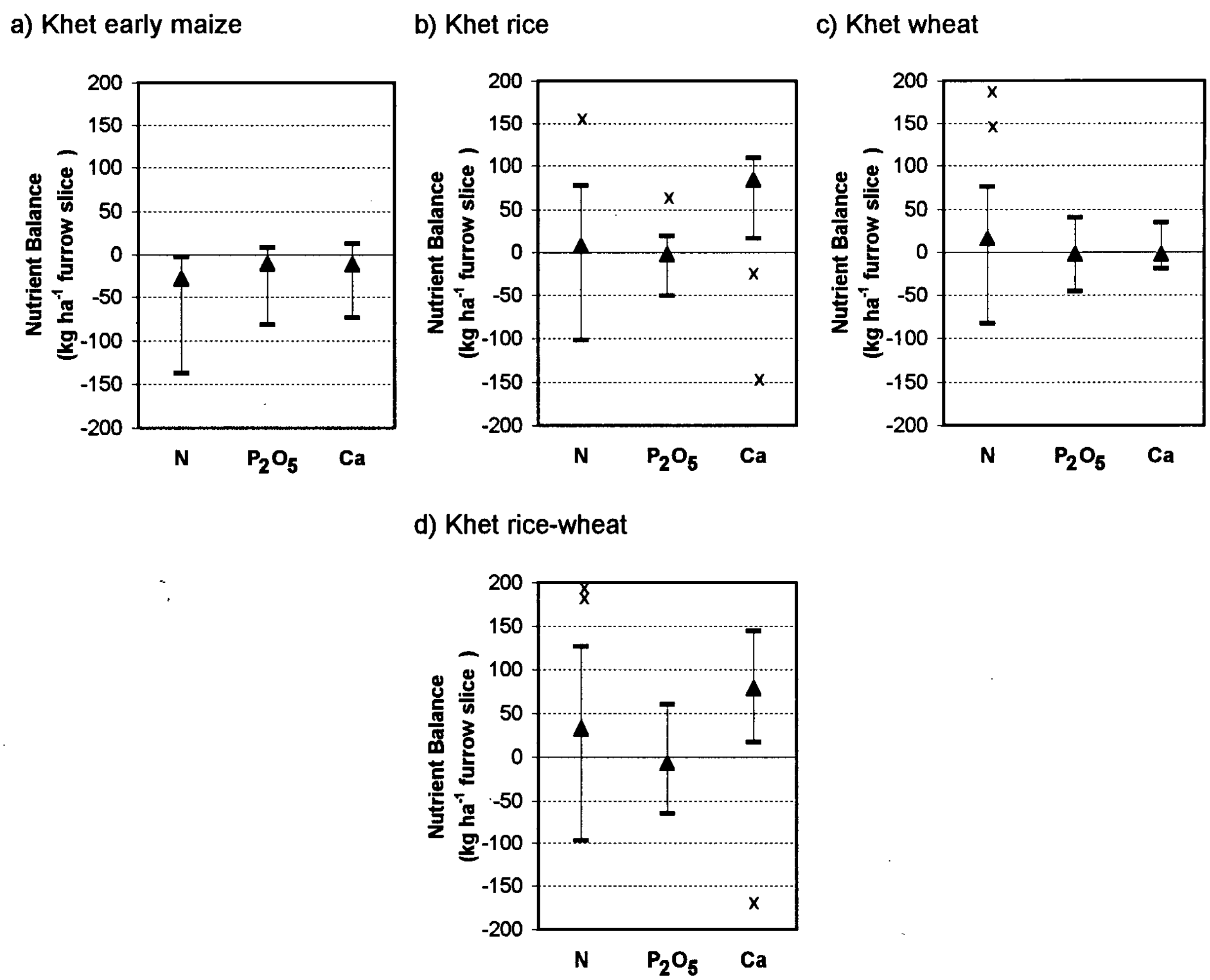


Figure 4.25. Field nutrient budgets for khet; median, minimum, maximum and outliers (n=85).

generally applied to premonsoon rice but not maize, and the additional premonsoon inputs will have a residual effect on monsoon rice production. Field based calculations for maize-wheat and rice-wheat rotations are also based on a smaller sample size.

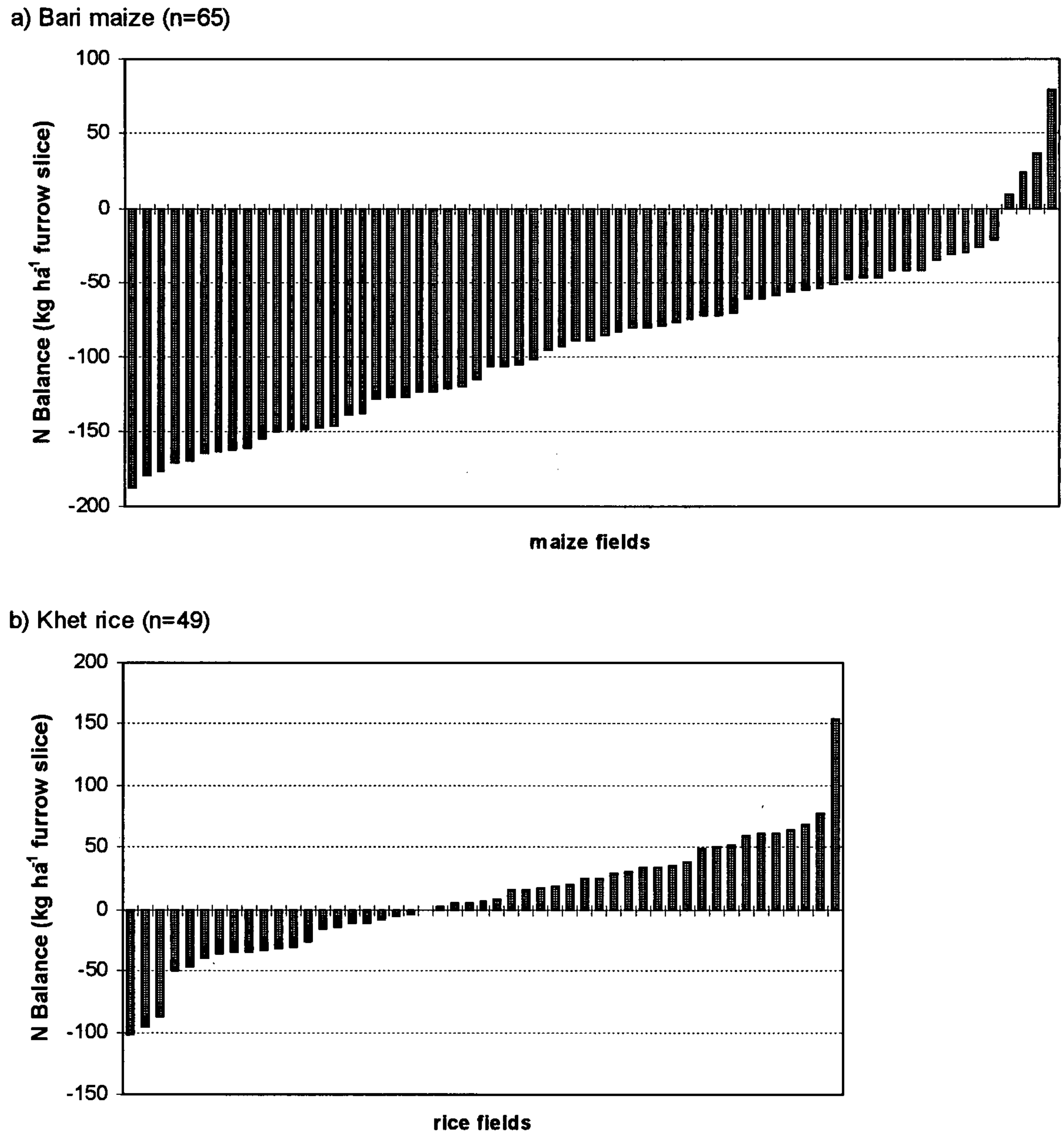


Figure 4.26. Variability in N budgets for dryland maize and irrigated rice production.

4.4.5 Implications for Soil Fertility

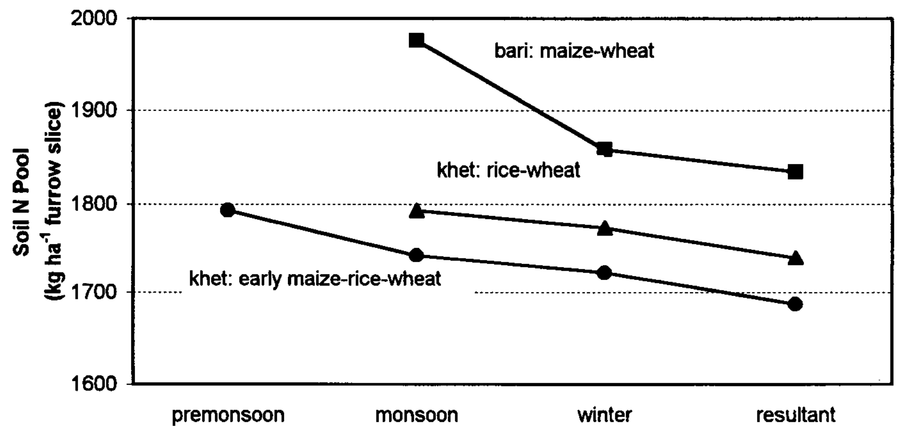
The direction of change in soil fertility is indicated by positive or negative nutrient budgets. Changes in the soil nutrient pool (initial pool $\pm$ nutrient budget) under the dominant cropping systems are shown in Figure 4.27. Bari production displays the greatest annual decline in the soil nutrient pool with estimated deficits of 142 kg N and 49 kg P_2O_5 per ha furrow slice. Khet production appears to be roughly sustainable under a two crop rotation, but the introduction of a third crop results in substantial N deficits (-106 kg N per ha furrow slice). Nutrient budgets for individual fields are variable but support declining soil fertility on most bari fields and overall neutral conditions on khet fields (e.g. Figure 4.27b). While the model simplifies soil processes by assuming constant rates for mineralization-immobilisation and adsorption-desorption, the relative differences between cropping systems provides an indication of the long term impact on soil fertility

4.5 Soil Fertility Dynamics

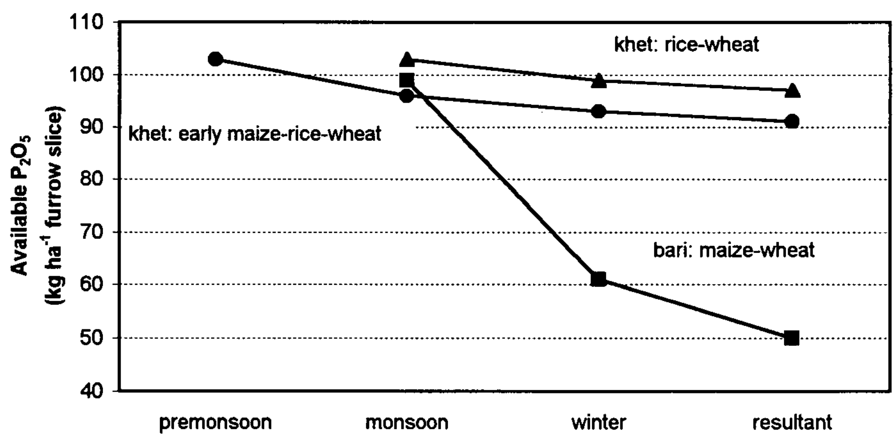
Interactions between components of the farming system depicted in Figure 3.2 result in a redistribution of nutrients between land uses, impact nutrient cycling and influence rates of change in soil fertility. As part of the Jhikhu Khola Watershed Project, Schreier et al. (1994b) evaluated nutrient cycling under khet, bari and forest land uses by comparing the fertility characteristics of soils originating from the same parent material but subjected to different land uses. The differences in soil fertility induced by land use management over time are then used to estimate rates of change in soil fertility.

Typical profiles under forest and agriculture were compared to test the assumption that soils in the test area are of similar origin. The profiles display the same sequences of horizons (AB, Bt and BC) and the chemical composition of the Bt and BC horizons are similar, supporting the assumption that the soils in the test area originate from the same parent material and the climatic conditions between the sites are the same. The impact of land use management on soil fertility was evaluated for irrigated rice cultivation, rainfed maize cultivation, and a pine plantation. Some 30 rice paddies have existed on the site for 5-20

a) soil N pool



b) available P_2O_5



c) exchangeable Ca

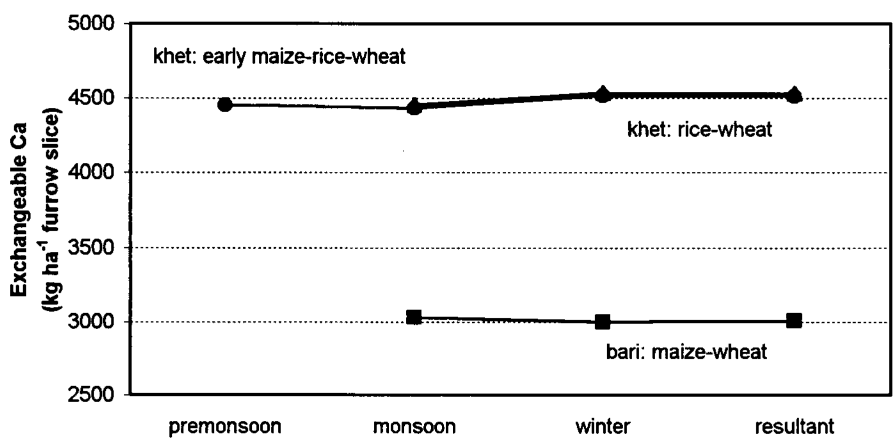


Figure 4.27. Estimated changes in the soil nutrient pool under dominant cropping systems for khet and bari.

years. The typical cropping sequence on khet is two crops of rice followed by a winter crop of wheat, tomato or potato. Irrigation water is supplied from a local spring but its availability is limited. The rainfed terraces have been under cultivation for more than 30 years. The typical cropping pattern is maize followed by winter wheat or millet and the bari land receives most of the organic matter inputs. The pine plantation was established 17 years ago under the Nepal-Australian Forestry Project. There has been no formal management or protection of the forest for the past 15 years, and the site is heavily used for grazing and litter collection. Lower tree branches are lopped for fuelwood and the understorey has been removed for agricultural use.

The soil fertility of surface samples taken under irrigated agriculture, rainfed agriculture and forest are compared in Figure 4.28, and significant differences between land uses are summarized in Table 4.16. The forested sites have significantly less ($\alpha<0.05$) exchangeable Ca, Mg, base saturation, available P, total N and organic C than khet or bari land, and CBD extractable Fe was significantly greater. Nutrient removal through biomass collection in the forest plantation over the past 17 years has resulted in a low nutrient status. The higher CBD extractable Fe is likely associated with tree root excudants and an acidic environment, and reflects the active component of total Fe which will occlude P, resulting in the lower available P in forest soils. Differences between khet and bari land are less significant. Available P, Ca, Mg and pH are greater in the irrigated site but only P and pH are significantly different at $\alpha<0.05$. The differences between dryland and irrigated fields suggest that nutrients and cations may be input via irrigation waters and the associated suspended sediments. Nutrient removal through harvesting will also impact soil fertility as rice is less nutrient demanding than either maize or wheat (Tables 1-3 Appendix B). Additionally, non-irrigated fields receive nearly double the organic matter input (Table 8 Appendix B) resulting in significantly greater organic C ($\alpha<0.10$) and total nitrogen ($\alpha<0.05$) than irrigated fields.

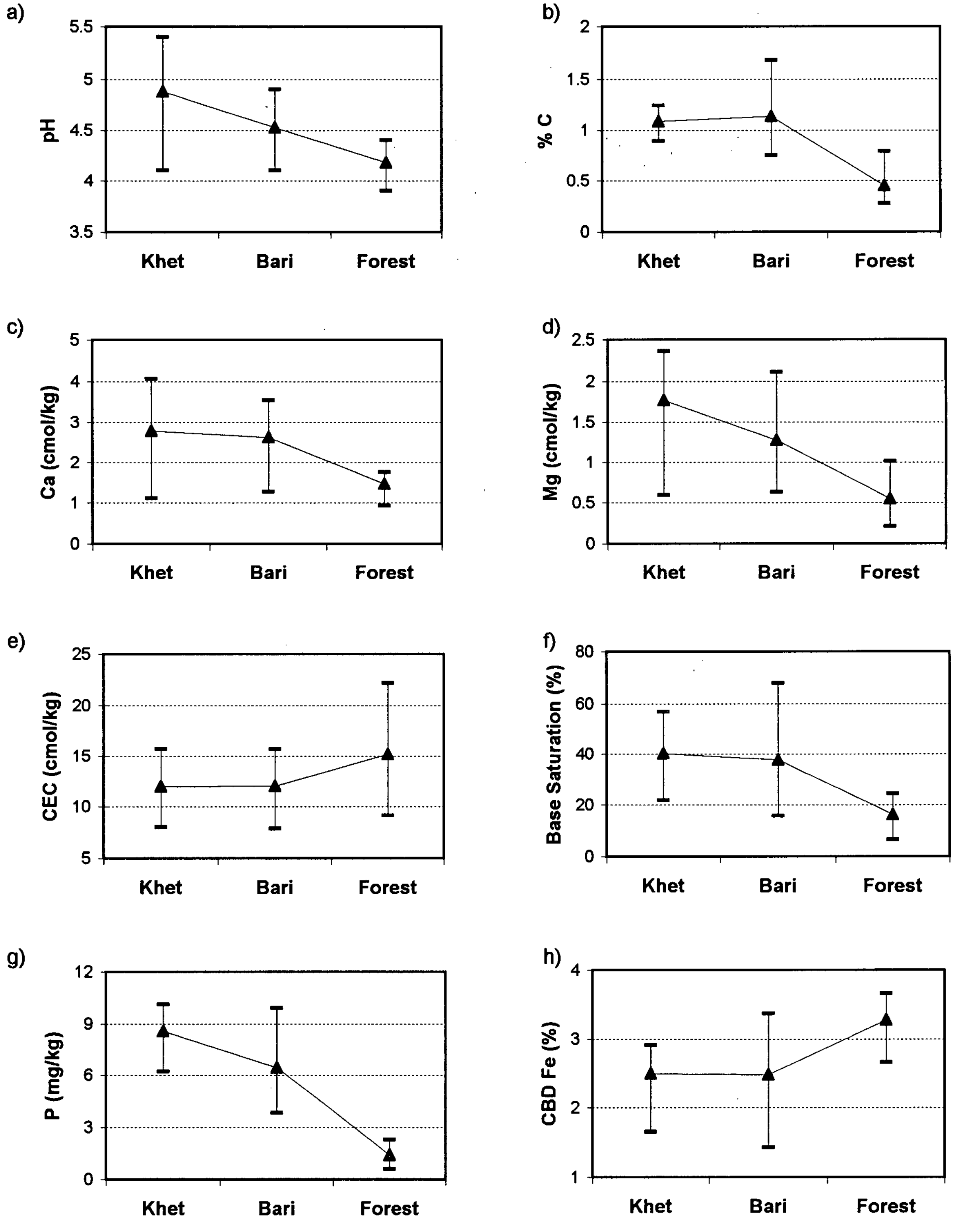


Figure 4.28. Soil fertility characteristics under khet, bari and forest; mean, minimum and maximum (data source: 1994 Jhikhu Khola nutrient cycling plot studies, n=30).

Table 4.16. Significant differences in soil fertility variables between land uses.

Variable	Khet vs. Bari	Khet vs. Forest	Bari vs. Forest
pH	●	●	●
C (%)		●	
N (g kg^{-1})	●	●	●
Ca (cmol kg^{-1})		●	●
Mg (cmol kg^{-1})		●	●
P (mg kg^{-1})	●	●	●
BS (%)		●	●
Fe - CBD (%)		●	●

data source: Jhikhu Khola nutrient cycling plot studies Schreier et al. 1994, n=30
significant differences based on t-test and Mann Whitney U-test, $\alpha<0.05$

4.5.1 Rates of Change

Rates of soil fertility decline are difficult to address without data on the initial soil fertility conditions and requires monitoring nutrient inputs and outputs over several decades. However, in the study area differences in nutrient status induced by land use management are contributing to poor overall soil fertility conditions even in fields receiving the largest inputs. Nitrogen, phosphorus, cations and pH are all low to deficient for most crops grown in the region (Tables 1-3 Appendix B). Rates of change between forest and bari sites, and between bari and khet sites originating from the same parent material (section 2.1.1) provide an indication of overall nutrient depletion. Table 4.17 lists current mean values of N, P, pH and base saturation for forest, bari and khet land uses. Forest soils, for example, have been depleted by 0.76 g N kg^{-1} and 5.0 mg P kg^{-1} of soil over the 17 years. Assuming a soil bulk density of 1400 kg m^{-3} and a soil depth of 15 cm, allows annual losses to be calculated.

Annual losses from the forests (Table 4.17) are approximately 94 kg N ha^{-1} furrow slice and 0.6 kg P ha^{-1} furrow slice. The nutrient content of stand leaf litter provides an estimate of the amount of nutrients removed from the forest through litter collection. The annual pine litter fall and nutrients measured at the test site by Feigl (1989) totalled 6.3 kg N ha^{-1}, 0.44 kg P ha^{-1}, and 9.1 kg total bases ha^{-1}. The potential N removal through litter fall only accounts for 7% of the estimated total annual N decrease. Additional losses of N by volatilization, leaching, erosion and timber uptake likely account for the difference. In contrast, the amount of P in the pine litter represents 73% of the estimated annual decline, and the remaining losses may be attributed to timber uptake and erosion.

Annual losses from bari lands are small, and reflect additional inputs from organic sources. Nutrient removal by maize is in the order of 130 kg ha^{-1}, 55 kg P_2O_5 ha^{-1} and 180 kg total bases ha^{-1} (Table 2 Appendix B), and suggests that annual losses from agriculture will be strongly influenced by management.

Table 4.17. Soil fertility dynamics

Variable	**Current Means (n=10)**[1]				**Annual Rates of Change**		
	Units	Forest	Bari	Khet	Units	Forest	Bari
N	g kg^{-1}	0.45	1.21	0.98	kg ha^{-1} f.s.	-94	28
avail. P	mg kg^{-1}	1.4	6.4	8.6	kg ha^{-1} f.s.	-0.6	-0.3
avail. P_2O_5	mg kg^{-1}	3.2	14.7	19.7	kg ha^{-1} f.s.	-1.4	-0.7
pH	pH	4.2	4.5	4.9	pH	-0.02	-0.02
Ca	mg kg^{-1}	589	1054	1118	kg ha^{-1} f.s.	-57	-8
Total Bases	mg kg^{-1}	826	1574	1679	kg ha^{-1} f.s.	-92	-13
Base Saturation	%	16.1	37.6	40.3	%	-1.3	-0.2

[1] data source: Jhikhu Khola nutrient cycling plot studies Schreier et al. 1994, n=30

f.s. = furrow slice (15 cm soil depth)

4.6 Summary

Soil Fertility Status

The overall soil fertility conditions of the study site are generally poor. Soil carbon and pH are particularly problematic, and P availability is a concern given the low pH values. Land use is the most important factor influencing soil fertility, followed by soil type. However, soil variables are influenced differently by individual factors. Red soils have a greater clay content, higher CEC and greater exchangeable Mg values than non-red soils, with higher Fe and Al content likely tying up available P. Khet sites show the best overall soil fertility, followed by bari and grassland, while forest soil fertility is the poorest. Differences between red and non-red soils reflect inherent soil properties but within a given soil type, land use management is an important factor influencing soil fertility.

The Site Factor Approach

Traditionally, soil maps are based on surficial materials and may distinguish differences related to topography, but additional factors influencing soil fertility, such as land use management, are not incorporated. The site factor approach using soil type, topography and land use to extrapolate from point data to a spatial coverage is a unique approach to the production of soil fertility maps. A rule set is developed from relationships between site specific soil fertility data and characteristics of the site. Mapped biophysical conditions (soil type, land use, elevation and aspect) are then related to soil fertility conditions for each combination of factors. GIS overlay techniques are used to display critical and adequate levels for key parameters. Exchangeable Ca is classified as moderate (>4 cmol kg^{-1}) for 29% of the area corresponding to khet land and low elevation south facing bari land. Soil pH is classified as critical (<4.8) for 55% of the area corresponding to forest, shrub and grasslands. Adequate levels of available P (>15 mg kg^{-1}) are related to khet or bari land on non-red soils, and khet or bari land on north facing red soils (38% of the classified area). Typically we assess only one limiting factor, but with the use of chemical fertilizer we may simply trade-off between factors. The GIS approach is useful in evaluating soil fertility in a cumulative manner. A composite soil fertility map was produced by combining the pH, available P and exchangeable Ca maps. Only 14% of the classified regions show adequate levels in all three parameters, while 61% have at least one limiting variable. This spatial analysis provides a more comprehensive picture of conditions throughout the study region, and highlights problem areas.

Phosphorus Fixation

Phosphate sorption studies conducted on 16 highly weathered red soils indicate moderately high P sorption ranging from 2-4 g P_2O_5 per kg soil. Measured sorption displays good relationships with AAO and CBD extractable Fe and Al, and P sorption calculated using Borggaard's model (r^2=0.85). Phosphate sorption calculated for non-red soils using Borggaard's model was an order of magnitude less than red soils. Within the red soils, forest sites sorbed significantly greater P than agricultural sites. A classified map of P sorption developed using a site factor approach based on soil type and land use indicates that 29% of the study area has a high P fixation >1.5 g kg^{-1} and 61% has a P fixation capacity >0.5 g kg^{-1}. The high P fixation capacity of red soils in the study region is a concern for P management as fertilizer applications will be highly inefficient.

Nutrient Management

Nutrient inputs, their redistribution and losses from the soil-plant nutrient pool will impact soil fertility conditions both spatially and temporally. Compost and chemical fertilizer are a major source of nutrients on cultivated fields. Compost is largely applied to bari fields and typically supplies 45% of the N and 100% of the Ca applied to maize fields. Chemical fertilizer is the main source of N and P_2O_5 on khet fields accounting for 81% of the N and 98% of the P_2O_5 applied to irrigated rice fields.

Erosion and sedimentation are important redistribution processes. Erosion from upland bari sites (26 t ha^{-1}) results in an average annual loss of 25 kg N ha^{-1} and 13 kg Ca ha^{-1}, and degraded lands loose an estimated 34 kg N ha^{-1} and 23 kg Ca ha^{-1} annually. Alternatively, sediment and the associated nutrients are recaptured on low lying khet fields through the irrigation system. Nutrient analysis of newly accumulated sediments on khet fields show an enrichment in N, P_2O_5 and Ca resulting in annual inputs of 11, 2.5 and 28 kg ha^{-1} respectively. Nutrients are also added to khet fields through irrigation water, particularly Ca. Some 300 kg ha^{-1} Ca may be input annually during rice production.

Potential losses from the soil-plant nutrient pool are difficult to quantify but include P fixation, N leaching, denitrification, NH^{3+} volatilization and Ca leaching. The red soils in the study area are particularly problematic due to their high P fixation capacity (6,700 kg ha^{-1}) limiting the efficiency of P fertilizer inputs. Fertilizer N efficiency is commonly low and leaching, denitrification and volatilization likely result in 30-50% losses. Organic matter inputs provide a slowly available nutrient source and while recovery by the first crop is commonly only 15-30 %, residual organic matter provides nutrients to subsequent crops. Calcium is less mobile than N in the soil but Ca concentrations in spring and irrigation waters provide evidence of Ca leaching. Available Ca is also impacted by the use of ammonium based fertilizers which may acidify soils unless sufficient liming material is present.

Crop Nutrient Uptake

Estimates of crop nutrient removal based on reported production and average nutrient uptake values provide an estimate of the nutrient inputs required to maintain the soil nutrient pool. Maize is the most nutrient demanding of the main staple crops grown on a % dry matter basis, followed by wheat and then rice. However, due to the low productivity of wheat in the study area, rice is more nutrient demanding on a total biomass (kg ha^{-1}) removal basis. Relationships between crop productivity and soil fertility are weak suggesting that nutrient management may play a key role in productivity.

Nutrient Budget Modelling

Nutrient budgets for khet and bari land indicate that the soil nutrient pool is being depleted under both intensive irrigated and extensive dryland production systems. Khet production appears to be sustainable under a two crop rotation, with 71% of the sampled fields displaying a positive N budget, but the introduction of premonsoon maize into the rotation results in a substantial N deficit (-106 kg ha^{-1}). On bari land nutrient inputs are insufficient to meet crop requirements and the negative nutrient budgets are an indicator of soil degradation. The use of best management practices result in a slight reduction in nutrient deficits, but the trend of soil fertility depletion remains. Sensitivity analysis indicates that crop yield is an important factor in determining nutrient budgets but productivity is a poor indicator of soil dynamics. Relationships between productivity and nutrient uptake are difficult to quantify, there are inaccuracies in reported and measured yield estimates, relationships with soil fertility are weak, and external factors such as disease or drought may impact productivity. Nutrient inputs provide a better index of the variability in management practices which affect nutrient budgets and soil fertility.

Rates of Change in Soil Fertility

Soil fertility characteristics of soils originating from the same parent material but subjected to different land uses were compared to determine how soil fertility is changing and to estimate rates of change. Due to the removal of litter and a lack of inputs, the forest sites showed the lowest N, P, exchangeable bases and pH values. The bari sites have the most C and N as they receive greater organic matter inputs. Irrigated sites have the greatest P, Ca and Mg due to enrichment by irrigation water and suspended sediments. The rate of soil fertility depletion may be estimated from differences in soil fertility related to land management. Annual nutrient losses from forest sites are substantial (94 kg N and 57 kg Ca per ha furrow slice), while losses from bari sites are small in comparison to crop uptake.

5. IMPACT OF LAND MANAGEMENT ON NUTRIENT DYNAMICS

"Every year the amount of fertilizer is being increased to get the same yield. The soil has become very tough... "

(Farmer S37)

Overall soil fertility conditions in the study region are poor; forest, shrub and grassland soils are being depleted; and the status of cultivated soils appears to be marginal. The focus of this chapter is to evaluate why soil fertility is declining by assessing the impact of land management on nutrient dynamics. The components evaluated and their interactions with soil fertility data from chapter 4 are shown in Figure 5.1. Land use change in the Jhikhu Khola Watershed from 1947 to 1990 is presented to provide the historical context for forest, cultivated land and shrub / grasslands. Recent land use trends in the Bela-Bhimsenthan study area from 1972 and 1994 are then compared to the overall dynamics.

Detailed evaluations of forest, bari, khet and grass / shrub land dynamics are assessed relative to site conditions and their impact on nutrient flows. Forest dynamics include an assessment of afforestation, changes in the types of trees and nutrient removal through biomass collection. The implications of nutrient outflows from the forest are discussed relative to nutrient cycling and soil fertility. Bari dynamics include an evaluation of agricultural expansion and marginalization. Relationships between nutrient inputs, crop uptake, nutrient budgets and soil fertility are presented, and nutrient budgets for maize and wheat are related to aspect, elevation and soil type. The implications of marginal inputs and nutrient losses through erosion are discussed relative to soil fertility conditions on bari land. Khet dynamics include an evaluation of agricultural intensification, market oriented production and agrochemical use. The impact of water management and sediment deposition on soil fertility is discussed relative to the nutrient status on khet lands. Relationships between nutrient inputs, crop uptake, nutrient budgets and soil fertility are presented, and nutrient budgets for rice and wheat are related to aspect, elevation and soil type. The implications of intensive cultivation are discussed relative to soil fertility and the sustainability of current management practices. Grass and shrub land dynamics include an assessment of crop nutrient uptake and nutrient

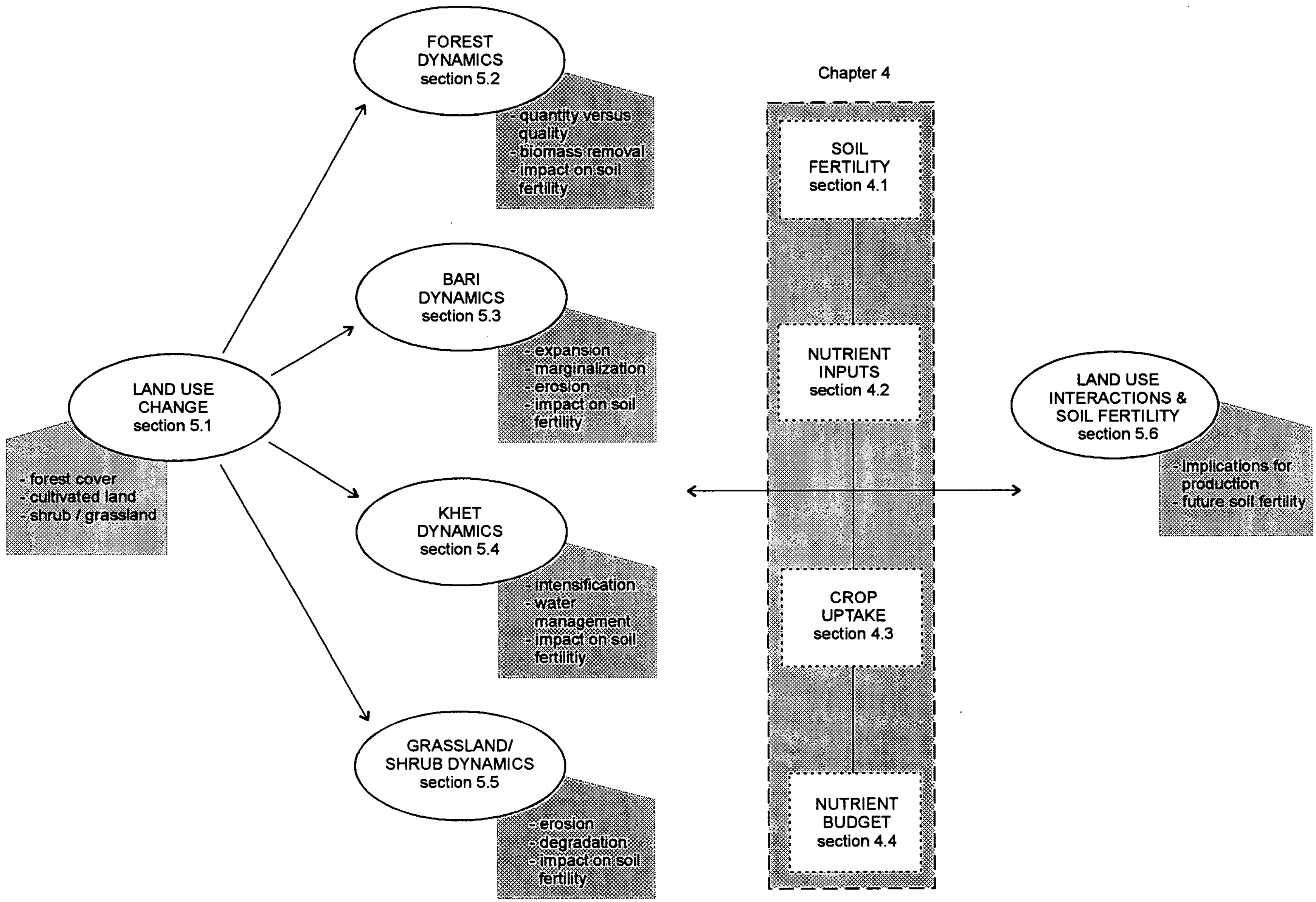


Figure 5.1. Components of land use and soil fertility dynamics evaluated in chapter 5.

losses through erosion. The implications of over utilization are discussed relative to soil fertility and rehabilitation efforts.

Land use interactions, nutrient flows between land uses and their impact on soil fertility provide an understanding of why soil fertility is changing. Differences in nutrient inputs with elevation, aspect and land use are quantified. Changes in the use of compost and chemical fertilizer, and constraints to chemical fertilizer use faced by farmers are analyzed. The implications of nutrient deficits and unbalanced nutrient flows between land uses for forest, crop and grass / shrub productivity are assessed. The impact of nutrient fluxes on soil fertility dynamics are evaluated by comparing predicted nutrient deficits and current soil fertility conditions. From these relationships a GIS based classification was developed which displays the spatial distribution of Ca and P degradation.

5.1 Land Use Change

Land use, as it reflects management, impacts soil fertility and an assessment of land use change is a precursor to understanding soil fertility dynamics. To document historic land use changes, land use evaluations conducted as part of the Jhikhu Khola Watershed Project (Schreier et al. 1994a) are presented in conjunction with data for the study region. Trends within land use categories are shown in Figure 5.2 a-c. Over the 48 year period, there have been significant changes in forest, shrub, grass and cultivated land. Three scales of land use mapping are represented: 1) 1:50,000 scale regional overview based on a 1947 British survey and 1981 LRMP mapping; 2) 1:20,000 scale land use mapping for the Jhikhu Khola Watershed based on aerial photo-interpretation for 1972 and 1990; and 3) 1:5,000 scale detailed evaluation of the Bela-Bhimsenthan study area for 1972 and 1994. Note that the 1:50,000 and 1:20,000 scale mapping cover the entire Jhikhu Khola Watershed, while the 1:5,000 scale mapping only covers a subset of the area encompassing Bela-Bhimsenthan.

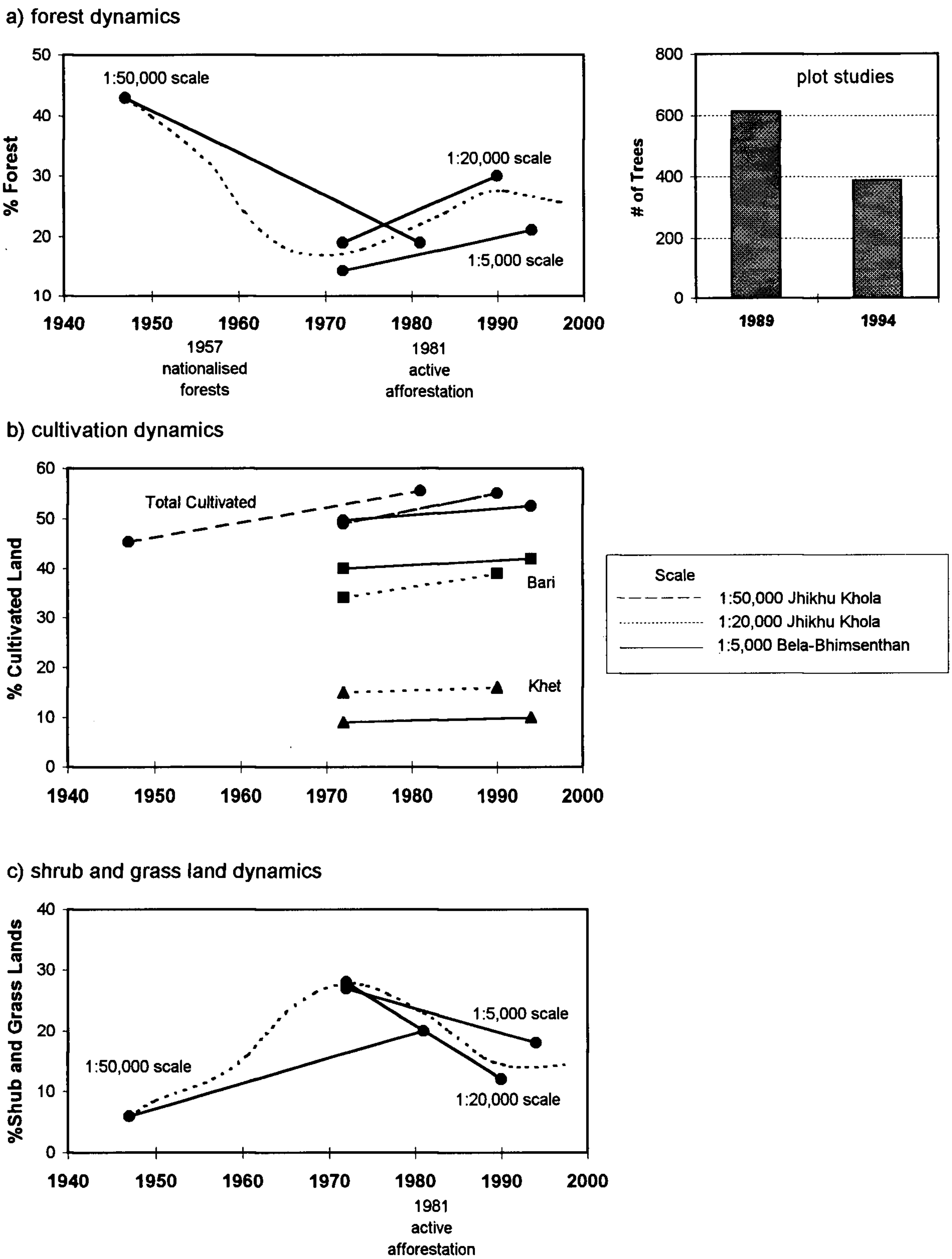


Figure 5.2. Regional land use dynamics 1947-1994 (dataset: Jhikhu Khola 1:20,000 land use mapping; Bela-Bhimsenthan 1:5,000 land use mapping; Jhikhu Khola forest plot studies).

5.1.1 Forest Cover

Historical forest cover data (Figure 5.2a) clearly indicates substantial deforestation during the 1950-1960 period and a subsequent reversal in the 1972-1990 period. The dotted line in Figure 5.2a shows the interpolated deforestation and recovery process. The lowest forest cover is likely to have occurred in the late 1960s and may partially be attributed to the nationalisation of forests in 1957, when all non-cultivated land was placed under the jurisdiction of the Forestry Department. This resulted in the clearing of forest land by villagers to maintain ownership. Post 1981, afforestation efforts initiated by the Nepal-Australian Forestry Project (NAFP) have resulted in significant increases in forest cover (Shrestha and Brown 1995, Schreier et al. 1993, Mahat 1987a, 1987b, Feigl 1989, Ingles and Gilmour 1989).

Recent forest dynamics (1989-1994) have been evaluated through a series of plot studies. Twelve forest plots (Figure 2.2) selected in 1989 for long term biomass monitoring (Feigl 1989) were re-examined in 1994. Individual trees were marked and these demarcations were maintained yearly. In 1994, changes in tree density and biomass over the six year period were determined. Between 1989 and 1994, the standing biomass diminished from 614 trees to 386 trees, a loss of 37% of the forest stand (Figure 5.2a). The losses varied greatly between plots and reflect different degrees of protection. The majority of trees lost to cutting were sal trees (*shorea robusta*) which are valuable as construction material and for brick making. Few pine trees were removed.

These results suggest that the decline in forests occurs in cycles. The historic information indicates at least two cycles of deforestation followed by efforts of rehabilitation. Large losses of forest cover occurred in the 1950's. Afforestation resulted in significant increases in forest cover, but only 50% of the losses were recovered by 1990. Renewed losses have been observed in the 1990s due to the increased demand of firewood for brick making, and of timber for house construction. Recent community based afforestation programs may improve the situation in the short term, but the overall trend of cyclic change appears to be in a decreasing direction.

5.1.2 Cultivated Lands

Historical trends on cultivated land (Figure 5.2b) show a slow but consistent increase in the area under cultivation. Agricultural land occupied about 45% of the Jhikhu Khola watershed in 1947 and has increased to around 55% in the 1990s. All three surveys (1:50,000, 1:20,000 and 1:5,000) support this trend. Recent increases in bari cultivation are largely associated with the conversion of grasslands, while changes in khet land were small, indicative of limited water availability.

5.1.3 Shrub and Grass Lands

Historic changes in shrub and grass lands (Figure 5.2c) show the inverse trend to the forest situation. During the 1950-1960 period, shrub and grass lands increased significantly in parallel with deforestation. The dotted line in Figure 5.2c shows the interpolated degradation and recovery process. The greatest shrub and grassland cover likely occurred in the late 1960s, and decreased through the 1980s in association with afforestation efforts.

5.1.4 Recent Trends in the Bela-Bhimsenthan Region

Land use in the Bela-Bhimsenthan region for 1972 and 1994 are shown in Plates 5a and 5b, and the dynamics between land uses are shown diagramatically in Figure 5.3. Over the 23 year period there were increases in forest cover (+7%), khet (+1%) and bari (+2%) land, and decreases in grass (-5%), shrub (-3%) and other land uses (-2%). Increases in irrigated agriculture were largely associated with the conversion of dryland agriculture, while at the same time, a net increase in bari land was also observed. The expansion of dryland agriculture was mainly associated with a loss of khet land, and the cultivation of grassland, abandoned areas and landslides. Forest cover increased significantly, however grass and shrub lands decreased considerably. The land use changes are dynamic in all categories, but the trends are indicate the main relationships.

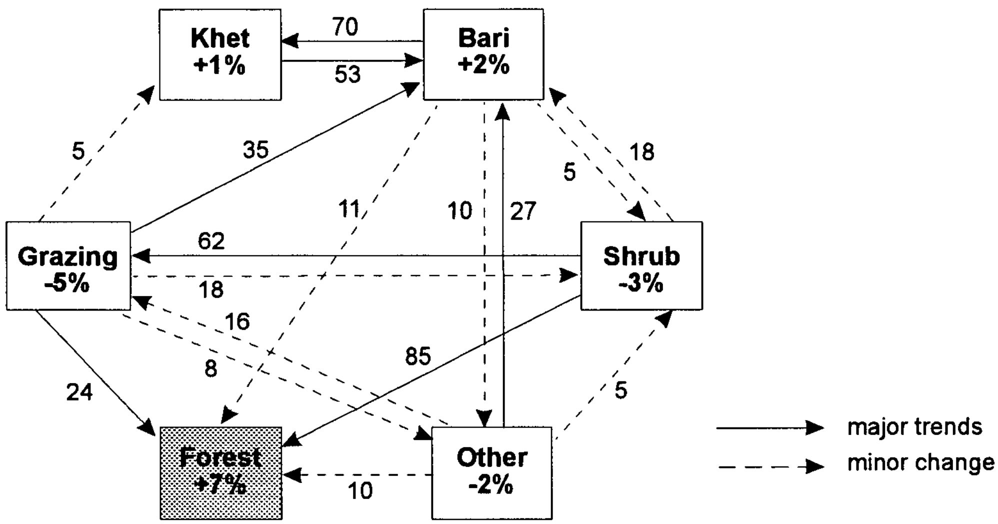


Figure 5.3. Land use trends in the Bela-Bhimsenthan region 1972-1994, numbers indicate changes in ha (dataset: Bela-Bhimsenthan 1:5,000 land use mapping).

5.2 Forest Dynamics: Quantity versus Quality

In the Bela-Bhimsenthan region, the area under forest cover increased 7% between 1972 and 1994, largely at the expense of grass and shrub lands. A large proportion of the gains in forest area are associated with chir pine (46%) planted with assistance by the Nepal-Australian Forestry Project (NAFP), and most of this expansion occurred on moderate to steep slopes, below 1200 m elevation (Table 5.1). Afforestation efforts resulted in an increase in forest cover from 1972-1994, but 75% of the current forest has crown density <50%, and 40% is pine forest. While plantations have increased the amount of chir pine in the study area, the plot studies indicate a reduction in sal and other hardwoods.

5.2.1 Nutrient Status and Biomass Removal

Forest soils showed the poorest overall soil fertility (Figure 4.3 a-h) and the greatest annual nutrient losses (Table 4.17). Forest soils receive minimal nutrient inputs and nutrients are lost through biomass removal. Trees and branches are cut for fuelwood, lopping of tree branches for animal feed is common, and most forest floors are devoid of understorey and litter due to the intensive collection of forest floor material for animal bedding and fodder (Photo 3). The collection of forest products and associated nutrient losses are

Table 5.1. Land use dynamics in relation to site conditions over the period 1972-1994.

Site Conditions		**Land Use Expansion**			**Land Use Losses**	
Slope (%)	**Area** (ha)	**Khet** (ha)	**Bari** (ha)	**Forest** (ha)	**Grass** (ha)	**Shrub** (ha)
<1	230	22	8	8	10	7
1-10	588	42	53	31	33	25
11-20	377	7	29	33	37	31
21-30	463	4	30	36	35	37
>30	269	4	14	25	19	27
Elevation (m)	**Area** (ha)	**Khet** (ha)	**Bari** (ha)	**Forest** (ha)	**Grass** (ha)	**Shrub** (ha)
800-899	675	68	48	37	27	23
900-999	380	2	40	44	61	48
1000-1199	393	5	22	38	36	35
1200-1399	301	3	15	10	9	18
≥1400	178	<1	9	4	1	3
Climate	**Area** (ha)	**Khet** (ha)	**Bari** (ha)	**Forest** (ha)	**Grass** (ha)	**Shrub** (ha)
hot dry	912	59	70	66	76	55
warm dry	196	<1	13	6	8	6
warm moist	536	16	40	53	48	52
cool moist	283	3	11	8	2	14

dataset: Bela-Bhimsenthan 1:5,000 land use mapping

summarized in Table 5.2. The surveyed households typically collect 715 kg fodder, 600 kg litter and 1365 kg of fuelwood per year from local government forests. Based on the number of households in the study area (1723) and the proportion of land classified as government forests within the region, an average of 0.3 ha of forest are available to each household. The amount of nutrients contained in foliage and litter for the dominant tree species found in local forests was determined by Schmidt (1992). The nutrient content of fodder is greater than litter due to a higher average nutrient content in fodder tree species and the translocation of nutrients from leaves to perennial organs before leaf fall. The amount of nutrients contained in branch and stem wood is estimated from averages for multipurpose agroforestry trees summarized by Young (1989).

Estimated annual nutrient removal through forest product collection is listed in Table 5.2. Losses of N (56 kg ha^{-1}), P (7 kg ha^{-1}) and bases (72 kg ha^{-1}) are substantial, and within the range of losses from forests soils determined through the plot studies (Table 4.17), and foliar and litter nutrient removal estimates calculated by Feigl (1989) and Schmidt (1992). Nitrogen and phosphorus losses related to fuelwood collection account for 45% and 60% of the estimated total nutrient removal respectively. Animal fodder and leaf litter for compost production are in high demand and account for 55% of N and 74% of the total bases lost from the forest.

Table 5.2. Forest production collection (median values) and associated nutrient losses.

	Fodder	Litter	Fuelwood
Household Collection (kg yr^{-1})[a]	400	374	780
Nutrient Content[b]			
N (g kg^{-1})	14	9.6	9.6
P (mg kg^{-1})	1,330	900	1,700
total bases (mg kg^{-1})	18,650	22,500	7,400
Annual Losses			
N (kg ha^{-1})	19	12	25
P (kg ha^{-1})	1.8	1.1	4.4
total bases (kg ha^{-1})	25	28	19

[a] dataset: 1994 Bela-Bhimsenthan household survey, n=85, female farmer responses

[b] Source: Schmidt 1992, Young 1989

5.2.2 Implications of Nutrient Outflows

Despite increases in forest cover from 1972 to 1990, recent decreases suggest a downward cycle indicative of renewed pressure on forest resources. Forty-five to 55% of the female farmers surveyed in the study region (n=85) report that the collection of fuelwood, fodder and litter from forest sources is more difficult today than five years ago. As the majority of forest product collection is conducted by women, shortages will lead to an increase in their work load. In addition to changes in the area under forest, the composition of the forest has changed, with 46% of the recently afforested land under pine plantations. Although pine trees are useful in stabilising soils and improving timber production, they are not useful for animal feed and pine litter collected during the dry season as inputs to agriculture are likely acidifying the soils (Schreier et al. 1994a).

The collection of fodder and litter results in a significant transfer of biomass from the forest and interferes with the natural forest nutrient cycle. This biomass removal contributes to a low soil organic matter content and to soil acidification through the removal of bases. The removal of understorey vegetation not only results in poor soil fertility and low site productivity, but leaves the forest floor unprotected to the monsoon rains and accelerates erosion. These adverse conditions may reduce the supply of forest products at a time of increasing demand (Carson 1986, Panday 1992, Gilmour, 1991, Schmidt 1992, Schreier et al. 1994a).

5.3 Bari Dynamics: Expansion and Marginalisation

From 1972 to 1994, a net increase in bari land (36 ha) was observed. This expansion of dryland agriculture is related to both marginalization and water shortages. Agricultural marginalization is reflected by the terracing and cultivation of former grass, shrub and abandoned lands (Photo 5), located on steeper slopes and at higher elevations than the gains in khet land (Table 5.1). Water shortages are associated with the conversion of irrigated to dryland agriculture in the Bhimsenthan region on hot dry slopes (Plates 5a and 5b). Cultivation of marginal land is of particular concern as these sites have inherently poor soil fertility and are prone to erosion.

5.3.1 Nutrient Gains and Losses on Bari

The nutrient status on bari lands is generally poor (Figure 4.3 a-h) and is depleted relative to khet lands (Table 4.17). Within the cultivated fields of the study region, N and P are two critical macronutrients which are potentially limiting to plant growth and may be significantly influenced by management. Nutrient fluxes for maize (Figure 4.13) and maize-wheat rotations (Figure 4.24) indicate that inputs to bari fields are insufficient to maintain the soil nutrient pool. Ninety-four and 92 percent of fields are deficit in N and P_2O_5 respectively, and Ca inputs are insufficient to neutralise the acidifying effect of chemical fertilizers.

To identify relationships between nutrient budgets, inputs, crop uptake and soil fertility, Pearson correlation coefficients were calculated for pairs of variables. Figures 5.4a and 5.4b display variables with correlation coefficients significant at the 95% confidence level (two tailed) for maize and wheat. Under maize cultivation, nutrient budgets for N, P_2O_5 and Ca are positively correlated with inputs and negatively correlated with crop uptake due to their co-dependence. Under dryland winter wheat production, only the P_2O_5 budget is correlated with fertilizer P inputs as organic residues supply the majority of inputs. Crop yield and nutrient uptake are weakly related to inputs and soil fertility status, and relationships between nutrient budgets and soil fertility are poor, indicative of the low overall fertility conditions and high variability within bari fields.

Differences in bari nutrient budgets with aspect, elevation and soil type are summarized in Table 5.3. For each group, median values are listed and differences between groups determined by Mann Whitney U test are displayed. Statistically significant differences are found between P_2O_5 budgets and aspect, elevation and soil type. Phosphorus deficits are greater on south facing, high elevation and red soil types. Red soils which are dominant at lower elevations, fix more soil P, while hot, dry, south facing bari fields typically receive lower inputs than north facing fields. The nitrogen budget under maize production shows a greater nutrient deficit on southerly aspects, corresponding to significantly lower fertilizer inputs, while Ca deficits are smaller on south facing and high elevation sites due to lower fertilizer induced acidity.

5.3.2 Implications of Marginal Inputs and Erosion Losses

Marginal nutrient inputs and erosion losses contribute to a negative nutrient budget on bari fields which can not be sustained in the long term. The expansion of dryland agriculture onto marginal lands will likely result in more rapid soil degradation. Marginal sites have inherently lower soil fertility, are less favourable for intensive nutrient management, have higher erosion rates and produce lower yields. Water shortages are particularly evident on south facing slopes during the dry season, while slope stability is a problem during the monsoon. The recent shift of organic matter inputs away from dryland agriculture into irrigated

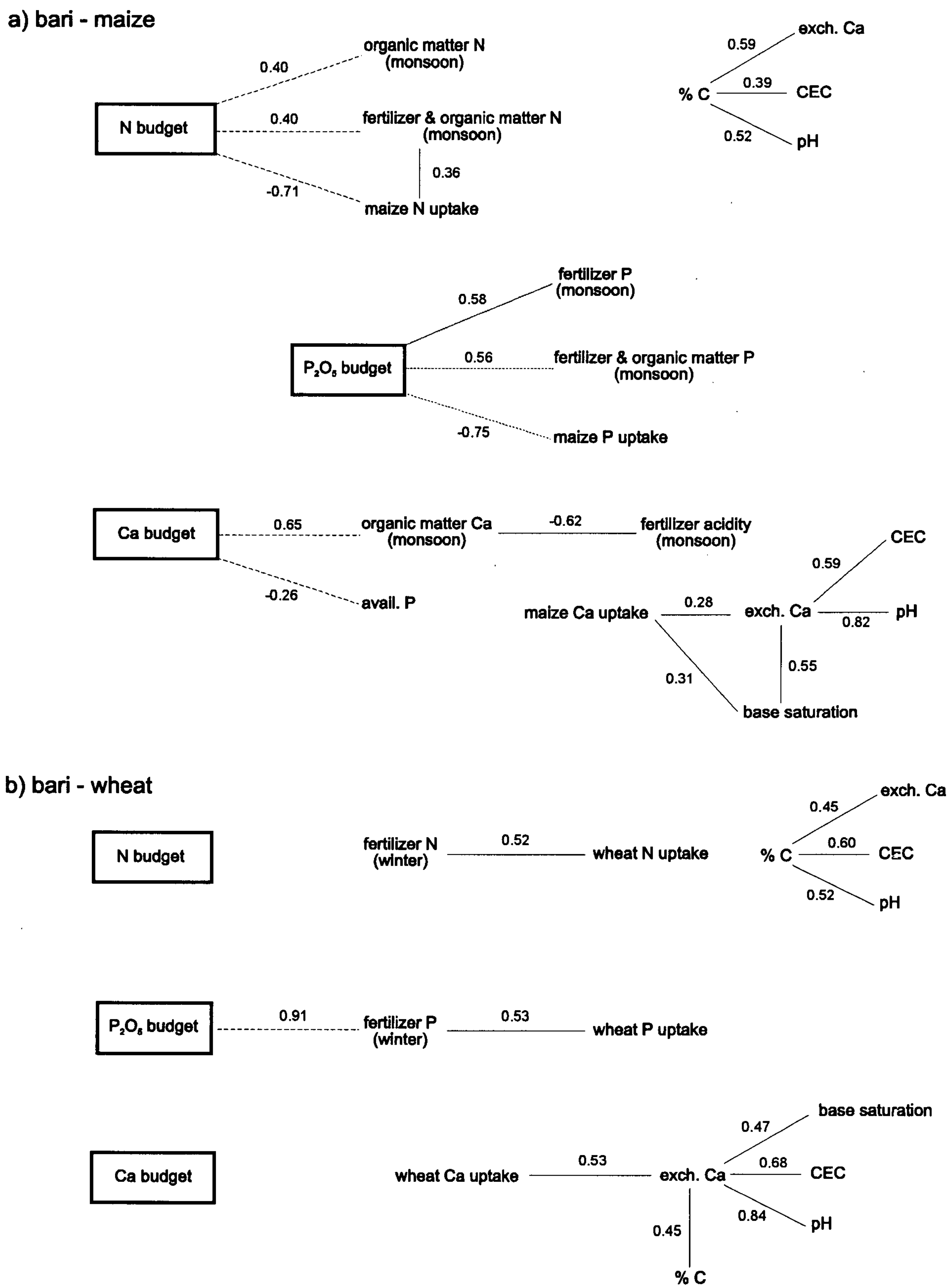


Figure 5.4. Selected correlations between nutrient budgets, inputs, crop uptake and soil fertility on bari sites (signficance of a<0.05; --- indicates co-dependence).

Table 5.3. Differences between factors affecting nutrient budgets on bari fields (sample median and Mann Whitney U test).

Crop	Factor	N budget (kg ha^{-1} f.s.)	P_2O_5 budget (kg ha^{-1} f.s.)	Ca budget (kg ha^{-1} f.s.)
Maize	**Aspect**			
	north (n=35)	-72	-21	
	south (n=30)	-125	-43	
	north vs. south	●	●	
	Elevation (m)			
	<1200 (n=31)		-18	
	≥1200 (n=34)		-39	
	<1200 vs. ≥1200		●	
	Soil Type			
	red (n=30)		-34	
	non-red (n=35)		-15	
	red vs. non-red		+	
Wheat	**Elevation (m)**			
	<1200 (n=11)		9	2
	≥1200 (n=10)		-4	9
	<1200 vs. ≥1200		●	○
	Soil Type			
	red (n=5)		-10	
	non-red (n=16)		3	
	red vs. non-red		○	
Seasonal	**Soil Type**			
	red (n=5)		-49	
	non-red (n=16)		-10	
	red vs. non-red		○	

● Significant differences between groups $\alpha<0.05$

○ Significant differences between groups $\alpha<0.10$

\+ Significant differences between groups $\alpha<0.15$

cash crop production will increase the dependence on chemical fertilizers to supply nutrients to bari fields. Acidification is a concern particularly on red soils, and will be further aggravated by any increase in chemical fertilizer use.

5.4 Khet Dynamics

From 1972 to 1994, there was a small increase in the area of khet land associated with the expansion of irrigation along the Jhikhu Khola, Andheri Khola and Namle Khola rivers (Plates 5a and 5b). The majority of khet expansion occurred below 900 m elevation and on slopes <10° (Table 5.1). Eighty-nine percent of this increase was associated with the conversion of bari land (Figure 5.2). While the amount of irrigated land has remained relatively constant, there have been changes in the cropping intensity and the type of crops grown (Photo 4).

Cropping Intensity

Cropping intensity is defined as the number of crops harvested each year from a parcel of land. Regional estimates of cropping intensity for 1980-1996 are summarized in Figure 5.5. In the 1980s Hagen (1980) and Panth and Gautam (1987) reported national averages of 1.3-1.6 crops per year. Riley (1991) reported averages of 2.0-2.45 crops per year in villages examined as part of the National Hill Crops Program. Estimates from the Jhikhu Khola Watershed Project range from 2.2-2.7 crops per year. Cropping intensity reported by khet farmers in the Baluwa 1989 and 1996 household surveys (n=27) increased from an average of 2.3 to 2.5 crops per year, although the change was not statistically significant (based on Wilcoxon signed ranks test). While these different estimates cannot be used to quantify changes, it does appear that the cropping intensity has increased from the 1980's to the 1990's.

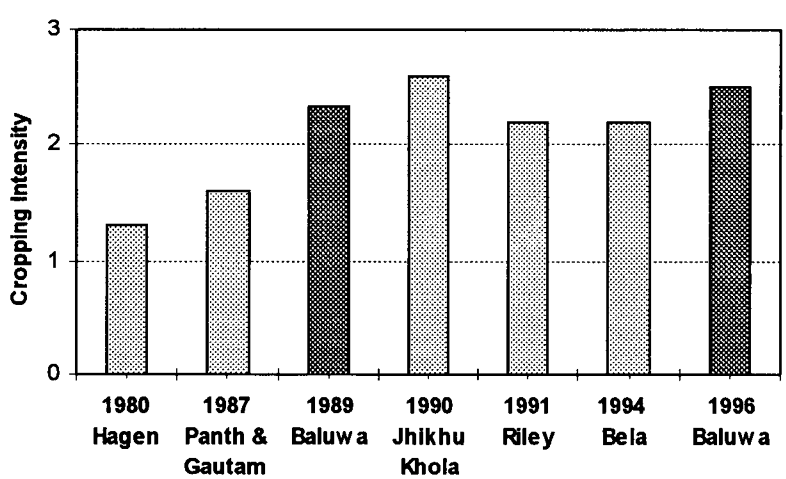


Figure 5.5. Cropping intensity estimates 1980-1996.

Market Oriented Production

Agricultural production specifically targeted for local markets has been promoted within the Jhikhu Khola watershed since the establishment of the Panchkhal Horticulture Farm in the late 1970s. Potatoes were the first major cash crop in the region and were widely grown by 1989, while tomatoes, introduced about 15 years ago, have become a popular cash crop (Kennedy and Dunlop, 1989, Srivastava 1995). Changes in cash crop production on khet in Baluwa (n=27) are summarized in Table 5.4. The number of households growing cash crops on khet land has increased significantly, with 70% of the surveyed households reporting potatoes, tomatoes, mustard or garlic production on some of their khet land. The area under cultivation of cash crops is relatively small, but more than doubled on khet from 1989 to 1996, indicating the importance of supplemental income derived from the sale of agricultural produce.

Table 5.4. Cash crop dynamics on khet land for 1989 and 1996.

Crop	**% Households**[1]		**Total Area Cultivated** (ha)	
	1989	1996	1989	1996
Khet				
potatoes	33	52	2.1	4.5
tomatoes	11	19	0.9	1.6
mustard	22	26	1.0	2.9
garlic	-	7	0	0.1
total	48	70	4.0	9.1

dataset: 1989 and 1996 Baluwa household surveys, n=27, male farmer responses

Pesticide Use

Intensive cultivation, market oriented production and the planting of high yielding varieties have promoted the use of pesticides in the study region. Information on the type and amount of pesticide applied, and application procedures are relevant to soil biology, human health and household economics (which will be further discussed in section 6.4.2). Grain and vegetable crops in the Middle Mountains are prone to infestations from a wide range of pests, and the resulting losses in yield may be as high as 15-20% (ADB 1987). The main pest problems reported by farmers are summarized in Table 5.5. Sixty-four percent of the households surveyed report using pesticides. Pesticide use is most intensive on high value cash crops.

Table 5.5. Dominant pest problems of the major crops.

Crop	**Pests** (common names)	**% of Producers Using Pesticides**
Rice	hoppers, rice bug, beetles, armyworm, leaf folder, stem borer, blight, whoral, smut, blast, leaf roller, white tip	62
Maize	aphids, crickets, corn borer, armyworm, shoot fly, stem pollen beetle, blast, whoral, white grub	8
Wheat	termites, thrips, rust, wheat bug	17
Potatoes	blast, blight, white grub, cutworm,	90
Tomatoes	blight, beetles, green bug, tomato bug	83
Mustard	root rot, beetles, aphid, painted bug	63

dataset: 1994 Bela-Bhimsenthan household survey, n=85, male farmer responses

However, as rice is the largest crop grown, rice receives the most pesticide in absolute terms. Farmers report that 62% of rice fields are treated with pesticides, 90% of potato fields, 83% of tomato fields and 63% of mustard fields.

Insecticides dominate the market due to their use for malaria control, but both insecticides and fungicides are used in the study area (Table 5.6). The main insecticides used are parathion-methyl, malathion, fenvalerate, and dichlorvos, and the main fungicide used is dithane-M45 (mancozeb). Mancozeb is a broad spectrum dithiocarbamate fungicide that is suspected of being carcinogenic when applied in high doses. In British Columbia, the use of mancozeb against pests of fruits and vegetables was suspended in 1975 as studies indicated a breakdown product could be chronically detrimental to human health after the cooking of treated crops. Fenvalerate is a chlorinated pyrethroid insecticide with some residual activity and its use in the United States is restricted due to adverse affects to aquatic organisms. Parathion methyl, dichlorvos and malathion are organophosphorus insecticides. Parathion methyl has stomach, contact, and fumigant action. It is highly toxic by inhalation and ingestion, is listed as extremely hazardous by the World Health Organisation, and its use in North America is restricted to certified applicators only. Dichlorvos is listed as a possible human carcinogen, it may affect the human immune system, and is highly toxic to bees. Its use is restricted in North America to certified applicators and protective clothing is required (BCMOE 1979, BCMOE 1990, EXTOXNET 1997, USDA 1980).

Table 5.6. Main insecticides and fungicides used in the study area.

Type	Action / Formulation[1]	Description	Farmer Application [2] (kg ai ha^{-1})	Recommended Use [3] (kg ai ha^{-1})
Dithane -mancozeb - maneb - zineb	Fungicide 80 WP 500 g pack	Group of broad spectrum carbamate foliage protectant fungicides; mancozeb suspended in Canada in 1975; cooking of treated crops chronically detrimental to human health	n = 57 ave = 10.2 max = 157 (10 packs on 0.5 ropani potatoes)	0.9 - 2.6
Fen Fen (fenvalerate)	Insecticide 20 EC 100 ml bottle	Broadspectrum chlorinated pyrethroid insecticide; some residual activity; moderate mammalian toxicity; high toxicity to fish; USEPA restricted use.	n = 30 ave = 0.34 max = 1.44 (11 bottle on 3 ropani tomatoes)	0.01 - 0.03
Metacide (parathion methyl)	Insecticide 50 EC 100 ml bottle	Broadspectrum organophosphorus insecticide; stomach, contact and fumigant action; short residual effect; extremely high oral and dermal mammalian toxicity, WHO extremely hazardous; USEPA restricted use, certified applicators only.	n = 38 ave = 0.81 max = 4.61 (11 bottles on 3 ropani tomatoes)	0.3 - 0.6
Nuvan (dichlorvos)	Insecticide 100 EC 100 ml bottle	Broadspectrum organophosphorus insecticide; nonpersistent, possible human carcinogen; high mammalian toxicity; highly toxic to bees and fish; USEPA restricted use; protective clothing required.	n = 34 ave = 1.76 max = 5.66 (1 bottle on 0.5 ropani tomatoes)	0.5 - 1.12
Malathion (cythion)	Insecticide 50 EC 100 ml bottle	Broadspectrum organophosphorus contact insecticide, nonpersistent, very low mammalian toxicity; toxic to fish and bees, banned in Indonesia due to adverse effects on predators.	n = 10 ave = 0.42 max = 0.98 (1 bottle on 1 ropani tomatoes)	0.5 - 1.4

[1] WP = wettable powder; EC = emulsified concentrate; ai=active ingredient

[2] dataset: 1994 Bela-Bhimsenthan household survey, n=85, male farmer responses

[3] source: Meister 1991, Worthing 1987, USDA 1974, 1980 & 1997, Scopes and Ledieu 1983, BCMOE 1979 & 1990, EXTOXNET 1997, BCMAFF 1995 & 1996, Gyawali 1996, ADB 1987.

The use of pesticides in the study area is highly variable. Application rates reported by farmers for the main pesticides are listed in Table 5.6 along with manufacturers' recommended use. Typically, farmers apply 1 bottle or pack of pesticide to an infested crop resulting in average application rates (kg active ingredient ha^{-1}) above recommended use for many fields. The percentage of farmers applying pesticides above or below guidelines are displayed in Figures 5.6 a-e. Excess application of pesticides is common with mancozeb, fenvalerate, parathion methyl and dichlorvos, particularly on potato and tomato crops. The number of different pesticides applied to a given crop are summarized in Figure 5.6f. While most

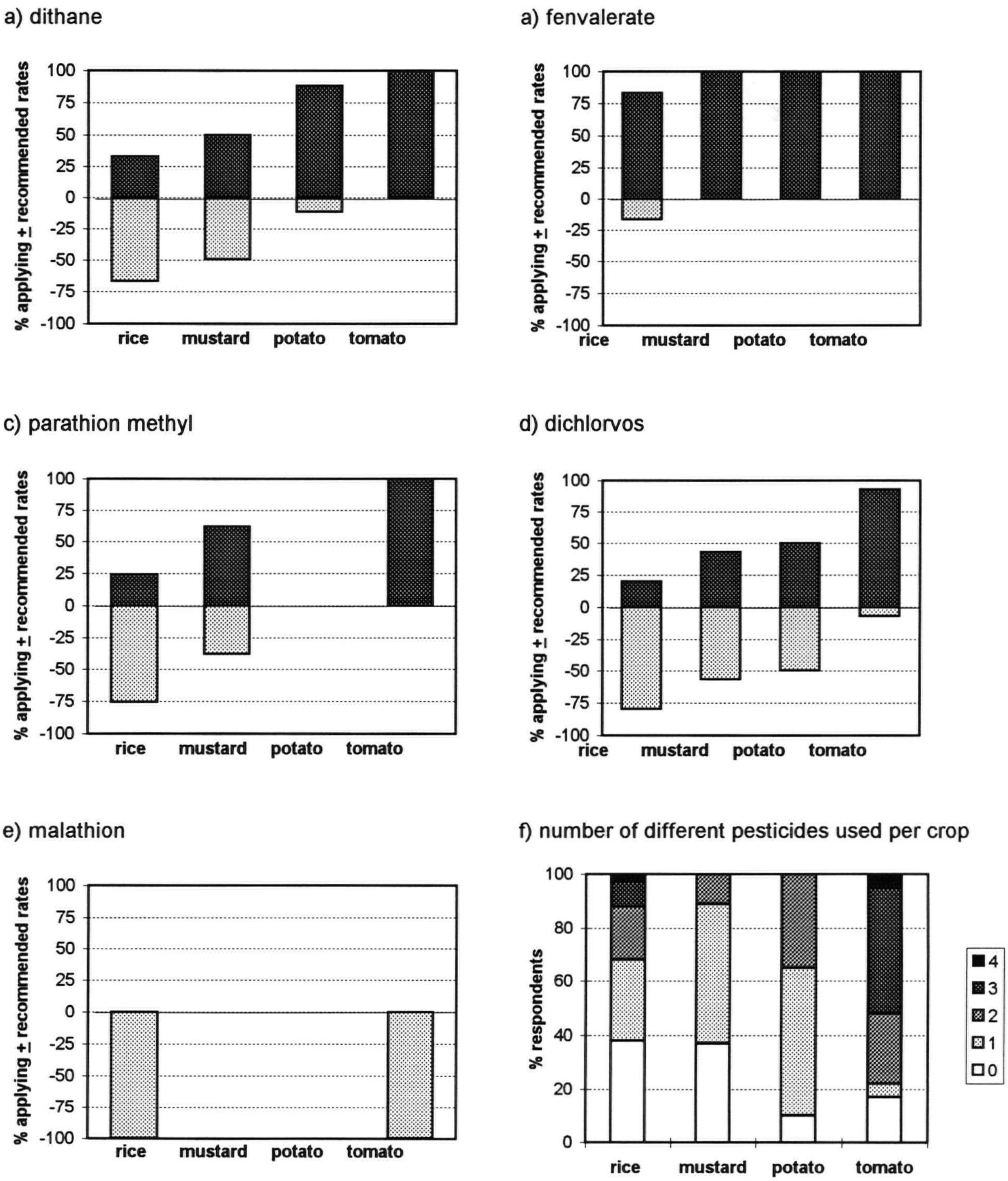


Figure 5.6. Pesticide application relative to manufacters recommended quidelines (dataset: 1994 Bela-Bhimsenthan household survey, n=85, male farmer responses).

farmers apply only one pesticide on a single crop, two or three pesticides are often used on tomatoes. The intensive use of insecticides and fungicides in vegetable production may result in unacceptable pesticide residues in the soil and crops, and in an expansion of pest resistance (ADB 1987, Jeyaratnam 1990, Lum et al. 1990).

The misuse of pesticides places farmers at risk to acute poisonings, and chronic health problems may result from prolonged exposure. Reports of pesticide misuse in the study area are listed in box 5.1. Farmers have been observed spraying pesticides upwind and the spraying tomatoes 1-2 days before harvest is not uncommon. When a farmer was asked why he used so much pesticide on his tomatoes he responded *"I'm not eating this, I'm not going to die. I'm selling it in Kathmandu."* Baker and Gyawali (1994), in a study of pesticide misuse in Nepal, report pesticide residues found in food, milk and water. Date expired pesticides are buried or dumped in open spaces, such as a river. Yield reductions due to pesticide misuse are estimated at 15-20%. The regular misuse of broad spectrum pesticides causes pests to adapt and become resistant so that more pesticides are required to achieve the same level of control. Increased pesticide use and the use of persistent organophosphate pesticides destroys natural enemies and secondary pest outbreaks (resurgence) may result from the disruption of natural controls (Baker and Gyawali 1994, Graham-Bryce 1981).

Presently there are no regulations governing the pesticide sector in Nepal. A company can import or produce any chemical regardless of its efficacy in pest control or its effects on yield, health and the environment. Dangerous pesticides, such as DDT and BHC, banned in many countries are still imported and used in Nepal. Pesticide residues on food sold in markets are currently not regulated. Farmers do not receive appropriate information on proper pesticide use or on ways of reducing chemicals such as integrated pest management. The present extension service is prescriptive; farmers are not taught why, when or how to use a certain chemical. They are merely given a piece of paper with a prescribed chemical solution (Baker and Gyawali 1994, ADB 1987).

Box 5.1 Reports of pesticide misuse in the study region.

spraying pesticides when there are no pests
using pesticides after the damage is done
using fungicides to control insects
under or over dosing pesticides leading to increased pest resistance
entering the field too soon after spraying
spraying pesticides 1-3 days before food is marketed
not targeting applications at specific pests
mixing pesticides in containers which are later used for drinking water
using pesticide containers for food or cooking oil storage
storing pesticides and sprayers in living rooms, bedrooms and kitchens
allowing children to play with empty pesticide containers
not wearing a mask, gloves, shoes or any other form of protective clothing while spraying
applying liquid pesticide with a broom instead of a sprayer
spraying pesticides into the wind

source: Shrestha 1996, Shah 1996

5.4.1 Nutrient Status and Water Management

The nutrient status on khet lands is generally adequate (Figure 4.3 a-h) and is enriched relative to bari fields (Table 4.17). Nutrient dynamics within khet lands are largely driven by chemical fertilizer use, nutrient enrichment associated with irrigation and sediment deposition, and cropping intensity. Inputs to rice-wheat rotations are generally sufficient while a three crop rotation results in a significant N deficit (Figure 4.19). For a rice-wheat rotation positive N, P_2O_5 and Ca budgets are noted for 71, 40 and 93 % of fields respectively (Figure 4.25d). Phosphorus deficits are generally small, and negative Ca budgets are associated with the high use of ammonium sulphate fertilizer.

Relationships between nutrient budgets, inputs, crop uptake and soil fertility, identified by Pearson correlation coefficients, are displayed in Figures 5.7a and 5.7b. Under rice cultivation, nutrient budgets for N and P_2O_5 are positively correlated with inputs and negatively correlated with crop uptake, which are co-dependent variables. Under irrigated winter wheat cultivation, only the P_2O_5 budget is related to inputs and crop uptake, while crop N, P_2O_5 and Ca uptake are weakly correlated with nutrient inputs. Soil C and pH are weakly correlated with nutrient inputs to rice and wheat fields, but relationships between soil

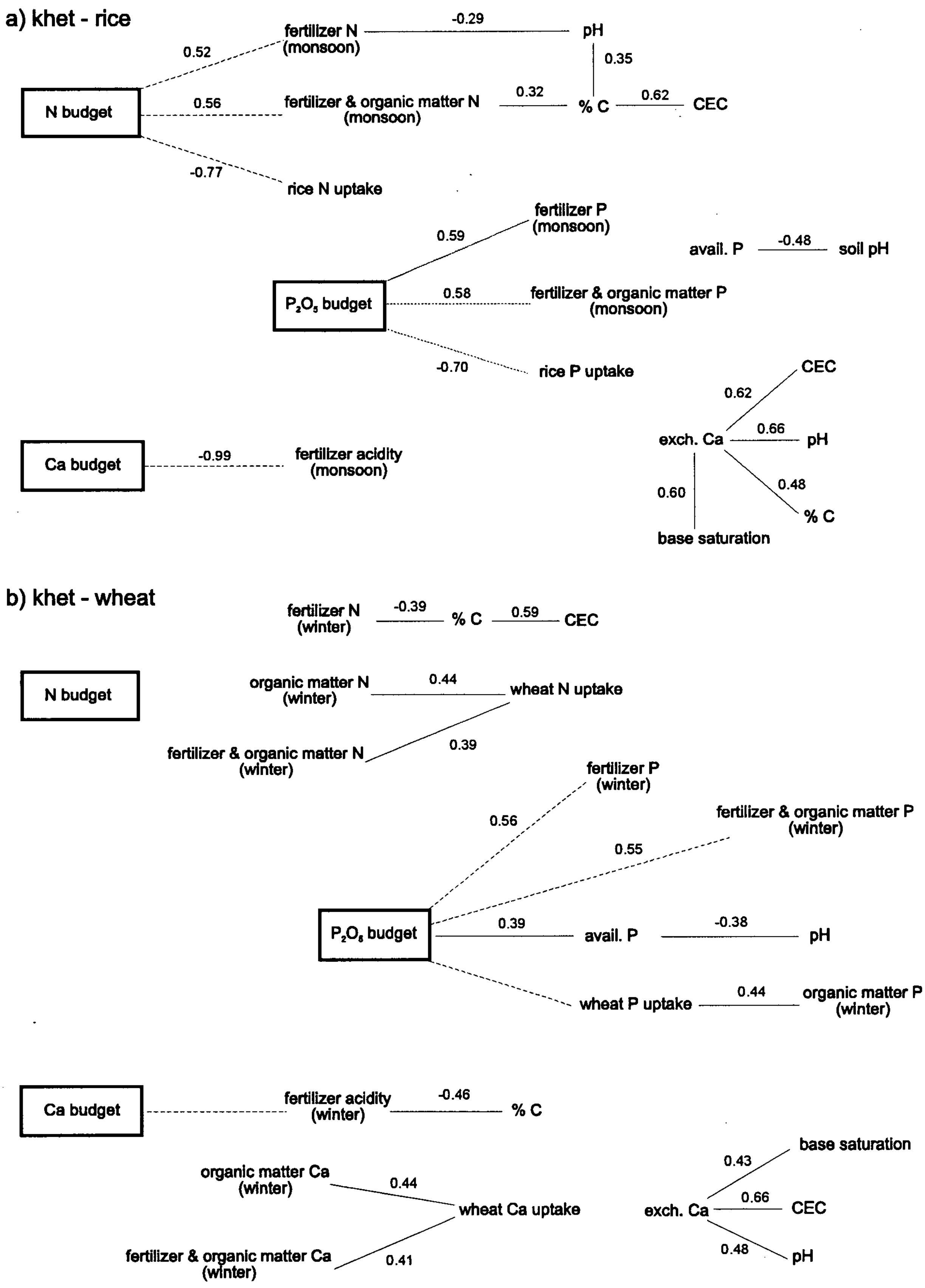


Figure 5.7. Selected correlations between nutrient budgets, inputs, crop uptake and soil fertility on khet sites (significance of a<0.05; --- indicates co-dependence).

fertility and nutrient budgets are poor and likely reflects the sensitivity of the nutrient model to water management and crop yield.

Differences in khet nutrient budgets with aspect, elevation and soil type are summarized in Table 5.7. Statistically significant differences are found between N budgets and aspect, elevation and soil type under rice production. Nitrogen surpluses are noted for high elevation, north facing slopes and non-red soils. Khet fields above 1200 m elevation are significantly less productive than low elevation sites resulting in

Table 5.7. Differences between factors affecting nutrient budgets on khet fields (sample median and Mann Whitney U test).

Crop	Factor	N budget ($kg\ ha^{-1}$ f.s.)	P_2O_5 budget ($kg\ ha^{-1}$ f.s.)	Ca budget ($kg\ ha^{-1}$ f.s.)
Rice	**Aspect**			
	north (n=30)	30	-1	79
	south (n=19)	-15	-7	86
	north vs. south	●	○	●
	Elevation (m)			
	<1200 (n=39)	-1	-6	83
	≥1200 (n=10)	43	2	79
	<1200 vs. ≥1200	●	○	○
	Soil Type			
	red (n=20)	-6		
	non-red (n=29)	20		
	red vs. non-red	○		
Wheat	**Soil Type**			
	red (n=11)			-5
	non-red (n=20)			1
	red vs. non-red			○
Rice-Wheat	**Aspect**			
	north (n=23)	35		73
	south (n=7)	-14		83
	north vs. south	+		○
	Elevation			
	<1200 (n=22)	28		
	≥1200 (n=8)	52		
	<1200 vs. ≥1200	+		

● Significant differences between groups $\alpha<0.05$

○ Significant differences between groups $\alpha<0.10$

\+ Significant differences between groups $\alpha<0.15$

lower nutrient demands. North facing slopes receive significantly greater fertilizer N inputs, while non-red khet fields are dominantly located at higher elevations (Plate 4). Calcium deficits are predicted for low elevation wheat fields, and budgets are lower on north facing aspects as greater ammonium fertilizer inputs and equivalent acidity values are noted for these sites.

5.4.2 Implications of Intensive Cultivation

Nutrient budgets on khet fields are roughly sustainable under rice-wheat production, but the introduction of premonsoon maize into the rotation results in negative seasonal budgets for N and P_2O_5 (Figure 4.19). Agricultural intensification and the introduction of cash crops has important implications for soil fertility as the nutrients removed from the soil by plant growth vary with the variety of plant and its yield. Tables 1-4 of Appendix B list nitrogen, phosphorus and potassium uptake by traditional staples and cash crops for typical yields in the Middle Mountains of Nepal. Tomatoes and potatoes require higher levels of N and P_2O_5 than rice or wheat, and K_2O uptake is significantly greater than rice, wheat or maize requirements. Cash crop production and the use of high yielding crop varieties are resulting in an increased dependence on chemical fertilizer, pesticide and micronutrient additions. Acidification on khet fields is less of a concern than on bari fields as the basic irrigation waters compensate for the acidifying effect of chemical fertilizers. While insufficient water during the dry season has limited the expansion of khet land, potential water quality problems are associated with the heavy fertilizer and pesticide use (Sharpley and Halvorson 1994, Owens 1994, Kirchman 1994, Laws 1993, Nimmo 1985).

5.5 Grass and Shrub Land Dynamics

The area under grass and shrub land decreased by 8% between 1972 and 1994, largely in association with the planting of chir pine, and the expansion of bari land (Figure 5.3). The majority of this expansion occurred on moderate to steep slopes, below 1200 m elevation (Table 5.1). This net loss of grass and shrub lands is significant as animal feed deficits have been identified as critical throughout the Middle Mountains (Schreier et al. 1991a, Fox 1987, Chitrakar 1990).

5.5.1 Nutrient Losses

The nutrient status on grass and shrub lands is generally poor and is depleted relative to bari lands (Figure 4.3a-h). Nutrient inputs are limited to manure and urine from grazing animals, but nutrients are removed through grazing, fodder and litter collection, and erosion. Common grass and fodder species on grass and shrub lands in the region are listed in Table 5.8. Within the Middle Mountains, the productivity of grass and shrub lands is highly variable both spatially and temporally, with the highest productivity obtained during the monsoon season. Unfertilized and unmanaged native grasses have low nutritive values, low digestibility and generally low productivity. Rangeland studies from the Middle Mountains suggest average yields of approximately 1 t ha^{-1} yr^{-1} (Pariyar et al. 1996, Melkania and Tandon 1988, Ranjhan 1985, LRMP 1986a). Tropical grasses may extract significant quantities of nutrients from the soil ranging from 60-300 kg N ha^{-1}, 20-100 kg P_2O_5 ha^{-1}, and 20-150 kg Ca ha^{-1} (Table 5 Appendix B), but uptake from the low productivity sites in the study region are likely near the lower range of values. Open grazing and cut grass production on common grass and shrub lands disrupts the natural nutrient cycling and contributes to the low soil fertility status of these sites.

Table 5.8. Grass and fodder species in the region.

Common Name		**Scientific Name**	**Common Name**		**Scientific Name**
Grass	Arthunge	*Herterotogon contortus*	Fodder	Angeri	*Lyonia ovalifolia*
	Dubo	*Cynodon dactylon*		Babiyo	*Eulaliopsis binata*
	Desmodium	*Desmodium intortum*		Bans	*Dendrocalamus spp.*
		Desmodium uncinatum		Kalo	*Ficus lacor*
	Khans	*Saccharum spontaneum*		Kanike	*Ligustrum confusum*
	Khar	*Cymbopogon microtheca*		Khari	*Celtis australis*
	Musekharki	*Pogonatherum paniceum*		Koiralo	*Bauhinia variegata*
	Napier	*Pennisetum purpureum*		Pithauli	*Rhus parvifolia*
	Siru	*Imperata cylindrica*		Sal	*Shorea robusta*
	Stylo	*Stylosanthes humilis*		Sirus	*Albizzia div. sp.*
		Stylosanthes guianensis		Sissoo	*Dalbergia sissoo*
				Utis	*Alnus nepalensis*

dataset: 1993/94 Bela-Bhemsenthan soil survey, n=70, male farmer responses; Gautam 1986; Pariyar et al 1996

Nutrient removal through erosion may also be significant on open access grass and shrub lands. Erosion on shrub lands of 10±2 t ha^{-1} yr^{-1} (Carver 1997) removes an estimated 10 kg N and 12 kg Ca per ha furrow slice (Table 4.7). Well managed grasslands will have minimal erosion, but 20% are degraded (75-90% soil exposure) and have high erosion rates (62±44 t ha^{-1} yr^{-1}). Additionally, 30% of shrub lands are classified as degraded (50-75% soil exposure). Nutrient losses from these degraded sites remove an estimated 34 kg N and 23 kg Ca per ha furrow slice.

5.5.2 Implications of Degradation

Land classified as shrub and grasslands are largely degraded forests and agricultural wastelands. Nutrient inputs are minimal and biomass production is generally low. Heavy grazing and cut-and-carry fodder production have resulted in degradation of some 96 ha (5% of the study area). Carver (1997) identified these severely degraded sites as a significant source of sediments to the overall basin sediment budget. Grazing and surface erosion have resulted in soil compaction, surface crusting, reduced infiltrability and a reduction in water holding capacity. Rehabilitation of these degraded sites has proven difficult but promising results have been obtained by Shah et al. (1995) through the use of N-fixing fodder trees, lime and trickle irrigation. While long term rehabilitation efforts require resources which are unavailable to most farmers, research projects may aid in the establishment of productive biomass.

5.6 Land Use Interactions and Soil Fertility

Nutrient flows between land uses are a critical component of the soil nutrient budget modelling. Fluxes between land uses are illustrated in Figure 5.8, and indicate that the transfer of nutrients within the farming system is unbalanced. Organic matter production and cycling on grass, shrub and forest lands is disrupted. Inputs are small, while nutrients are redistributed to khet and bari fields through litter and manure. Bari fields receive inputs via compost and fertilizer, but nutrients are transferred to khet fields through erosion. Khet fields act as a nutrient sink receiving inputs from compost, fertilizer, sediment and water.

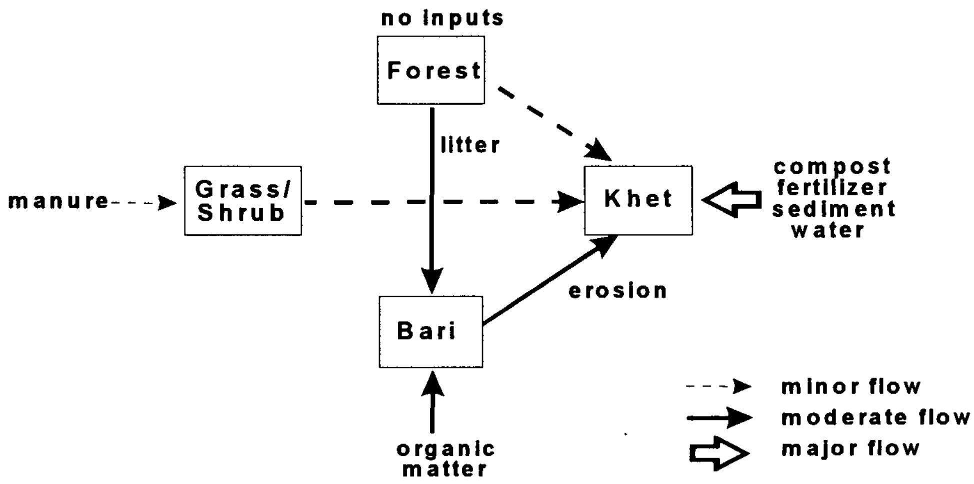


Figure 5.8. Nutrient flows within the farming system.

Nutrient inputs from chemical fertilizer and organic matter sources to topographic and land use classes are shown in Table 5.9. Significant differences are noted for elevation, aspect and land use categories, while no differences were noted with soil type. The greatest difference in inputs is noted between khet and bari sites, with khet fields receiving significantly greater chemical fertilizer and total inputs of N and P_2O_5, and bari fields receiving significantly greater organic matter inputs (based on Mann Whitney U test). Differences with elevation are largely a manifestation of changes in land use above and below 1200 m, while differences with aspect reflect management. Both khet and bari fields on north facing slopes receive significantly greater fertilizer inputs than the hot, dry south facing slopes.

Dynamics in Nutrient Inputs

Changes in the agricultural production system to include more cash crops has important implications for nutrient fluxes. Organic matter traditionally applied to bari land is used to supplement production on khet lands, and chemical fertilizers are acquiring greater importance within the farming system (Photo 6). Relative changes in the amount of organic matter and chemical fertilizer inputs are presented in Figure 5.9a and 5.9b. In 1989 and 1996, farmers in Baluwa were asked to compare their current nutrient inputs to levels 5 years ago. The number of female farmers reporting organic matter use increased significantly

Table 5.9. Differences in nutrient inputs with topography and land use (sample median and Mann Whitney U test).

Factor	Fertilizer		Organic Matter			Total	
	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	Ca (kg ha^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})
Elevation (m)							
<1200 m (n=80)	114	69	44	4	59	178	79
≥1200 m (n=50)	81	25	54	5	72	147	31
<1200 vs. ≥1200	●	●	○	○	○		●
Aspect							
north (n=70)	144	63	44	4	59	195	68
south (n=60)	65	39	45	5	60	118	44
north vs. South	●	○				●	○
Land Use							
khet (n=50)	162	79	33	3	44	201	80
bari (n=80)	66	34	53	5	71	122	41
khet vs. Bari	●	●	●	●	●	●	●

dataset: 1993/94 Bela-Bhimsenthan soil survey, n=130

● Significant differences between groups α<0.05 ○ Significant differences between groups α<0.10

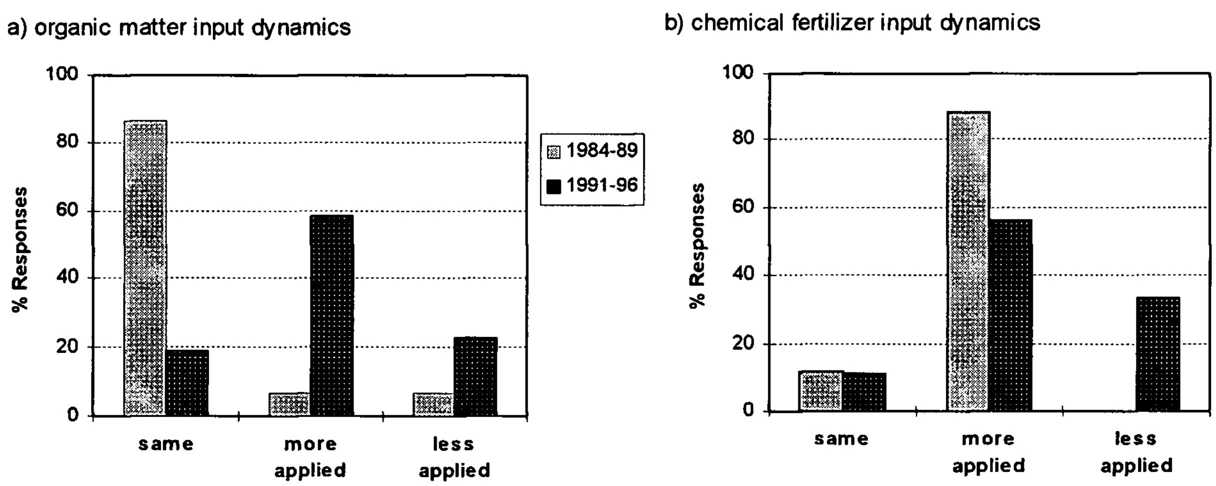


Figure 5.9. Nutrient input dynamics for a) organic matter and b) chemical fertilizers (dataset: 1989 and 1996 Baluwa household surveys, n=27; a) female farmer responses b) male farmer responses).

from the 1984-89 period to the 1991-96 period. In 1989, 86% of female farmers reported using the same amount of organic matter as in 1984, while in 1996, 58% reported applying more organic matter. Chemical fertilizer application showed a somewhat different trend, with 88% of the male farmers interviewed in 1989 reporting more fertilizer being applied compared to 1984, while 55% report using more chemical fertilizer in 1996 and 41% use less fertilizer. The main reasons given for applying less chemical fertilizer in 1996 were high cost and the negative impact on soil structure. Alternatively, the main reasons listed for using more fertilizer were: 1) to increase yield; 2) more fertilizer was required to maintain yields; and 3) declining yields. The increased use of fertilizer to maintain current levels of production or because of declining yields was also reported by 41% of farmers in the Bela-Bhimsenthan 200 site soil survey. The increased reliance on chemical fertilizers to maintain productivity levels is indicative of declining soil fertility and the higher level of inputs may negatively impact soil pH and structure.

Mineral fertilizer use in the Middle Mountains is constrained by availability (fertilizer type and timing) and cost. The availability of chemical fertilizer is strongly tied to foreign aid which varies from year to year, contributing between 20 and 90% of the supply. Since 1972, fertilizer pricing has been fixed by the Agricultural Inputs Corporation and transportation costs to the hills have been subsidised. Subsidies vary between years and between fertilizers. The relative fertilizer prices in Nepal and India determine the profitability of smuggling fertilizer across the free international border. Informal estimates indicate up to 85% of some fertilizer shipments intended for Nepal have gone to India. In 1993, the government eliminated a major portion of the subsidy on most fertilizers (except urea) and prices doubled limiting the affordability to only the more prosperous farmers. Fertilizer availability is particularly problematic for farmers who may only have experience with a particular type of chemical fertilizer but may only be able to purchase a different kind. For example, the Lumle Agricultural Research Centre reports farmers complaining of a lack of effectiveness of double superphosphate (0-46-0) compared with complex© (20-20-0) suggesting a lack of understanding of effective fertilizer use and a need for extension. (Chitrakar 1990, Kennedy and Dunlop 1989, Pandey et al. 1995, Srivastava 1995, Sthapit et al. 1988, Wallace 1986, Thapa 1995).

Problems reported by farmers in the Baluwa region related to obtaining fertilizer are summarized in Table 5.10. In 1989, farmers reported significant problems related to fertilizer availability, but in 1996 availability was not an issue. Cost, however, has remained an issue with farmers. The type of fertilizer most commonly applied on khet and bari land in 1989 and 1996 are summarized in Figure 5.10. Complex© (20-20-0) was the most commonly used fertilizer on both khet and bari land in 1989, but urea (46-0-0) was more heavily used in 1996. The reduction in the use of complex© is linked to limited availability from 1993 and DAP (diammonium phosphate) was recommended as an alternative (Srivastava 1995). The increased use of urea is likely price related, as it became relatively less expensive with the removal of subsidies on alternative fertilizers. Both urea and complex© are ammonium based fertilizers, and the increased N concentration of urea will negatively impact soil pH with sustained use. While chemical fertilizers have the potential to enhance soil fertility, the traditional recycling of organic residues is vital to maintaining soil tilth (Carson 1992, Foth 1990, Sherchan and Gurung 1995).

Table 5.10. Difficulties in obtaining chemical fertilizer.

Problem	% Responses[1]	
	1989	1996
Wrong type	74	7
Wrong time	74	7
Unable to pay	41	30

[1] dataset: 1989 and 1996 Baluwa household surveys, n=27, male farmer responses

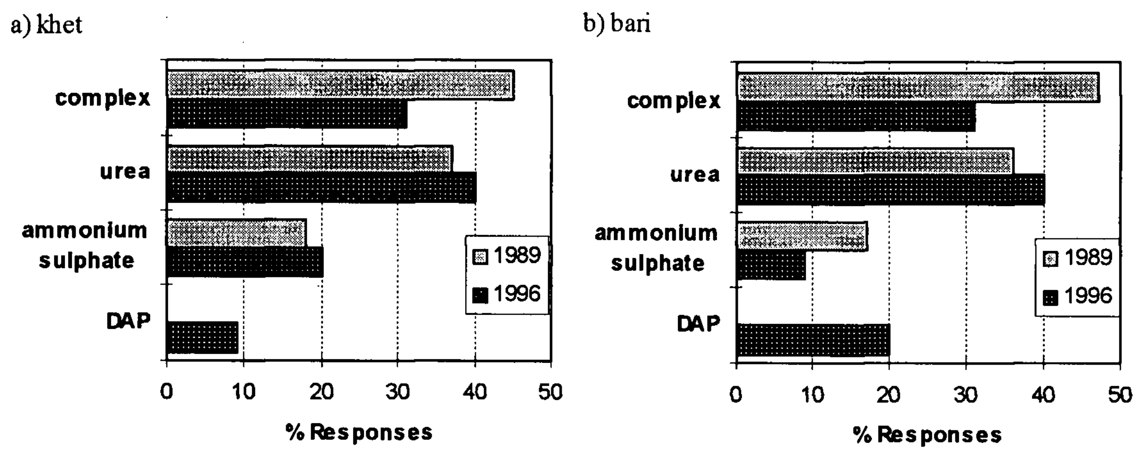


Figure 5.10. Types of fertilizer commonly used on a) khet and b) bari land in 1989 and 1996 (dataset: 1989 and 1996 Baluwa household surveys, n=27, male farmer responses).

5.6.1 Implications for Production

Nutrient deficits and unbalanced nutrient flows between land uses will negatively impact future biomass production. The farming system integrates bari, khet, forest, shrub and grass lands such that pressure on one component will impact the entire system and alter the transfer of nutrients. Current and future productivity are linked to nutrient fluxes both within and between land uses.

Forest Productivity

Forest biomass estimates in relation to site quality provide an estimate of the impact of soil fertility on site productivity. In the Sindhu Palchok District, Applegate et al. (1988) found total above ground biomass on high and low quality sites of 35 ± 5 t ha^{-1} and 8 ± 2 t ha^{-1} respectively. The mean annual increment at age nine years was 7 t ha^{-1} on high quality sites and 2 t ha^{-1} on low quality sites, indicating a substantial reduction in productivity rates. In the Dhulikhel subwatershed, Schmidt (1992) found that most foliar samples for sal and pine fall below critical levels for N and P indicating the low soil nutrient status of these sites.

In a typical forest ecosystem the annual cycling of most nutrients via litterfall and foliar leaching is substantially greater than fluxes into and out of the system. Litterfall is the predominant mechanism in the aboveground return of N, P, Ca and Mg to the soil. The collection of fodder, litter and fuelwood, however, disrupts nutrient recycling, and may lead to a depletion in key soil nutrients (Johnson and Todd 1990, Richter et al. 1994, Sanchez et al. 1985, Young 1989). Feigl (1989) notes a relationship between total biomass and guarding status (protection afforded by human action) in the Jhikhu Khola watershed. Total biomass in chir pine and hardwood stands with no protection ranged from 7 to 22 t ha^{-1} while protected stands ranged from 18 to 53 t ha^{-1}. Differences between total biomass produced on stands of similar age suggest a 15% increase in biomass production when forests are guarded and no litter, fodder or timber is removed. Both Feigl (1989) and Schmidt (1992) found that protected stands in the Jhikhu Khola Watershed are characterised by significantly higher soil pH, CEC, base saturation, Ca, Mg, K and P.

During the past three decades, afforestation projects in the study region have been active planting chir pine which now comprises 40% of the forest area. The influence of forests on soil fertility is often assumed to be beneficial, however long term data sets (10-30 years) suggest that fast growing pine trees often deplete exchangeable bases and decrease soil pH. Some species, such as *Gmelina arborea* (khamari) are able to capture and recycle soil nutrients more efficiently, but *Pinus sp.* produce litter with significantly lower Ca and Mg contents (Johnson and Todd 1990, Richter et al. 1994, Sanchez et al. 1985).

Crop Productivity

Farmers are not interested in soil fertility per se, but in the resulting productivity. To identify relationships between crop productivity, soil fertility and nutrient management, Pearson correlation coefficients and multiple regression models were calculated. Figures 5.11a and 5.11b show correlation coefficients for the dominant crops on bari and khet fields. Maize and wheat yields are weakly correlated with nutrient inputs and soil fertility, while no significant relationships were noted for rice yields suggesting the importance of irrigation water and sediment deposition in supplying nutrients to paddy fields. Multiple regression analysis using both nutrient inputs and soil fertility parameters improved relationships with yield over relationships with inputs or fertility in isolation. Scatter plots of reported and modelled yield for maize, rice and wheat are shown in Figures 5.12 a-c. Maize yield is estimated using fertilizer N, base saturation, exchangeable K and CEC. The model has an r value equal to 0.52 and predicts a median maize yield of 3988 ± 1840 kg ha^{-1} (two standard deviations). Rice yield is estimated using fertilizer acidity, fertilizer N and P, soil C, exchangeable Ca and pH. The relationship is somewhat weaker with an r value equal to 0.43 and predicts a median rice yield of 2485 ± 1464 kg ha^{-1}. Wheat yield on both khet and bari land is estimated using organic matter, fertilizer N and P, base saturation, exchangeable K and CEC The model predicts a median wheat yield of 1275 ± 1680 kg ha^{-1}, and has an r value of 0.68. For all three crops, under dryland and irrigated conditions, farmers applying more nutrient inputs report higher yields.

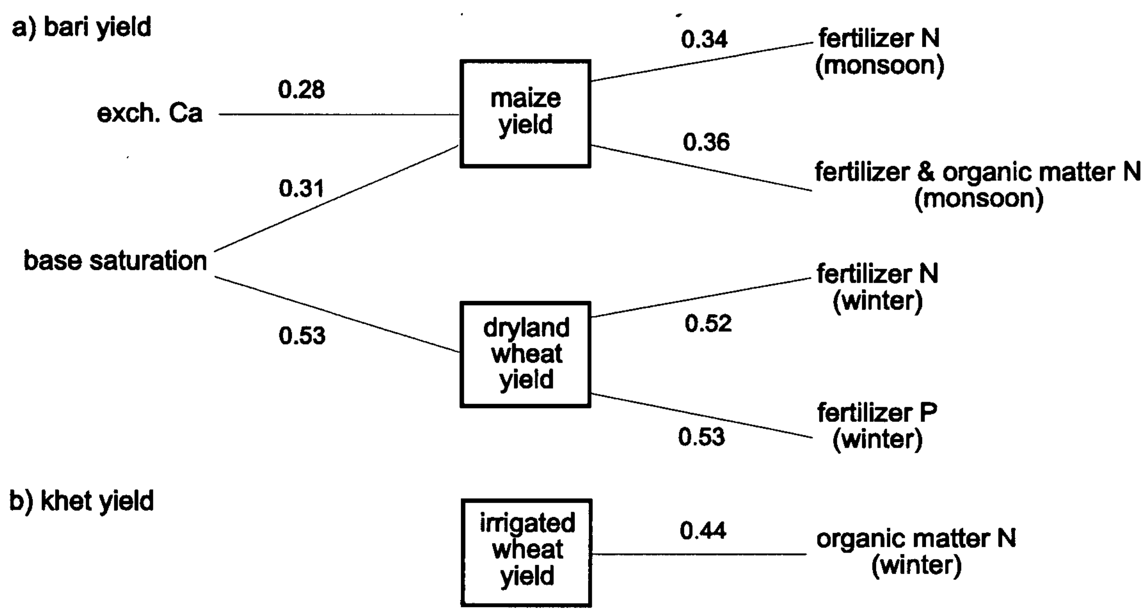


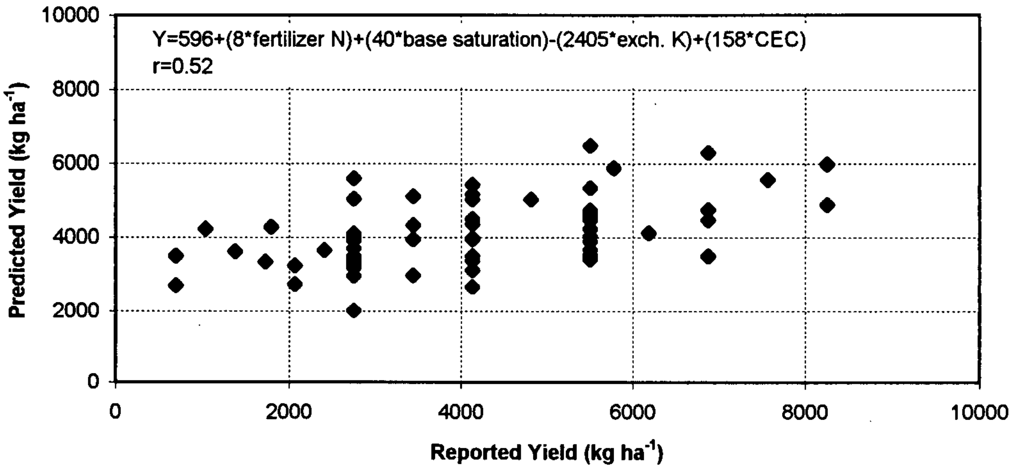
Figure 5.11. Correlations (r values) between crop productivity, soil fertility and nutrient management (significance of a<0.05).

The weak relationships between crop yield and soil fertility, and improved relationships with nutrient inputs and multiple regression analysis suggest that the soil is providing short term nutrient storage and that nutrient inputs are more important in determining yield. Soil conditions may limit nutrient availability (e.g. low available P on red soils) or limit plant growth through toxicity (e.g. Al toxicity at low pH), but nutrient inputs are the dominant factor driving yield.

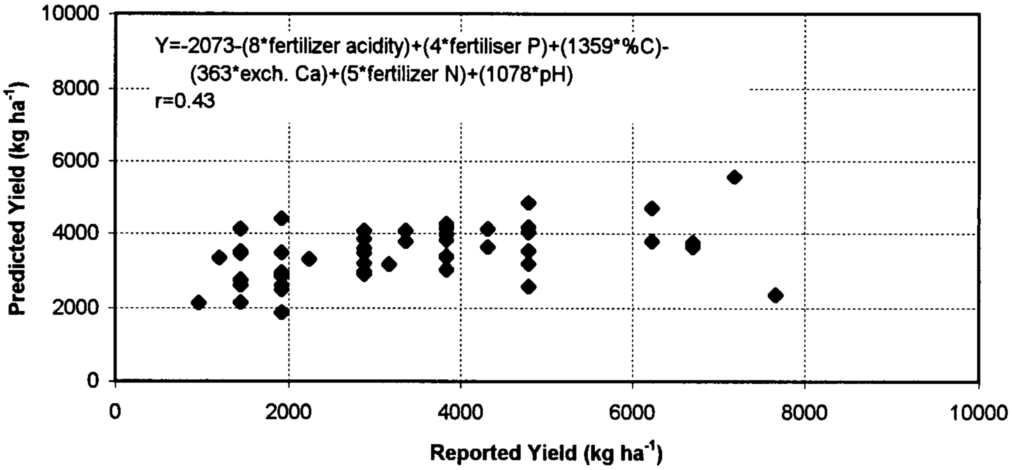
Grass and Shrub Productivity

Current biomass production on grass and shrub lands is low, and cut-and-carry fodder production and extensive grazing will likely perpetuate low productivity. The majority of these sites are agricultural wastelands and degraded forests, and continued biomass removal with minimal nutrient inputs contributes to their low soil fertility status. The potential impact of heavy exploitation and the resulting negative nutrient budget on grass and shrub lands is represented by degraded sites within the study region. One quarter of the current grass and shrub lands are classed as degraded, having >50% soil exposure and subject to high erosion rates.

a) bari - maize



b) khet - rice



c) winter wheat

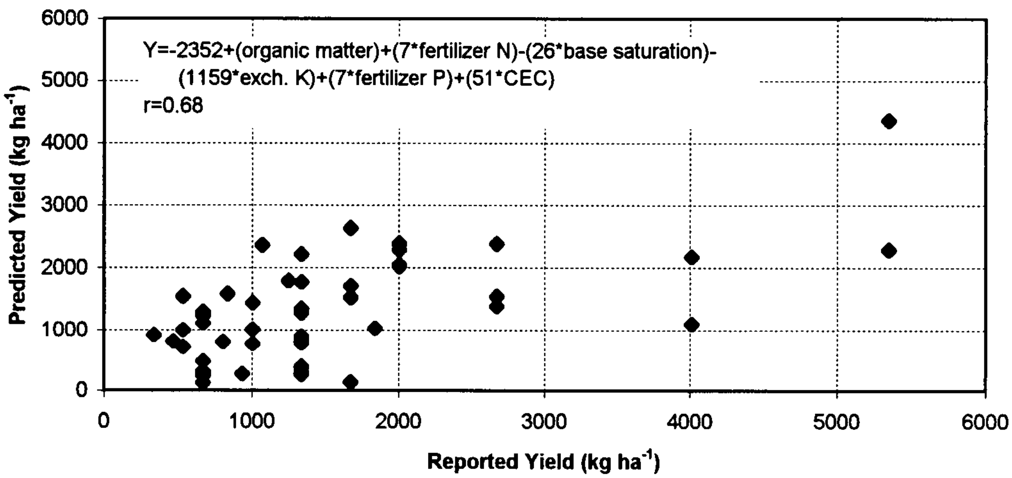


Figure 5.12. Multiple regression analysis of yield, nutrient inputs and soil fertility conditions.

Protection from grazing is a prerequisite for grassland improvement. In Mid-Himalaya grasslands, Melkania and Tandon (1988) found yields increased from 0.9 t ha^{-1} under free range grazing to 2.4 t ha^{-1} after two years of protection, and a further increase to 3.0 t ha^{-1} after three years of protection. Rotational grazing supported by stall-feeding is suggested as an alternative to extensive grazing.

Production Constraints

To determine the main production constraints on cropland, the male household heads were asked "What is the biggest problem preventing you from increasing your yields per ropani?" The results for Baluwa in 1989 and 1996 are presented in Table 5.11. A lack of irrigation facilities, and the availability and prohibitive cost of chemical fertilizer remain the dominant production constraints. The increasing demands placed on water resources are indicated by the large number of responses (60%) reporting a lack of irrigation as a major limitation in 1996 compared to the 43% noted in 1989. Disease problems were not reported by surveyed farmers in 1996 compared to 14% in 1989, and are likely related to increased pesticide use in the study region. Agricultural equipment and improved seeds were less of an issue in 1996, but 5% of farmers cite labour as a major constraint.

Table 5.11. Changes in production limitations, 1989 - 1996.

Limitation	**% Responses**	
	1989	**1996**
irrigation	43	60
chemical fertilizer	29	33
disease	14	0
agricultural equipment	7	0
improved seeds	5	2
labour	2	5

dataset: 1989 and 1996 Baluwa household survey, n=27, male farmer responses

5.6.2 Nutrient Dynamics and Future Soil Fertility

The impact of nutrient fluxes on future soil fertility can be assessed by comparing predicted nutrient deficits and current soil fertility conditions. Nutrient budgets for individual fields are related to the factors which account for their variability, specifically land use, soil type, aspect and elevation. Using the soil fertility classification developed in section 4.12 and predicted nutrient budgets for each class, soil degradation can be assessed and extrapolated to the entire study region using GIS overlay techniques.

Degradation maps are developed for soil P and Ca using nutrient budgets based on rice for khet land, maize for bari land, plot study data for forest and shrub lands, and plant uptake estimates for grasslands. Soil carbon is not evaluated as levels are currently very low under all land uses. The main factors accounting for the variability in soil P budgets are land use, soil type, aspect and elevation. Samples are stratified by these factors and changes in the soil nutrient pool are estimated for each group. The results are lumped into two categories delineating areas of small (<20 kg per ha furrow slice) and large (<20 kg per ha furrow slice) nutrient deficits. Land use, soil type, aspect and elevation themes are combined within the GIS, assigned the appropriate P change category and overlain with the current soil P classification (Plate 11). The results shown in Plate 14 indicate that 25% of the area has adequate available P and is subject to low change (shown in green). Management concerns exist on 37% of the area (shown in red, orange and yellow) corresponding to regions of adequate available P subject to large deficits, and low available P subject to large or small deficits. These areas correspond to bari land on red and non-red soils, south facing khet land on red soils, grasslands on non-red soils, and south facing grasslands on red soils. Areas shown in blue are already very low in available P and are being degraded further.

The main factors accounting for the variability in soil Ca budgets are land use and aspect. Samples are stratified by these factors and changes in the soil Ca pool are estimated for each group. The results are lumped into three categories: surplus Ca, small deficits (0-40 kg per ha furrow slice) and large deficits(>40 kg per ha furrow slice). GIS overlay techniques are used to extrapolate Ca change spatially and identify areas of concern relative to current soil Ca conditions (Plate 15). Minimal change is anticipated on khet lands which have moderate soil Ca and surplus Ca budgets (represented in green). Management concerns exist on regions of moderate and adequate soil Ca subject to high or low deficits (represented in red and yellow). These areas cover 46% of the study region and correspond to south facing, low elevation bari land; north facing bari land; and low elevation grasslands. Regions shown in blue are already below desirable Ca levels.

The soil Ca and P degradation maps illustrate regions where current land use practices are having a limited impact on soil fertility and regions of management concern. Khet production appears to be sustainable under a rice dominated cropping system but intensive cash crop production will likely result in negative nutrient budgets and soil degradation. Regions of management concern are dominated by bari lands. Current soil fertility conditions on non-red bari sites are generally adequate and subject to small nutrient deficits with the exception of high elevation, south facing sites. Bari fields on red soils have low to adequate soil fertility but are subject to high P deficits. These sites are of particular concern due to their high P fixation capacity. The timing of organic matter inputs is critical to soil P availability for crop uptake as fertilizer P inputs on red soils will be largely fixed. Calcium and N deficits are prevalent on most bari sites sampled and significantly greater deficits occur on south facing sites. While organic matter inputs supply roughly one-half the N and all the Ca applied to bari fields, N and Ca deficits imply insufficient organic matter inputs. Regions with poor current soil fertility conditions are largely forest, shrub and high elevation grasslands. Rehabilitation of these sites will require substantial effort and resources, and is complicated by government ownership.

5.7 Summary

Land use change, its impact on nutrient flows and relationships between nutrient inputs, crop uptake, nutrient budgets and soil fertility are used to assess why soil fertility is changing. General land use trends show a cyclical decline in forest cover, limited expansion of cropped land and recent decreases in grass and shrub land.

Forest dynamics may be described as a function of quantity versus quality. Afforestation efforts during the 1980's resulted in a 50% recovery of previous losses but the focus on chir pine resulted in large areas of monoculture forest, and renewed losses of hardwoods have been observed in the 1990's. Forest soils show the lowest overall soil fertility and the greatest annual nutrient losses. The collection of fodder, litter and fuelwood results in a significant transfer of biomass from the forest and interferes with the natural forest nutrient cycle. Biomass removal and the associated outward flow of nutrients is the dominant management factor causing soil fertility degradation on forest land.

Bari dynamics may be described as a function of expansion and marginalisation. Expansion of bari land from 1972 to 1994 is related to the terracing and cultivation of former grazing, shrub and abandoned lands located on steep, high elevation slopes, and the conversion of previously irrigated fields due to water shortages. Cultivation of marginal lands is of concern as they have inherently poor soil fertility and are prone to erosion. The nutrient status on bari lands is generally poor and nutrient fluxes indicate that inputs are insufficient to maintain the soil nutrient pool. Nutrient budgets are related to fertilizer and organic matter inputs but relationships with soil fertility are poor, indicative of the low overall fertility conditions and high variability within bari fields. Phosphorus deficits are significantly greater on red soils which have a high P fixation capacity, and on south facing sites which receive less organic matter inputs. Acidification is a concern for nutrient availability particularly on red soils, and will be aggravated by increases in chemical fertilizer use. Changes in soil fertility on bari land are complicated by topographic conditions and inherent soil characteristics, but insufficient nutrient inputs and the cultivation of steep slopes which results in nutrient losses through erosion are the main management factors driving soil fertility degradation.

Khet dynamics is best described by intensification. The amount of irrigated land has remained relatively constant but cropping has intensified and shifted towards more market oriented production. Intensive cultivation, cash crop production and the planting of high yielding varieties have prompted the use of agrochemicals, and pesticides use is widespread. Fungicides and insecticides are often applied above manufacturers recommended rates, and inappropriate use raises concerns about human health and environmental pollution. The soil nutrient status on khet lands is generally adequate. Khet fields act as a nutrient sink receiving inputs from compost, fertilizer, sediment and water. Inputs to rice-wheat rotations are usually sufficient but triple cropping results in significant N deficits. Nutrient budgets are related to fertilizer and organic matter inputs, but relationships with soil fertility are poor reflecting the sensitivity of the nutrient model to water management and crop yield. Nitrogen budgets are significantly lower at elevations below 1200 m and on south facing slopes as high elevation sites are less productive and therefore less nutrient demanding, and north facing slopes receive greater fertilizer inputs. Water management and the associated sediment accumulation on low lying khet fields is the key management practice maintaining soil fertility on the intensively managed khet lands. However, nutrient inputs may not be sufficient to sustain triple cropping and increased agrochemical use threatens the environmental quality.

Grass and shrub land dynamics are characterized by minimal inputs and low productivity. The nutrient status is generally poor, and tropical grasses extract significant quantities of nutrients from the soil. Open grazing and cut-and-carry biomass removal disrupt the natural nutrient cycling and contribute to the low soil fertility status. Nutrient removal through erosion is also important, particularly on degraded sites (>50% soil exposure). The lack of nutrient inputs and over utilization resulting in biomass removal and accelerated erosion are the dominant management factors contributing to soil fertility degradation on grass and shrub lands.

Overall, the transfer of nutrients within the farming system is unbalanced, organic matter cycling is disrupted and nutrient inputs vary both spatially and temporally. Chemical fertilizer use has increased, to counteract declining yields, but varies year to year with price fluctuations. Nutrient deficits and unbalanced nutrient flows between land uses will negatively impact future biomass production. Related studies found that forest productivity is lower on sites with extensive biomass removal compared to protected sites. Crop productivity is related to both soil fertility and nutrient inputs on irrigated and dryland sites, but nutrient inputs are more important than soil fertility in determining yield. Grassland and shrub productivity is low, but protection has been found to increase yields in other parts of the Mid-Himalaya. Soil degradation maps suggest that khet production is currently sustainable but management concerns exist on bari lands. Red soils are particularly problematic due to their high P fixation capacity and organic matter management is critical on these soils.

6. UNDERLYING SOCIO-ECONOMIC FACTORS

The pattern of life in most rural communities of the Middle Mountains has been largely determined by processes acting at the village level and changes within their biophysical environment. Within these traditional communities, local knowledge and experiences play an integral role in decision making. In recent years, however, rapid population growth, increasing pressure on the resource base, and the increased availability of Western technology have accelerated change. The introduction of improved varieties of wheat and rice in the 1970s and 1980s made agricultural intensification possible, but this intensified agriculture is more demanding on soil, water and human resources. Chemical fertilizers were also adopted in the 1970s, and their usage in the Middle Mountains has increased an average of 9% per annum, furthering the need for capital. Communities near major markets such as Kathmandu are no longer isolated, but are changing as they become more integrated into the cash economy. Local farmers are innovators and experimenters, adapting technology to local conditions and incorporating elements from the industrial world into their traditional system. Chemical fertilizers for example, are used in conjunction with traditional compost, and plastic pipe is replacing hollowed log conduits within irrigation systems. However, traditional farming systems evolved over many generations in a relatively stable environment, and their ability to adapt to the rapidly emerging social, economic and biophysical pressures is limited (Chitrakar 1990, Kennedy and Dunlop 1989, Conway 1986, Ehrlich et al. 1971, Gill 1991b, Chambers et al. 1989, Rhoades 1989, Mwadime 1996).

Population growth, land tenure, culture and poverty are the underlying socio-economic factors influencing farming system dynamics in the Middle Mountains, and define the contextual framework under which soil fertility depletion is occurring. Their current status and recent changes impact land use, nutrient management and consequently soil fertility. The implications for soil fertility are both direct and indirect, and provide further insight into why soil fertility degradation is occurring. The components evaluated, and their interaction with soil fertility data from chapter four are shown in Figure 6.1. For each socio-

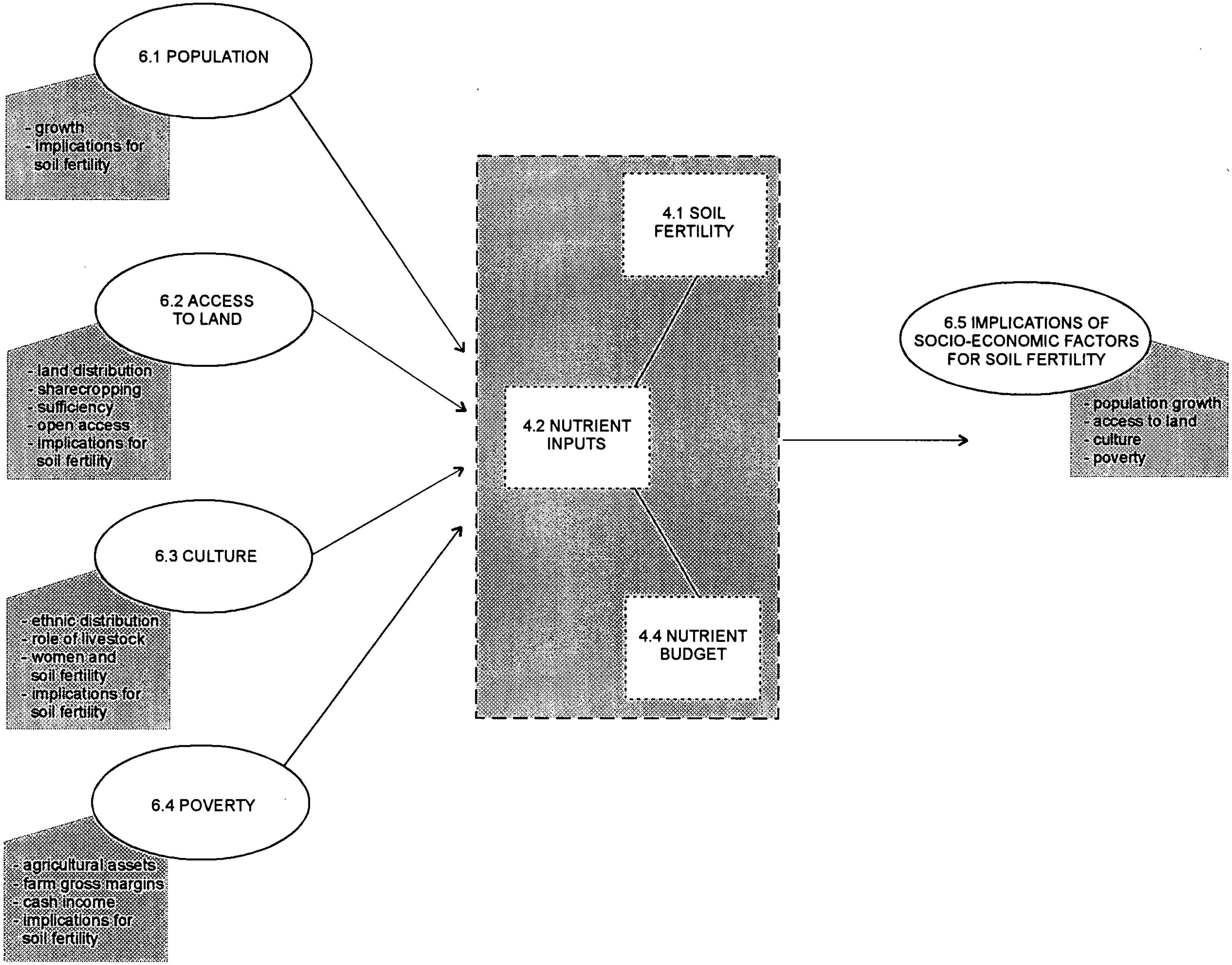


Figure 6.1. Socio-economic factors driving nutrient management and soil fertility dynamics evaluated in chapter 6.

economic factor key indices are presented and the implications for soil fertility are examined. Population growth is discussed relative to land use change and nutrient fluxes both within and between land uses. The influence of land tenure is evaluated through the distribution of land ownership, share cropping, household sufficiency from farmed land and open access resources (forest, shrub and grasslands). The cultural factors considered are ethnic distribution, the changing role of livestock and the involvement of women in soil fertility management. The poverty indices selected are agricultural assets (land and livestock), farm gross margins from crop production (total returns and variable costs), cash income derived from the sale of agricultural products (vegetable crops and milk production) and off-farm employment. Relationships between each index, management factors and soil fertility are evaluated using correlation, regression analysis and Mann Whitney U tests. The management factors evaluated include chemical fertilizer, organic matter and pesticide inputs to khet and bari land; N, Ca and P_2O_5 budgets for individual crops, and nutrient budgets for the dominant crop rotations on khet and bari land. The soil fertility variables evaluated include base saturation, CEC, Ca, Mg, K, available P, pH and %C. The overall implications for nutrient management and soil fertility are then summarized.

6.1 Population

To evaluate the current population and recent trends within the study area, a survey of constructed houses was undertaken for 1972, 1990 and 1995. The number of houses identified on 1972 and 1990 aerial photographs were counted and compared to the number of houses observed in the field in 1995. Population numbers were calculated from the number of houses and the average family size (6.7 people per household) determined from household surveys. Figure 6.2 displays the recent changes in the number of houses and population. The number of houses in the study area increased from 1104 in 1972 to 1723 in 1995. The average population growth for the 1972-1990 period was 1.8% per annum and increased to 2.6% per annum for the 1990-1995 period. The recent increase is due to both population growth and immigration. Recent household surveys show that the average family size has not decreased, that is the increase in the number of houses is not due to the extended family being broken up, but a number of young

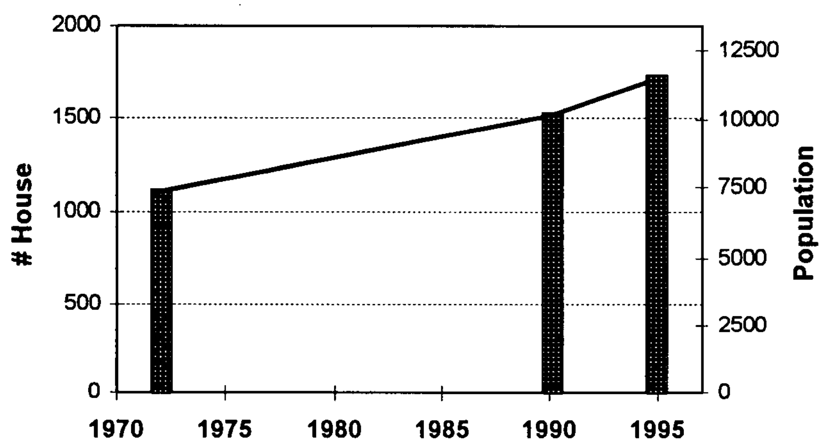


Figure 6.2. Bela-Bhimsenthan population dynamics 1972-1995.

families from nearby communities have immigrated to the area and are currently building houses in the region.

6.1.1 Population Growth, Land Use Change and Nutrient Dynamics

Population growth and the resultant increased demand for food places additional pressure on the resource base and specifically on soil resources. The per capita availability of land in the study area decreased from 0.26 ha in 1972 to 0.17 ha per capita in 1995, which is a greater decrease than for Nepal as a whole. Double and triple crop rotations are applied where water is available but nutrient inputs may not be sufficient to sustain these intensive levels of production (Figure 4.19). Agricultural marginalisation (Table 5.1) in response to population pressure has brought steeply sloping and low soil fertility lands under cultivation to provide additional food supplies. Recent declines in forest cover (Figure 5.2a) and reported shortages of forest products are indicative of the continuing pressure on forest resources, and the increased demand for wood in house construction and brick making. Population growth, both locally and regionally, is a dominant factor driving land use dynamics within the study region, and the associated increase in demand for food, animal feed and fuelwood results in increased nutrient removal.

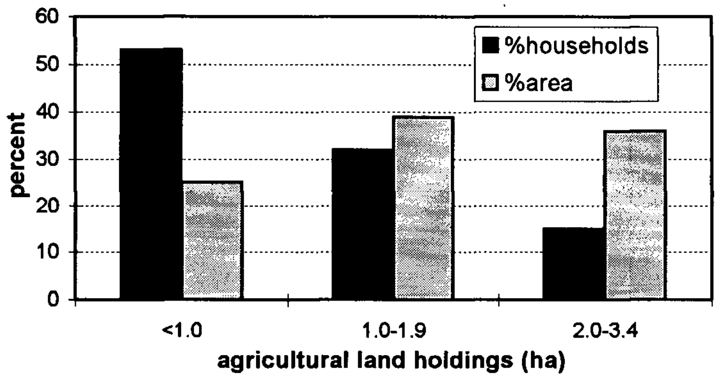
6.2 Land Tenure

Historical land tenure policies have shaped agricultural development in Nepal. The feudal land tenure system (abolished by the 1957 Birta Abolition Act) resulted in a small minority of larger landowners possessing a substantial portion of the arable land. Land registration implemented in 1963 encouraged the private registration of previously public lands through low tax rates, and resulted in increased pressure on the remaining public forest and grass lands. Land surveys were conducted demarcating areas according to ownership, but confusion between the Land Administration Office and Land Revenue Office resulted in many occupied public lands being registered as private land. The Forest Nationalisation Act of 1957 likely accelerated deforestation as land with trees on it could not be registered as private land. The 1964 Nepali Lands Act strove to improve the status of land tenure for small scale farmers by establishing a ceiling on land holdings and providing rights to tenants, but the program has been largely ineffective (Seddon 1987, Regmi 1976, Jha 1987, Yadav 1984, Dhungel 1987, Dahal 1987).

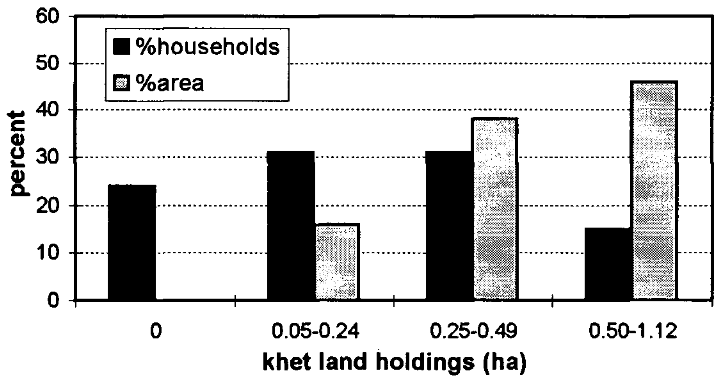
6.2.1 Land Distribution

Land ownership within the agrarian economy of the study area provides a major source of income, and inequity in land distribution translates to economic disparity. Farmers with limited access to land, or poor quality land will have little economic incentive or ability to invest in soil fertility management (Blaikie et al. 1980b, World Bank and UNDP 1991, Seddon 1987). In the Bela-Bhimsenthan household survey (n=85) the median land holding per household is 0.92 ha (1 ha = 19.7 ropani), but the amount of land varies significantly across different size categories (Figure 6.3). Land ownership is unevenly distributed with 53% of the households owning only 25% of the total agricultural land area, with total holdings per household <1 ha. Large landowners (holdings >2 ha) make up 15% of households, but own 36% of the agricultural land. Two families own no land. The average amount of khet land is 0.24 ha per household, but 24% of households own no khet land. Households with larger khet holdings (>0.5 ha) comprise only 15% of the households and own 46% of the khet land. The average amount of bari land per household is

a) agricultural land distribution



b) khet land distribution



c) bari land distribution

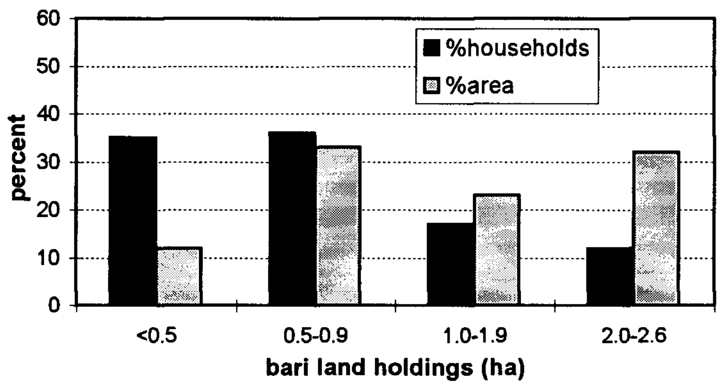


Figure 6.3. Agricultural land distribution among surveyed households (dataset: 1994 Bela-Bhimsenthan survey, n=85, male farmer responses).

0.81 ha but ownership of bari land is also unequally distributed. Large landowners (bari holdings >2 ha) comprise 12% of the households and own 32% of the bari land.

6.2.2 Share Cropping

Secure land tenure is necessary before farmers are willing to invest in soil fertility. Twenty-eight percent of the households surveyed in Bela-Bhimsenthan (n=85) report an involvement in sharecropping. A total of 7.2 ha of bari and 6.6 ha of khet land are reported as shared cropped by the surveyed farmers. These estimates should be considered lower bounds as farmers were hesitant to answer questions relating to share cropping. The 1964 Nepali Lands Act requires landlords to provide compensation to tenants amounting to 25% of the value of the land in the event that part or all of the rented land is resumed by the landlord. As a result, informal sharecropping is common and information on land tenure is tenuous. Typical share cropping arrangements involve the landlord receiving 50% of the crop, coincidentally the maximum permitted under 1957 legislation. Land used to produce potatoes or tomatoes may be share cropped for only part of the growing year, avoiding the 25% compensation regulation (Kennedy and Dunlop 1989, Regmi 1976, Hitchcock 1963).

6.2.3 Sufficiency from Farmed Land

Fulfilment of subsistence requirements is the primary objective of the majority of farmers in the Middle Mountains. If the land farmed cannot provide a household's basic needs, soil fertility maintenance will not be a priority and labour will be diverted to off-farm employment (Seddon 1987, Panday 1992, Carson 1992). Basic needs are defined as access to a minimum of food, water, shelter, primary health care and basic education (McHale and McHale 1977, Acharya 1982). The unequal distribution of land suggests that some households may not be able to produce sufficient food to feed their families. As an indication of the amount of land required to support a household living in the Bela-Bhimsenthan region, farmers were asked: "Does the land that you farm generate enough food and income to meet your family's basic needs?" Fifty-three percent of the households surveyed report that the land they farmed was enough, while 13%

responded that the land they farmed was insufficient. Thirty-four percent of the responses from male and female farmers within one household were contradictory suggesting a marginal sufficiency status. The ratio of the land farmed to the number of people in a household, for sufficient and non-sufficient households, provides a rough estimate of the amount of land required to support each individual (Table 6.1). Among the households reporting that the land they farmed was not enough, the average ratio of land owned to the number of people is 0.13 ha per person, of which 0.11 ha per person is bari land. Among the households reporting that their land provided enough food and income, the average ratio is 0.20 ha per person, and the amount of khet land per person is more than double. In the Bela-Bhimsenthan region, roughly 0.15 ha of land (0.03 ha of khet and 0.12 ha of bari) is required for every person a household hopes to feed.

Table 6.1. Per capita availability of agricultural land.

Sufficient	**n**	**Per Capita Land Ownership**[1] (ha per person)		
		Cultivated Land	Khet Land	Bari Land
No	11	0.13	0.02	0.11
Marginal	29	0.15	0.03	0.12
Yes	45	0.20	0.05	0.15

[1] dataset: 1994 Bela-Bhimsenthan household survey, n=85, combined male and female farmer responses

6.2.4 Open Access Resources

Historically, hill tribes managed land communally under the traditional *kipat* system. Land was distributed amongst tribal members according to need. Individuals held exclusive use to agricultural land, but ownership was tribal. Fodder and fuelwood collecting rights were controlled and specified areas were designated for grazing. The *kipat* system did not provide secure land tenure and thus discouraged investment in the land base, but it was effective in controlling resource over-utilisation on forest and 'waste' lands. With the expansion of Hindu groups into the Middle Mountains and the development of a centralised government, the *kipat* tenure system deteriorated. Legislation introduced in 1963 and 1968 resulted in the transition of *kipat* lands to government administered *raikar* lands. Less controlled resource exploitation was introduced at a time when population growth was increasing resource usage (Poffenberger 1980, Yadav 1992, Regmi 1976).

Community forestry was initiated in 1978 and strove to devolve authority and responsibility for forests and their management to the forest users. The transfer of government forest land to community management requires the formation of a forest users group, development of a management plan by the users, and plan approval by the District Forest Officer. Operational plans typically involve restocking and restricted access, with technical assistance provided by the Department of Forestry. Progress in implementing community forestry was initially slow, and the transfer of forest lands to local control was limited. By 1989, the total area of government forest transferred to forest user groups in the Kabhre District was only 2.6%, but since democracy the formation of forest user groups has accelerated (Gilmour 1991, Gilmour and Fisher 1991, Schmidt 1992).

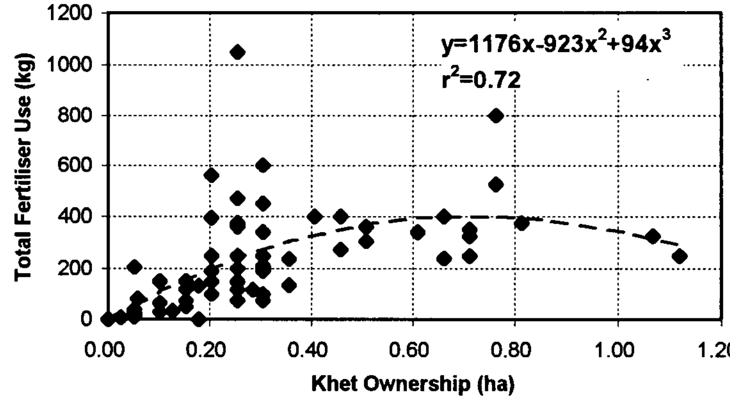
6.2.5 Unequal Access to Land, Nutrient Inputs and Soil Fertility

Soil fertility management is influenced by access to land and it's inherent soil fertility. Relationships between land holdings, sufficiency, land tenure, nutrient fluxes and soil fertility are examined using Pearson correlation, regression analysis and Mann Whitney U tests.

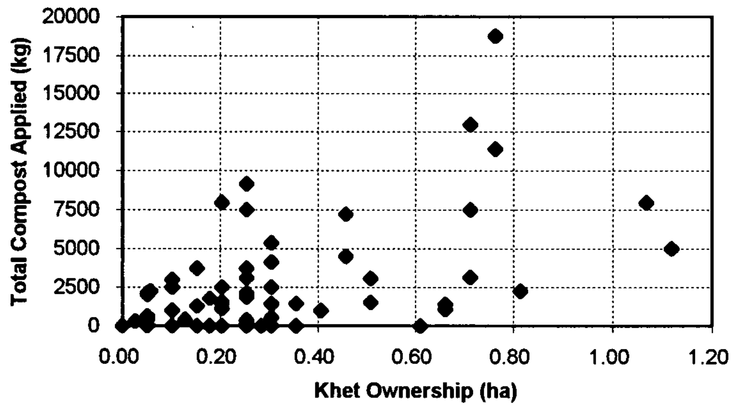
Farm Size

Nutrient inputs may vary with farm size due to limited availability or economic constraints. Regression functions between land ownership, and fertilizer and compost use (Figures 6.4 a-d) show increasing total inputs with land ownership on both khet and bari land for small and medium sized farms, but decreasing inputs on larger farms. On a kg ha^{-1} basis, relationships are not statistically significant, but inputs to bari fields display a decreasing trend with bari land ownership, while inputs to khet fields are roughly constant. Relationships between land ownership, crop nutrient budgets and soil fertility are summarised in Table 6.2. Significant differences in nutrient budgets are noted between small, medium and large farms and

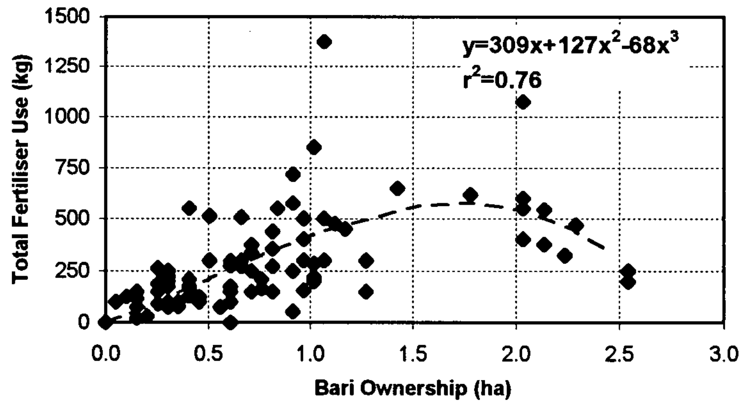
a) khet fertiliser use



b) khet compost use



c) bari fertiliser use



d) bari compost use

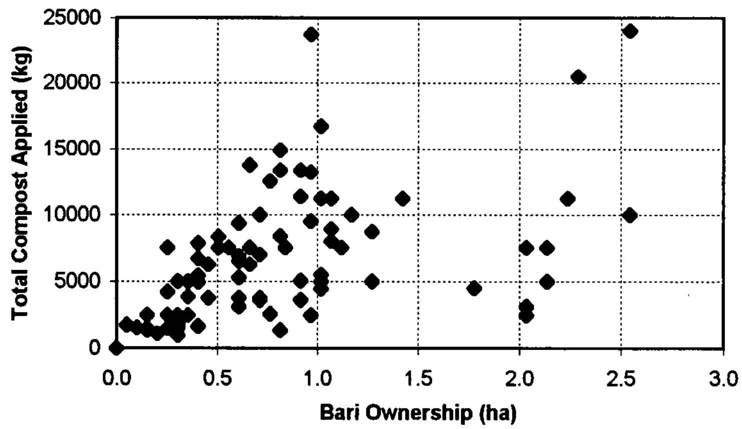


Figure 6.4. Fertiliser and compost use versus land ownership for khet and bari land (dataset: 1994 Bela-Bhimsenthan household survey, n-85. male farmer responses).

reflect decreasing fertilizer inputs on large farms and the distribution of land types with farm size. Both small and large farms are dominated by bari land and display lower nutrient budgets. Households owning moderate amounts of land (1.0-1.9 ha) typically own a mix of bari and khet land, apply the most fertilizer and compost to their fields, and sustain the best nutrient budgets. Differences in soil variables are also noted with farm size. Larger farms display lower exchangeable Ca, CEC and %C, suggesting a limited availability of organic matter inputs on larger farms.

Table 6.2. Relationships between farm size, crop nutrient budgets and soil fertility (median values and Mann Whitney U test).

	P-M-W nutrient budget (kg ha^{-1} furrow slice)		
Farm Size	**N-budget**	**P_2O_5-budget**	**Ca-budget**
small <1.0 ha (n=20)	-24	-29	-16
medium 1.0-1.9 ha (n=8)	-18	35	9
large 2.0-3.4 ha (n=6)	-32	-43	-15
small vs. medium farms	○	●	●
medium vs. large farms	●	○	○
	Exch. Ca	**CEC**	**C**
Farm Size	(cmol kg^{-1})	(cmol kg^{-1})	(%)
small <1.0 ha (n=20)	3.4	11	0.9
medium 1.0-1.9 ha (n=8)	4.4	12	1.0
large 2.0-3.4 ha (n=6)	3.3	9	0.8
medium vs. large farms	+	○	●

● Significant differences between groups α<0.05

○ Significant differences between groups α<0.10

\+ Significant differences between groups α<0.15

Share Cropping

It is anticipated that share cropping may have a negative impact on land management due to the uncertainty of land tenure arrangements, and an unwillingness on the part of tenant farmers to invest in share cropped land. Differences in inputs and production on owned and share cropped land for rice and maize, the dominant crops grown on share cropped khet and bari fields, are shown in Figure 6.5. Significant differences between owned and share cropped land are noted for total pesticide expenditures on

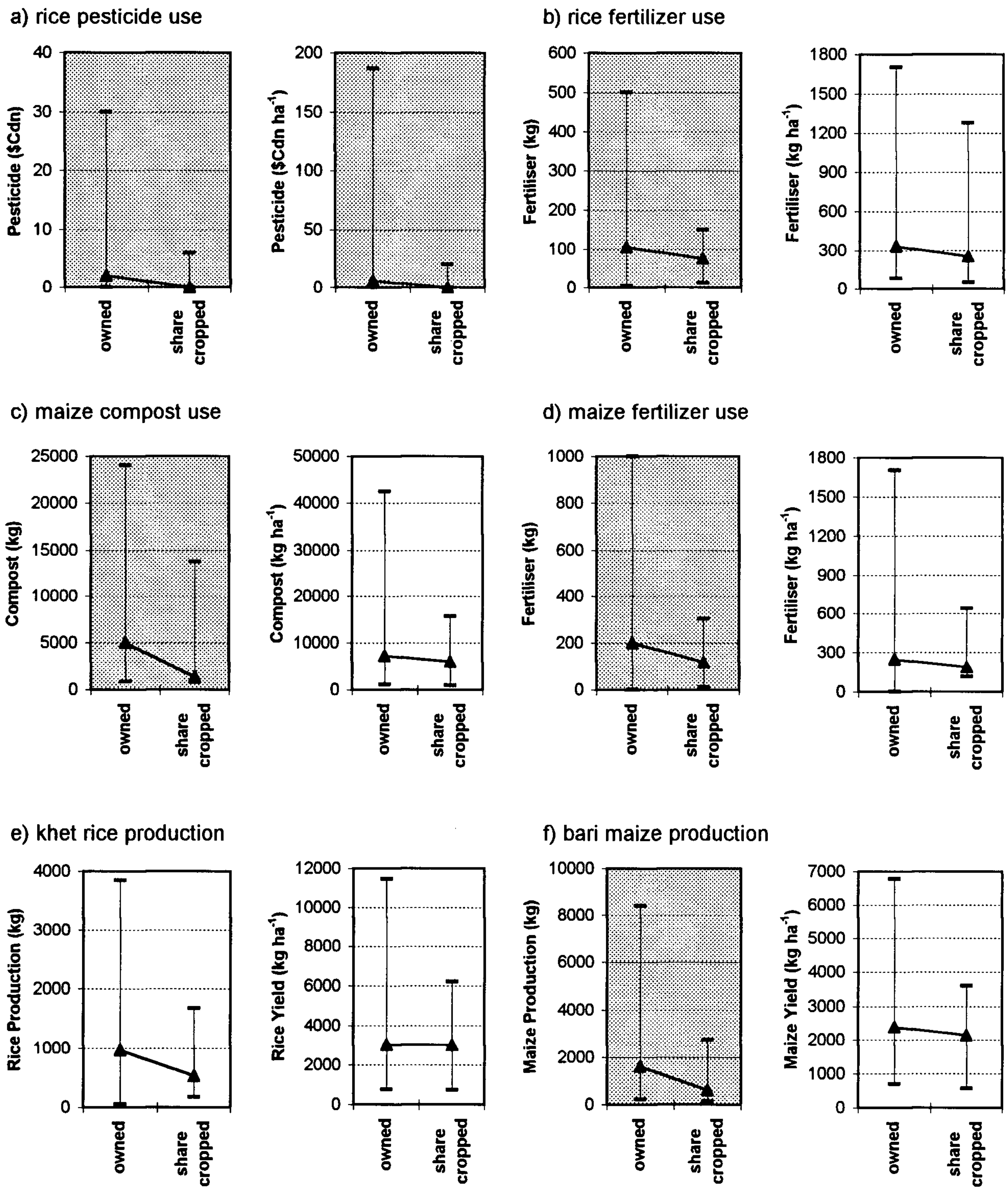


Figure 6.5. Management on owned versus share cropped land; median, minimum and maximum values, significant differences (α<0.05) highlighted (dataset: 1994 Bela-Bhimsenthan household survey, n=85, male farmer responses).

rice fields, total compost use on maize fields, total fertilizer use on both rice and maize fields, and maize production. On a per ha basis, differences in inputs are not significant, but median pesticide, fertilizer, and compost values are all lower on share cropped land. No difference is noted in rice yield between owned and share cropped fields, but maize production on share cropped bari fields is significantly lower. The variability in agrochemical use and crop production is substantially greater on owned versus share cropped land, with the greatest inputs applied to owned land. While this limited data set is not conclusive, share cropped fields on both khet and bari lands appear to be less intensively managed than fields with secure land tenure. Rice yields are comparable on both owned and share cropped fields, but maize productivity appears to be negatively impacted under share cropping.

Open Access Resources

The poorest soil fertility conditions within the study region are found on grass and forest lands (Figure 4.3 and Plate 12). Grasslands are largely unmanaged and community forestry has historically focused on short term biomass production through pine plantations. Erosion on well managed grasslands and forests with understorey vegetation may be minimal, but degraded shrub and grasslands have elevated erosion rates (Table 4.7). Community forestry initiatives have been successful in establishing forest cover and in transferring decision making to user groups. Within the study region all national forests are currently managed by local user groups. Initially, afforestation efforts focused on pine plantations, but user group priorities have prompted the planting of fodder species such as *Dalbergia sissoo*.

Options to improve dry season production on grass lands, such as the incorporation of legumes and deferred grazing are constrained by the current land tenure system. The successful implementation of pasture management techniques will require the establishment of property rights either privately or communally, similar to the establishment of forest user groups. To date, the Department of Forestry has concentrated on planting trees and limited resources have been focused on grasses.

Culture

Cultural practices influence land management in the Middle Mountains. Ethnic distribution, the role of livestock, and women as resource users and managers are three components of Nepali culture which may potentially impact soil fertility in the study region.

6.3.1 Ethnic Distribution

Caste affiliation and the ethnic distribution generally reflect the class structure and influence access to resources within the study area. High caste groups tend to be larger landowners, while the low caste households have the poorest access to arable land. The relationship between caste and landownership is related to historic land tenure policy, with the state traditionally granting land to members of the ruling class and local notables. However, class relations are dynamic and in many villages, high caste groups may be landless or poor peasants (Bista 1972, Seddon 1987). In the Bela-Bhimsenthan sample (n=85), land ownership is unequally distributed both across caste/ethnic groups and within each group (Table 6.3). Median land holdings vary by caste from 0 to 0.31 ha of khet land, and 0.2 to 1.42 ha of bari. Brahmin, Newar and Tamang families have the largest median holdings. The sample high (a Brahmin household) owns 1.12 ha (22 ropani) of khet land and 2.24 ha (44 ropani) of bari land, while two households (Danuwar and Chhetri) own no land. Note that the 1964 Lands Act imposed a ceiling on agricultural land holdings of 4.07 ha (80 ropani) in the Middle Mountains (Regmi 1976).

Table 6.3. Land ownership by caste / ethnic group.

Caste	**Sample No.**	**Khet / Household (ha)** median	min.	max.	**% Owning Khet**	**Bari / Household (ha)** median	min.	max.	**% Owning Bari**
Brahmin	46	0.25	0	1.12	85	0.81	0.10	2.54	100
Newar	13	0.25	0	0.76	77	0.61	0.25	1.07	100
Tamang	7	0.31	0	0.81	71	0.41	0.15	2.14	100
Danuwar	9	0.05	0	0.20	67	0.20	0	1.02	89
Chhetri	5	0	0	0	0	0.46	0	0.71	90
Others	10	0.13	0.05	0.20	100	1.42	0.66	2.14	100
Median	85	0.20	0	1.12	76	0.71	0	2.54	94

dataset: 1994 Bela-Bhimsenthan household survey, n=85, male farmer responses

6.3.2 Changing Role of Livestock

Livestock, via the production of manure, are a major contributor to traditional soil management practices in the Middle Mountains. The quantity of compost is a critical issue given the increased nutrient demand of higher yielding varieties of rice and wheat, and cash crop production (Carson 1992). Changes in the livestock holdings of surveyed farmers in the Baluwa region (n=27) from 1989 to 1996 are provided in Figure 6.6. The number of calves for both cattle and buffalo, and the number of chickens decreased from 1989 to 1996, while the number of female cattle and buffalo increased slightly. The increase in female buffalo per household is related to the establishment of a local dairy collection centre, promoting the sale of milk. The TLU (tropical livestock units) remained similar, however, indicating limited change in the potential nutrient supply from organic sources.

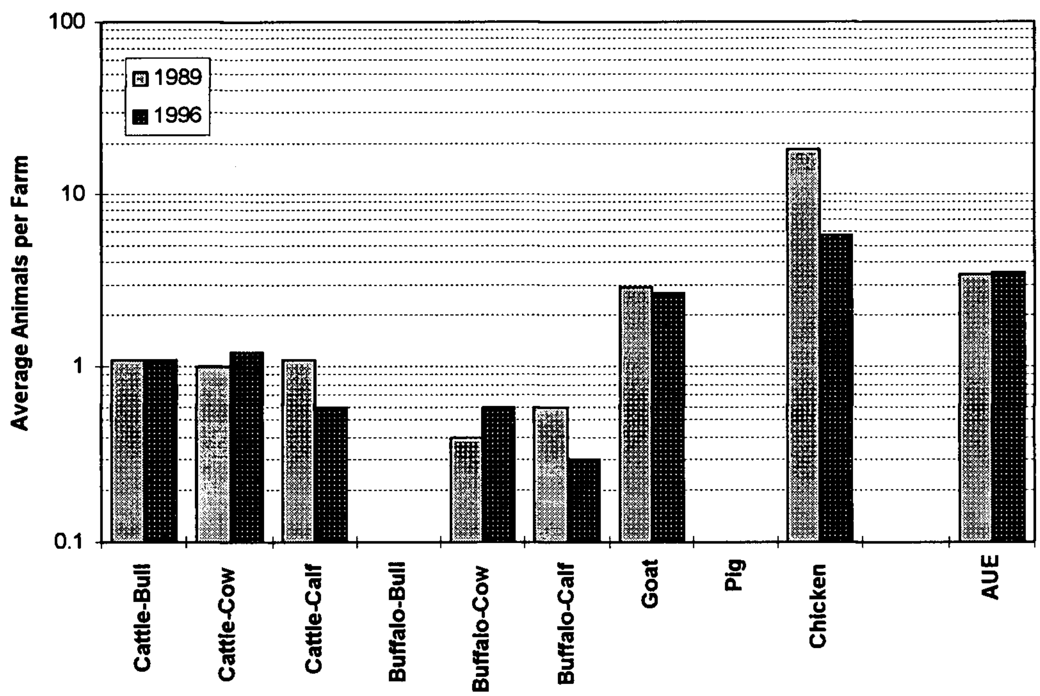


Figure 6.6 Livestock holding dynamics
(dataset: 1989 and 1996 Baluwa household surveys, n=27, female farmer responses).

The free grazing of animals, and the resultant removal of vegetation and trampling of the soil surface impact soil infiltrability and erosion, and heavy grazing is responsible for much of the environmental degradation on government lands (Carson 1992, Riley 1991). The proportion of stall-fed versus grazed animals during the wet and dry seasons reported by the female farmers surveyed in 1989 and 1996 are reported in Figure 6.7. No change is noted between dry season feeding in 1989 and 1996, but stall-feeding during the wet season increased significantly from 63% in 1989 to 85% in 1996. Female farmers were asked: "Compared to five years ago, has the availability of grazing areas for your animals changed?" For the 1991-1996 period, 79% responded that there were significantly fewer grazing areas available in 1996. Traditionally the forests supplied 40-60% of the total fodder (Uprety 1986, Gurung 1987, Dhungel 1987), but pressure on the forest ecosystem from increasing human and livestock populations, and agricultural encroachment has lead to reduced fodder availability, and a recent decrease in livestock holdings.

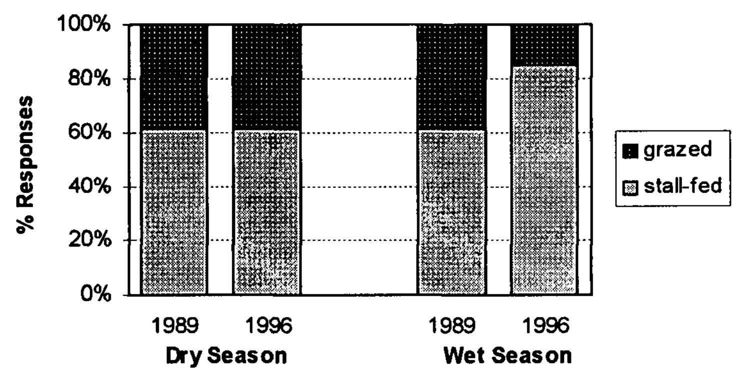


Figure 6.7. Stall-feeding and grazing dynamics
(dataset:1989 and 1996 Baluwa household surveys, n=27, female farmer responses).

6.3.3 Women and Soil Fertility Management

Women are central in soil fertility management due to their traditional role within the farming system. Their responsibility for livestock husbandry, manure and litter collection, and compost application directly impact soil fertility. Changes within the farming system, however, impact the responsibility and labour requirements imposed on women. The allocation of labour by task is summarised in Table 6.4 for

Table 6.4. Dynamics of household allocation of labour by task
(n=26, shaded tasks show significant differences based on Fisher exact probability α>0.05).

Task	Labour Allocation (# of households)						Change in Labour 1989 to 1996			
	1989			1996						
	M	F	S	M	F	S	↑M	↓M	↑F	↓F
Land Preparation										
ploughing	11	0	5	14	1	2	5	2	1	0
terrace repair	16	0	1	14	1	2	3	5	1	0
irrigation	18	1	6	20	1	2	6	4	1	1
Fertilising										
gather litter / manure	0	18	1	0	26	0	0	0	8	0
composting	0	21	5	17	3	1	17	0	1	19
apply compost	0	12	13	2	15	2	2	0	8	5
apply fertilizer	5	6	14	15	6	3	12	2	5	5
Planting										
what to plant	21	3	2	23	1	2	4	2	1	3
nursery	18	1	5	22	0	2	7	3	0	1
transplanting	2	4	17	2	0	22	20	0	0	4
seeding	2	0	20	1	2	23	0	1	2	0
Harvesting										
cutting	0	1	22	2	9	7	2	0	9	1
threshing	1	0	21	11	4	2	0	0	4	0
Livestock										
gather fodder	2	9	3	0	25	1	0	2	16	0
grazing	0	4	6	3	12	3	3	0	8	0
stall feeding	0	20	5	1	22	3	1	0	4	2
make dhana[1]	0	20	3	1	23	1	1	0	5	2
watering	0	22	2	2	24	0	2	0	2	0
milking	3	7	6	6	18	2	3	1	11	0
Household Care										
collect fuelwood	0	17	6	0	22	4	0	0	8	3
fetch water	0	22	3	1	23	2	1	0	4	3
household money	12	5	8	14	12	0	5	3	9	2
what to buy	20	4	2	15	10	1	5	16	10	4
what to sell	20	4	2	20	3	3	4	4	3	4
Farm Management										
farm labourers	17	4	4	16	6	3	7	8	5	3
purchase seed	22	1	3	22	0	1	4	4	0	1
purchase fertilizer	20	1	4	22	0	1	6	4	0	1
purchase livestock	20	1	0	24	0	0	6	2	0	1

dataset: 1989 and 1996 Baluwa household surveys, n=27, female responses

[1]dhana = cooked feed made from maize (wheat) flour and grains, water and salt for buffalo (cattle)

M = male; F = female; S = shared responsibility dominantly adult male, adult female or shared responsibilities based on the Baluwa household surveys (n=27) from 1989 and 1996. Change in the responsibility of male and female adults is also listed. Adult male and female family members (over 16 years of age) are presented as they hold the main responsibility for most tasks either independently or shared, while children and hired labour are typically minor contributors. Hired labour is largely utilized for 'heavier' work such as ploughing and terrace repair, and children are active in supervising livestock grazing. Tasks where there has been a significant change in labour allocation over time are highlighted (Table 6.4 based on Fisher exact probability test).

Land preparation, planting, household care and farm management have remained relatively stable with respect to labour allocation over time with the exception of keeping household money and purchasing livestock. Fertilising related activities have been the most dynamic. Female responsibilities for gathering forest litter and manure, and applying compost and organic fertilizer have increased significantly from previously shared responsibilities. Adult males are more active in composting and the application of fertilizer. Tasks related to livestock have also been dynamic with significant increases in female work loads due to an increase in the number of households raising female buffalo. Harvesting activities have also shifted from dominantly shared tasks to greater individual responsibility.

Though the same questions were asked to the same individuals, the shift from shared to greater individual responsibility may reflect a difference in the interpretation of shared versus dominantly male or female activities. Even considering possible differences in interpretation between 1989 and 1996, the allocation of labour appears to have shifted toward greater responsibility for adult females. In addition to their usual household duties, females are taking greater responsibility for gathering organic fertilizing material and livestock care. The daily feed requirement of improved breed buffalo is 84 kg or 2 head loads of fodder per day, and an extra 2-3 head loads (110 kg) of fuelwood per week are required for preparing the dhana (cooked feed). Scarcity of fodder and fuelwood has meant that women and girls travel great distances, and spend more time foraging for household and livestock needs. More girls are dropping out of school to assume livestock responsibilities, and households with few daughters seek early marriage for their sons to gain an additional labour source. While women are the primary caretakers of livestock, few have access to or control over earnings from milk production or livestock sale. Women in households which sell milk typically are not aware of the rupees earned per litre of milk, monthly income or annual income from milk sales. Nor do they receive any direct rewards for added milking chores. Women frequently responded that "I received two sarees a year prior to raising buffalo. I receive two now" (Acharya 1982, Bhatt et al. 1994).

6.3.4 Cultural Factors, Nutrient Management and Soil Fertility

Caste and Ethnic Affiliation

A household's access to capital and other resources is influenced by caste and ethnic affiliation, and thus compost, fertilizer and pesticide use may vary between groups. Differences in inputs used by high, medium and low caste groups are presented in Table 6.5. On khet lands, high caste households apply more fertilizer while low caste households apply more compost suggesting affordability may limit chemical fertilizer use by low caste households. On bari fields, high caste households apply more total fertilizer and compost, but no significant differences are found on a kg ha^{-1} basis. Lower caste households own significantly more livestock on a TLU ha^{-1} basis and distribute compost differently than high caste households. Low caste households concentrate their manure inputs on khet fields while high caste households apply more compost to bari fields. Differences in soil fertility are also noted between fields owned by high and low caste groups, with high caste households owning fields with better soil fertility conditions, but differences may reflect the sampling design. Sampled fields were selected based on soil fertility conditions and more khet fields owned by high caste households were sampled. Recognising the complexity of the Nepali class structure, caste and ethnic affiliation appear to influence nutrient management and potentially soil fertility conditions.

Table 6.5. Relationships between caste/ethnic affiliation, land management and soil fertility (median values and significant differences based on Mann Whitney U test).

		Caste			Significant Differences	
		high	medium	low	high vs. medium	high vs. low
khet						
compost	(kg)	1313	0	1124	○	
	(kg ha^{-1})	2725	0	4786		
fertilizer	(kg)	195	15	50	●	●
	(kg ha^{-1})	522	128	284	○	○
pesticide	($ Cdn)	2	0	0		●
bari						
compost	(kg)	7500	5160	2500		●
	(kg ha^{-1})	8346	7097	7259		
fertilizer	(kg)	274	220	155	○	●
	(kg ha^{-1})	320	236	359		
livestock						
	TLU	3.7	3.8	4.1		
	TLU ha^{-1}	3.6	3.9	5.7		●
soil fertility						
base saturation	(%)	60	57	45		●
exch. Ca		3.9	3.0	3.2		●
pH		4.9	4.8	4.6		●

high caste = Brahmins (n=46); medium caste = Chhetri, Newar, Jogi & Magar (n=20); low caste = Tamang, Danuwar, Kami & Sarki (n=19)

● Significant differences between groups $\alpha<0.05$

○ Significant differences between groups $\alpha<0.10$

Livestock and Traditional Soil Management

Livestock type and holdings influence compost application to a household's farm land. Manure lost through grazing is decreasing as more households are stall feeding their livestock (Table 6.7), and the selling of manure is rare. The relative manure production potential of different types of livestock is represented by tropical livestock units (TLU). Compost applied to bari land as a function of TLUs displays a weak positive correlation, but only 10% of households own more than 10 TLU ha^{-1}.

Women and Soil Fertility Management

Females are taking greater responsibility for the gathering of organic fertilizing material and livestock care. Time use studies indicate that deforestation may increase the workload of women in forest product collection by 1-1.5 hours per day, and dairy development adds an average of three extra hours of work per day. The farming systems are extremely labour intensive with women accounting for 60% of the labour requirements of farming in addition to their household responsibilities. The already heavy workload of women farmers is increased with the addition of market oriented vegetable and milk production, and diminishes their capacity to be effective resource managers (Gurung 1995a, Acharya 1982, Pfanner 1987, HMGN 1993).

6.4 Poverty

Rural poverty in Nepal is associated with a number of factors including: population growth, minimal land holdings, poor land productivity, limited marketing infrastructure, limited alternative employment opportunities, poor educational attainment and a socio-economic structure (caste system) which favours class division. Changes in factors such as land holdings, the type of crops grown, yields, input costs, livestock holdings and soil fertility will impact a household's ability to fulfil their subsistence requirements over time. To assess the temporal dimension of household sufficiency from farming, responses from male farmers in Baluwa surveyed in 1989 and 1996 (n=27) are compared (note this is a different dataset than presented in section 6.2.3). In response to the question: "Does the land that you farm generate enough food and income to meet your family's basic needs?" 74% of the male farmers interviewed in Baluwa in 1989 responded "yes" and in 1996 there was little change (78%). Still, one quarter of the households reported that they were not able to fulfil their basic needs from farming, and most were not able to improve their situation over the six year time span (1989-1996).

The impact of poverty on nutrient inputs, nutrient budgets and soil fertility are evaluated using relationships with indicators of economic well-being. Agricultural assets (land and livestock), farm gross margins from crop production (total returns less variable costs), cash income derived from the sale of crops and milk, and off-farm employment are utilized. Relationships between each indicator, nutrient inputs, nutrient budgets and soil fertility are evaluated using correlation analysis, and the implications for soil fertility are discussed.

6.4.1 Agricultural Assets

The main agricultural assets of farmers in the region are land and livestock. Farmers own virtually no machinery and only basic implements such as a hoe, wooden plough or sprayer (Kennedy and Dunlop 1989). The dollar value of land and livestock owned by a household provides one indicator of poverty. To compute agricultural asset values for each household, average local prices for land and livestock were used.

Land

Local land values differentiate land on the basis of quality, with poor bari land valued as low as $4,700 Cdn ha^{-1} and good quality khet land valued at up to $56,775 ha^{-1} (Shah 1996). Average prices for bari ($9,462 ha^{-1}) and khet ($28,386 ha^{-1}) thus provide a weighting mechanism to sum total land holdings in a manner which reflects not only value but production potential. Land values are summarised in Table 6.6. In general, the land values should be considered as rough estimates. The median land holding is valued at $5,776 for khet and $6,734 for bari per household. While khet holdings account for less than 25% of the land owned on an area basis, their value makes up nearly 50% of total land values.

Table 6.6 Total land values per household in the study area.

	Khet		**Bari**		**Total**	
	ha	**$ Cdn**	**ha**	**$ Cdn**	**ha**	**$ Cdn**
min.	0	0	0	0	0	0
median	0.20	5,776	0.71	6,734	0.92	12,508
max.	1.12	31,768	2.54	24,050	3.36	52,932

dataset: 1994 Bela Bhimsenthan household survey, n=85, male farmer responses

Livestock

Values for the various types of livestock are based on key informant interviews conducted under the Jhikhu Khola Watershed project in 1996. Livestock will vary between households in age, size, quality etc., so these values should be considered rough estimates. The values assumed for each category of livestock are given in Table 6.7 along with the median, minimum and maximum values for livestock owned per sampled household. The median value of livestock is $870 per household, 50% of which is accounted for by buffalo cows.

Table 6.7. Livestock values and assets.

Type of Livestock	Local Value		Household Assets ($ Cdn)		
	Rupees	$ Cdn.	min.	median	max.
Cattle - Bull	2,000 - 4,000	49 - 96	0	0	290
Cattle -Cow	4,000 - 5,000	96 - 120	0	108	432
Cattle - Calf	1,500	36	0	0	216
Buffalo - Bull	3500	84	0	0	168
Buffalo - Cow	16,000 - 20,000	433	0	433	1299
Buffalo - Calf	12,000	289	0	0	2312
Goat - male	1,200 - 6,500	29 - 156	0	242	1029
Goat - female	600 - 1,800	14 - 43	0		
Pig	500 - 3,000	12 - 72	0	0	42
Chicken	125 - 300	3 - 7	0	10	300
Duck	200	5	0	0	20
Total			0	870	3036

dataset: 1994 Bela-Bhimsenthan household survey, n=85, female farmer responses

6.4.2 Farm Gross Margins

The relative profitability of agricultural production between farms provides a mechanism to compare the economic status of farming households with diversified cropping systems. An indication of the profitability of each farm can be obtained by computing gross margins, defined as total returns less total variable costs. Total returns are equal to the value of all crops produced (including crop residues), irrespective of whether the crop is sold. Total variable costs include the purchase of seed, fertilizer and pesticides, hiring oxen and all labour involved in cultivation activities. Labour includes the time spent in planting, irrigation, fertilizing, spraying, weeding, harvesting, transportation and selling, and includes the opportunity cost of family labour. The gross margin can thus be viewed as the return to fixed costs (land and livestock) and management.

Gross margins for the 85 surveyed households in Bela-Bhimsenthan were calculated from production information provided by the male farmers. For each crop grown on khet and bari land, farmers indicated the amount of land farmed (ha), crop production (kg), seed use (kg), fertilizer (kg), pesticide (g or ml), bull oxen use (days) and total labour (days). Occasionally farmers responded 'don't know' to a particular question (e.g. seed rate for wheat). Any missing data were estimated from site specific information provided by the same farmer in the 200 field soil survey when the same crop was reported, or an average value was used if necessary. Selling price and costs of inputs for 1996 were then used to calculate returns and variable costs for each crop. For crops grown under a share-cropping arrangement, 50% of the total returns and variable costs were accrued to both the tenant and landlord. Total gross margins from cultivation activities for each household were obtained by summing returns minus variable costs for all crops. Production returns, variable costs and gross margins for individual crops and totals for each household are summarised in Figures 6.8 and 6.9.

Total Returns

Calculation of the total returns from crop production are summarised in Table 6.8. For each crop the median area cultivated is listed. Crop production (kg) represents grain or vegetable components and does not include crop residues. Estimates of crop residues were obtained by multiplying the grain or vegetable production by the ratio of residues to crop. A ratio of 1.25 was used for rice, and 1.22 for maize and wheat (Grist 1986, Olson and Kurtz 1982, Cox et al. 1985, LRMP 1986a, Aldrich et al. 1975, Stoskopt 1985). Selling price is the market value of the crops and does not include the value of crop residues. The value of crop residues is included separately as it represents the opportunity cost of residues for animal fodder or soil amendment. Residues are valued at roughly 5-10 rupees per doko (basket) or \$0.007 kg^{-1}.

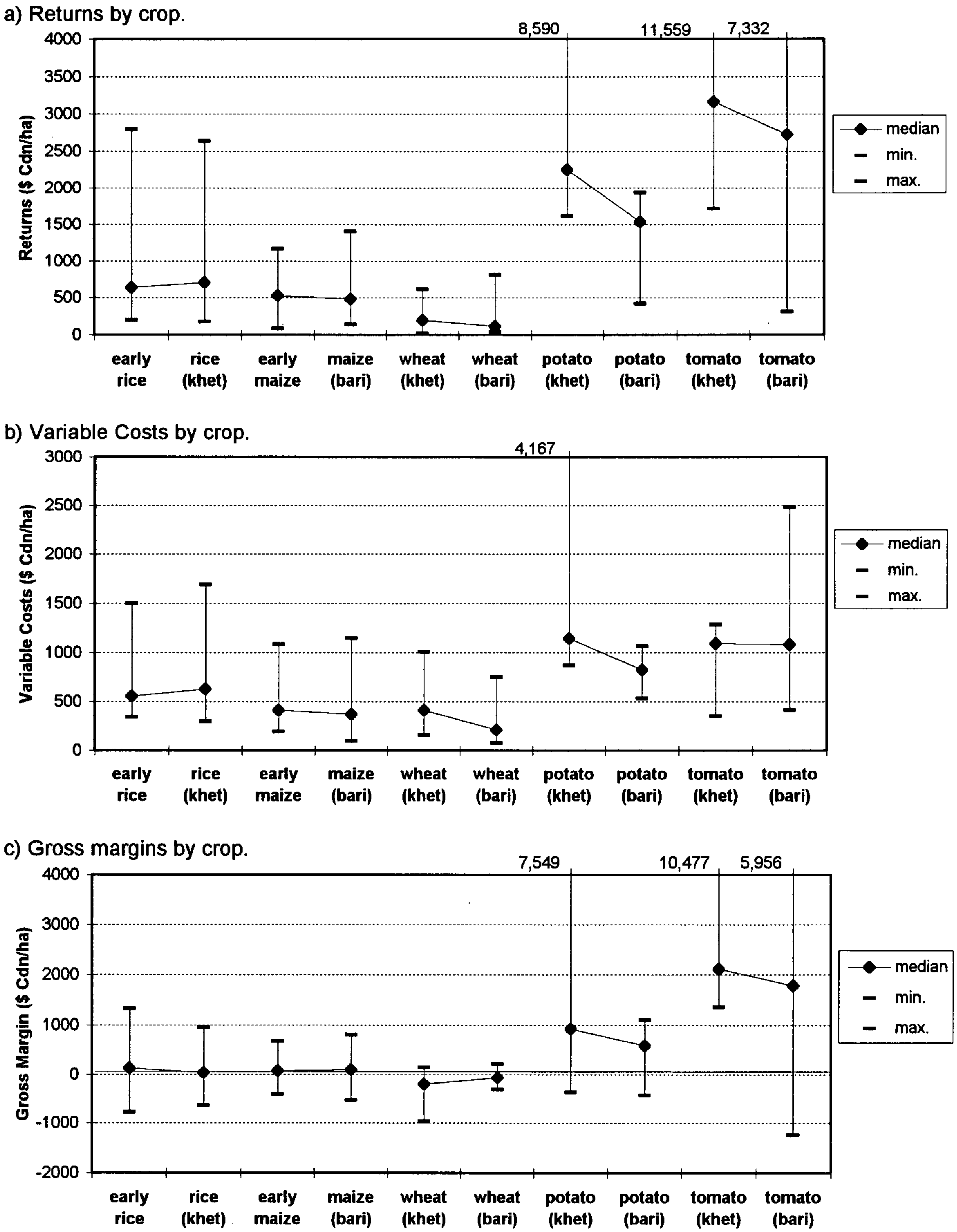


Figure 6.8. Returns, variable costs and gross margins by crop.

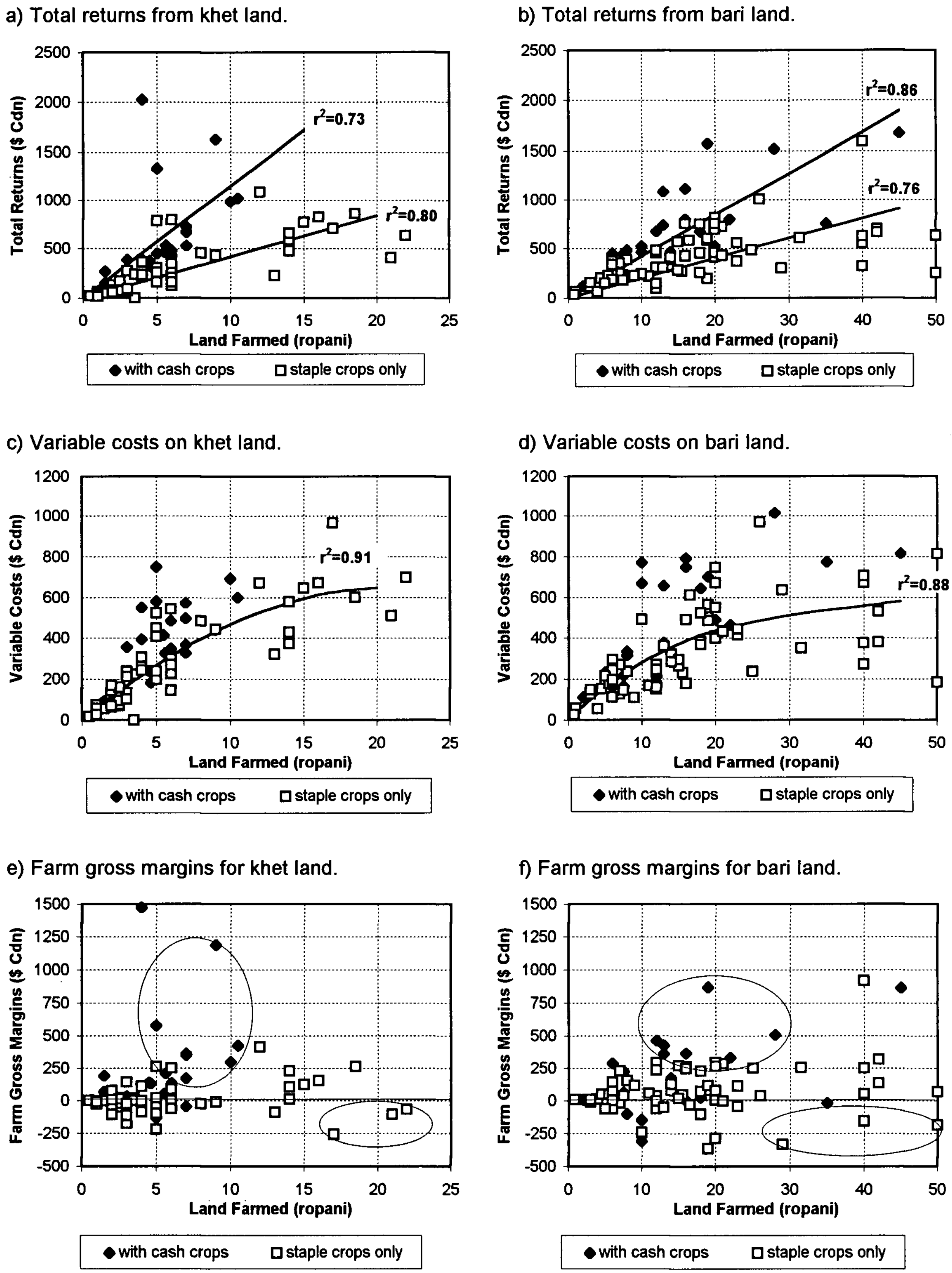


Figure 6.9. Total returns, variable costs and household gross margins on khet and bari land.

Total returns on a per ha basis are greatest for tomatoes and potatoes grown on both khet and bari fields (Figure 6.8a). Median returns for tomatoes, potatoes and wheat on khet are higher than returns from the same crops grown on bari, indicative of the greater production potential of khet lands. The variability in total returns per ha is high between households, and may be related to farmer knowledge, marketing skills, soil quality or data irregularities. Returns to the farming household from a particular crop are dependent on the returns per ha and the area under cultivation (Table 6.8). For khet land, tomatoes and potatoes have the highest total returns, but rice grown during the monsoon is also an important crop as a relatively large amount of land is under rice cultivation. For bari land, tomatoes and maize make up the greatest proportion of total returns reflecting the high returns per ha of tomatoes and the large area under maize cultivation. Total returns from all crops separated by households growing only staple crops and those which incorporate some vegetable production are shown in Figures 6.9a and 6.9b. For both khet and bari land, best fit regression lines illustrate the significance of cash crops to total returns ($ per household from all crops) with households producing some vegetables displaying greater total returns.

Variable Costs

The break down of variable costs for seed, chemical fertilizer, pesticide, oxen and labour expenditures are listed in Table 6.9. Typical rates and prices are given in Tables 9-12 of Appendix B. The total variable costs are dominated by labour and oxen costs, and represent the opportunity costs of alternative activities. Labour costs are greatest for tomatoes and potatoes on a per ha basis, but labour inputs to rice and maize are significant on a total cost basis ($ per household). The purchase of chemical fertilizers contribute significantly to the variable costs of rice and potatoes on khet, and maize on bari sites. Pesticides are generally a small expenditure with the exception of households growing tomatoes on khet, but application rates are highly variable between sampled households. In addition to the costs listed above, 20% of the farmers apply micronutrients to their tomato and potato crops.

Table 6.8 Total production returns (median values) for the major khet and bari crops.

Crop	n	Area (ha)	Production[1] (kg)	Price[2] ($ kg^{-1})	Returns total $	Returns $ ha^{-1}
Khet						
early rice	12	0.11	360	0.20	76	639
early maize	23	0.10	325	0.16	58	531
monsoon rice	69	0.25	964	0.19	175	708
wheat	47	0.18	280	0.12	37	197
tomato	10	0.10	620	0.52	322	3165
potato	16	0.09	477	0.41	196	2251
mustard	17	0.05	37	0.36	13	197
Total	72	0.25			287	1148
Bari						
maize	84	0.71	1610	0.16	289	482
wheat	40	0.31	385	0.12	52	118
tomato	15	0.08	431	0.52	224	2732
potato	9	0.10	239	0.41	98	1533
mustard	40	0.31	124	0.36	46	187
Total	85	0.71			429	604

[1] production of grain/vegetables only, does not include kg of crop residues

[2] selling price of grain/vegetables, does not include value of crop residues

Table 6.9. Variable costs (median values) for seed, chemical fertilizer, pesticide, oxen and labour.

Crop	n	Seed ($)	Fertilizer ($)	Pesticides ($)	Oxen ($)	Labour ($)	Variable Costs total $	Variable Costs $ ha^{-1}
Khet								
early rice	12	3	19	0	15	24	67	585
early maize	23	2	8	0	14	20	58	228
monsoon rice	69	5	30	2	36	72	155	609
wheat	47	6	15	0	29	24	80	413
tomato	10	5	8	322	22	66	111	1090
potato	16	20	27	5	18	31	109	1140
mustard	17	<1	5	0	7	8	27	472
Total	72						263	993
Bari								
maize	84	8	60	0	43	96	246	373
wheat	40	6	5	0	36	23	74	215
tomato	15	5	8	9	7	36	61	1081
potato	9	19	15	4	14	30	84	826
mustard	40	1	10	0	29	20	61	177
Total	85						320	449

Total variable costs for the dominant crops grown on khet and bari land are shown in Figure 6.8b. Costs are greatest for tomatoes and potatoes, and somewhat higher on khet fields. The distribution of variable costs per ha is skewed, and households reporting the highest costs do not always report the greatest returns. Variable costs separated by households growing only staple crops and those which incorporate some vegetable production are shown in Figures 6.8c and 6.8d. Variable costs diminish with the amount of land farmed, suggesting that economies of size exist. Cubic functions which reflect these dimishing costs are fit to data for households growing only staple crops, and illustrate the decreasing costs with larger farm size, and the higher variable costs on khet fields.

Household Gross Margins

Gross margins for the main crops grown in the study region are shown in Figure 6.8c. Tomatoes and potatoes are the most profitable, on both khet and bari land, although differences between households are highly variable. Median gross margins for rice and maize are low, and gross margins for wheat are slightly negative. Gross margins for maize, potatoes and tomatoes, and the relative profitability between crops are similar to estimates by Kennedy and Dunlop (1989) and Srivastava (1995). One exception is potatoes where Srivastava found a negative gross margin related to a dramatic increase in the price of chemical fertilizer. Since 1993, the selling price of potatoes has quadrupled, resulting in an increase in their profitability.

Total gross margins for a household are determined by summing total returns less variables costs for all crops grown on all the land farmed by a household. Farm gross margins, based on all crops grown by a household, range from -$566 to $1736 dollars per annum (Figure 6.10). Twenty-eight percent of the households surveyed are very poor having gross margins <0 and 47% have gross margins below $100 per year. Negative gross margins imply households are not earning their opportunity costs of labour on their own farms and could earn more by working off-farm. Thirty-seven percent of households fall within the $100-$400 per annum range, and 16% have gross margins above $500 per year. Farm gross margins

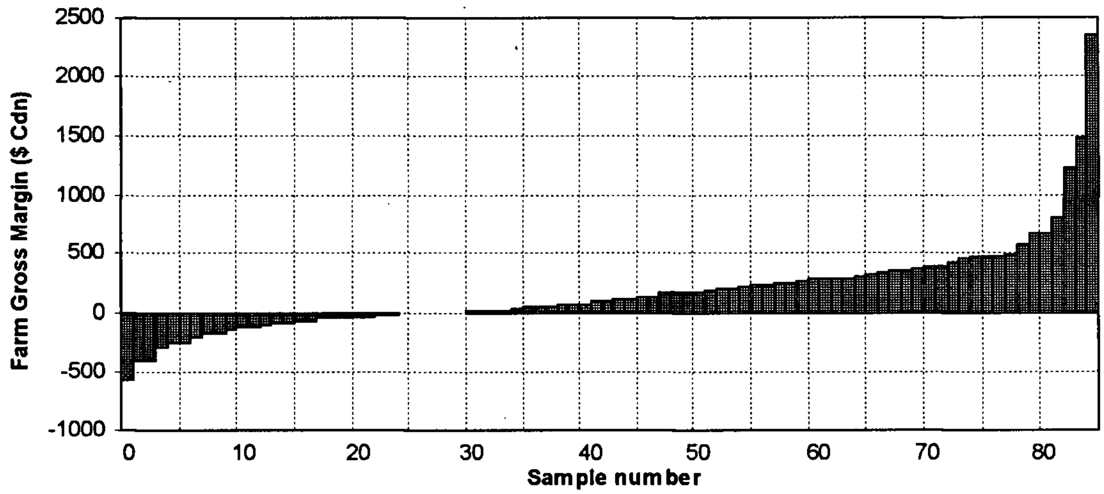


Figure 6.10. Annual gross margins from agricultural production
(dataset: 1994 Bela-Bhimsenthan household survey, n=85, male farmer responses).

separated by households growing only staple crops and those which incorporate some vegetable production are show in Figures 6.9e and 6.9f. The highest gross margins are noted for households growing cash crops as part of their rotation and households with greater land holdings. However, households with negative gross margins include both vegetable growers and large landowners reflecting crop failures and poor management.

6.4.3 Cash Income

A lack of capital is a important constraint to agricultural production in Nepal. Two sources of cash income available to farmers in the study region are the sale of agricultural products and off-farm employment.

Agricultural Products

Involvement in market oriented production is one way a household can generate income for the purchase of chemical fertilizer, and reduce the reliance on adjacent grassland and forest resources for the maintenance of soil fertility. The amount and type of crops sold and purchased by farming households is indicative of their level of involvement in the market (Carson 1992, Seddon 1987, Panday 1992). Farmer's were asked: "Do you sell any of your crops?" and "Do you buy additional food for your family members?"

Farmers sell a variety of crops (Table 6.10) including traditional staples (cereal crops) and non-traditional cash crops (vegetables). Only a small minority of farmers systematically produce for the market, but the majority of farmers derive some income from the sale of agricultural produce. Maize is sold by 38% of the households, followed by rice (26%) and wheat (14%). The majority of producers sell <50% of the crop, suggesting that sales are surplus production. Only 6% of the surveyed households sell >50% of their total crop production (on a weight basis) and just 14% sell >25% of their total production. Tomatoes and potatoes are the main cash crops, with the largest amount sold on both a weight and revenue basis.

Table 6.10. Crops sold by households.

Crop Sold	**% Households Selling Crops**	**% Producers Selling >50%**	**Amount Sold** (kg yr^{-1}) min.	median	max.	**Gross Revenue** (1996 $CDN)
Maize	38	28	0	0	2,100	0-602
Rice	26	13	0	0	1,920	0-337
Wheat	14	0	0	0	490	0-43
Tomato*	11	50	0	480	42,000	0-6,318
Potato	8	43	0	190	4,275	0-425
Mustard	4	67	0	0	93	0-32
Onion	1	100	-	52	-	24
Garlic	1	100	-	96	-	48
Total	45					0-6,941

dataset: 1994 Bela-Bhimsenthan household survey, n=85 , male farmer responses
* 1 large tomato producer

Farmers in the study area have been hesitant to produce primarily for the market. Current transportation and marketing systems are rudimentary. The high costs of inputs such as fertilizer, pesticides and seed restrict opportunities for farmers with limited access to capital. Retail prices fluctuate both seasonally and from year to year. Vegetable yields are often erratic and small farmers are hesitant to plant a large proportion of their land in cash crops. Labour requirements may be increased dramatically; for example tomato production requires 2-3 times more labour than rice (Srivastava 1995, Kennedy and Dunlop 1989, Villareal 1980). From 1989 to 1996, farmers surveyed in Baluwa (n=27) report selling more crops, but when corrected for inflation, gross revenues decreased 6%. In 1989, farmers report a median gross revenue of $119 (corrected for inflation) compared to $112 in 1996. Over the past 10 years inflation has averaged 11% per annum (World Bank 1996) resulting in a reduction in the purchasing power of income derived from the sale of crops by local farmers.

Households purchase a range of food products to supplement or complement the crops they grow. Table 6.11 lists the main crop purchases by households within the sample. Fifty-three percent of households report buying additional food. Rice is the crop purchased most often (33% of households) followed by potatoes and maize. The largest amounts purchased are rice and maize on a weight basis, and rice and tomatoes on an expenditure basis. Thirty-two percent of the farmers surveyed purchase but do not sell any crops, indicating their need to supplement subsistence food production.

Table 6.11. Food products purchased by households.

Food Product Bought	**% Households**	**Amount Bought** (kg year^{-1})	**Expenditure** (1995 $CDN)
Rice	33	0-700	0-282
Potato	26	0-380	0-183
Maize	15	0-560	0-87
Wheat	8	0-375	0-36
Mustard	6	0-124	0-39
Total	53		0-460

dataset: 1994 Bela-Bhimsenthan household survey, n=85 , male farmer responses

<u>Milk</u>

Commercial milk production provides an alternative source of income for local farmers. Forty-five percent of the households surveyed in the Bela-Bhimsenthan study (n=85) sell buffalo milk. Median milk production per cow buffalo is 5.0 litres per day in the monsoon and 4.0 litres in the dry season, of which 60% is sold. The median gross revenue from milk sales is $43 per year, but ranges from 0-182 $ per year.

Forty percent of these households have been selling milk for less than 5 years, and 20% are currently selling more milk than 5 years ago. The first commercial dairy operation in the region was established in the Jhikhu Khola watershed in 1994, and milk production will likely continue to expand.

Off-Farm Employment

Off-farm activities are an important source of family income. Many households have at least one male member who is employed outside the community at least on a seasonal basis. Off-farm employment in the Bela-Bhimsenthan sample for 1994 is summarized in Table 6.12. Income denotes both cash and other forms of payment (e.g. meals) which have been converted to $Cdn. Sixty percent of households were involved in off-farm activities and grossed a median of $439 Cdn. per year. The highest reported off-farm income was a priest earning $1,160 per year. Small businesses and brick making provide a median income of approximately $549 per person per year, and farm labour $220 per year. Forty-one percent of husbands spend time off-farm and the dominant activities are brick making / masonry (17%) and carpentry (14%). Wives are less involved in off-farm activities (12%), and the main activities are shop / business and household labour. Sons and daughters spend a large portion of their time studying, but brick making / masonry activities are also noted. The daughter-in-laws and brothers of the household head which are involved in off-farm activities all work in brick making. Increased brick making activities in the last five to ten years reflect the increased demand for construction materials in Kathmandu. There were only 35 brick making units in 1981/82 in the Kathmandu Valley, but in 1991/92 there were 142 (Mishra 1995). In addition to money earned by the immediate household, family members living away often send money home. Forty-two percent of the surveyed households receive money from their extended family, and typically receive $36 per year.

6.4.4 Economic Well-Being, Nutrient Inputs and Soil Fertility

As soil fertility impacts crop productivity, households farming more productive land will be more likely to meet their families' basic needs through farming. Alternatively, soil fertility is impacted by management,

Table 6.12. Off-farm activities.

Household Position	n	% Involved Off-farm	Dominant Activity	Time per Activity (%)	Median Income ($Cdn yr^{-1})
Husband	85	41	Brick Making	17	387
			Carpenter	14	127
			Shop / Business	9	435
			Farm Labour	6	179
Wife(s)	91	12	Shop / Business	36	303
			Farm Labour	18	220
			Brick / Mason	9	176
Sons	112	98	Studying	78	n/a
			Brick / Mason	5	356
Daughters	83	78	Studying	100	n/a
Daughter-in-law	23	100	Brick Making	100	330
Brothers	9	78	Brick Making	100	351
Others	26	38			
Whole Family	51	60			439
Money Sent Home	36	42			36

dataset: 1994 Bela-Bhimsenthan household survey, n=85, combined male and female farmer responses

which may be constrained in poor households. Relationships between economic indicators and management are assessed using Pearson correlation. Agricultural assets (land and livestock), household gross margins (total returns and variable costs) and cash income (vegetable crops, milk production and off-farm employment) are evaluated relative to nutrient inputs and soil fertility. The results shown in Figure 6.11 indicate that households with higher agricultural asset values and gross returns apply greater amounts of compost and fertilizer to both khet and bari land. Combined agricultural assets (land and livestock) are positively correlated with total compost and fertilizer applied (kg) to both khet and bari fields, but relationships on a kg ha^{-1} basis are not significant. Compost applications per ha on bari land are typically greatest for farms with low and moderate agricultural assets and least for high asset farms. Fertilizer use per ha on khet land increases with agricultural assets up to roughly $25,000 but inputs are low on farms with high asset values. Both trends suggest a limited availability of inputs on large farms (high agricultural assets) and diminishing economies of size.

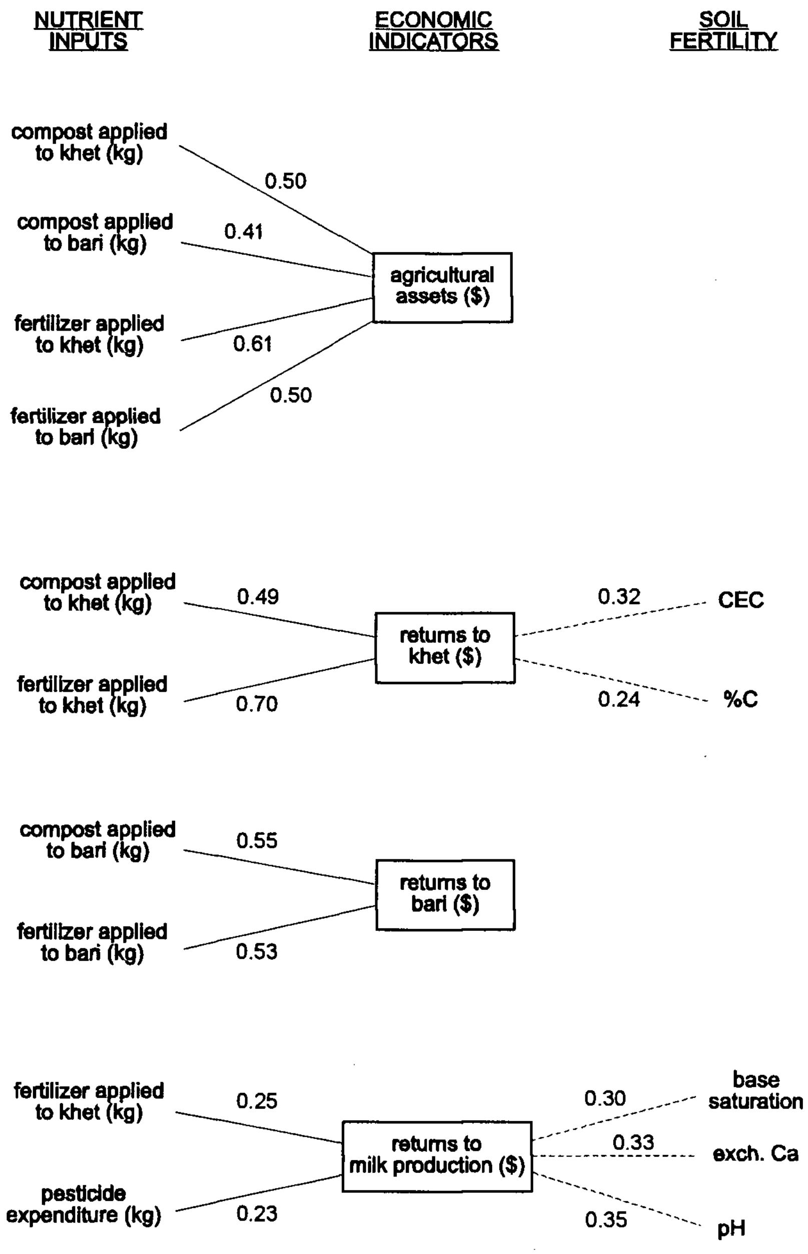


Figure 6.11. Correlations between economic indicators, nutrient inputs and soil fertility (α<0.05; --- indicates indirect relationships).

Total returns ($) to khet and bari land for all crops are also positively correlated with total compost and fertilizer use (kg). Total returns increase with the amount of land farmed (Figure 6.9a) and nutrient inputs tend to be lowest on small farms (Figure 6.4). Relationships on a kg ha^{-1} basis are highly variable with the highest inputs applied to a few farms which have both high and low total returns. Relationships with gross margins are weak and reflect the relationships with total returns; gross margins are weakly correlated with total compost applied to bari and total chemical fertilizer use on khet. Variable costs incorporate agrochemical use, but labour is a large component of the costs for the main crops grown. Consequently relationships between gross margins (total returns - variable costs) and inputs are weaker than correlations with total returns.

Cash income derived from the sale of milk is weakly correlated with total pesticide and chemical fertilizer use. While the average gross revenue from milk sales is low ($43 per year) these relationships suggest that the purchase of agrochemicals may be limited by cash availability.

Relationships with soil fertility are weak but households with higher returns to khet land and milk production appear to farm fields with better soil fertility conditions. Sites with better soil fertility should produce higher yields and consequently greater total returns, while households with greater cash income are more likely to be able to afford better quality land or to maintain soil fertility. Relationships between nutrient budgets (N, P_2O_5 and Ca) and indices of economic well-being show no discernible trends. While agricultural asset values, total returns and milk production are related to nutrient inputs, the nutrient budgets are strongly influenced by yield (crop nutrient uptake).

No relationships are noted with off-farm activities, but male out-migration in pursuit of wage employment leaves women with greater responsibility for decision making and carrying out major farm activities. Increasing access to education mainly to males also affects the workload of women as tasks previously carried out by older children now have to be absorbed by women. While off-farm employment provides capital resources, there is less labour available for livestock tending, compost and manure carrying, the collection of fodder and litter, and other on-farm activities which influence soil fertility (Gurung 1995a, Carson 1992, Vaidya et al. 1995, Biot et al. 1995).

6.5 Summary and Implications of Socio-Economic Factors for Soil Fertility

Socio-economic factors, farm management and soil fertility are interrelated within the study region. Relationships are both direct and indirect as displayed in Figure 6.12. Open circles represent the contextual framework, quantified relationships are shaded, direct linkages are shown by solid arrows and the dashed arrow signifies indirect relationships. Socio-economic factors directly impact farm management, which in turn impacts soil fertility. Population growth, land tenure, poverty and culture are the underlying socio-economic factors influencing farming system dynamics. Population growth rates of 2.6% have lowered available land per capita, contributed to agricultural intensification and marginalisation, and placed additional pressure on forest resources. Land distribution is highly skewed, with 15% of the surveyed households owning 46% of the khet land. Share cropping is practised by roughly one-third of households. Greater than one-half of households (55%) are not able to meet their basic need requirements from the land they farm. Caste affiliation and ethnic distribution reflect the class structure and access to resources, the role of livestock is shifting towards commercial production, and the workload of women is increasing. Agricultural assets (land and livestock), farm gross margins (total returns less variable costs), market oriented production, commercial milk production and off-farm employment provide indices of household well-being, and reflect differences in production constraints faced by poor households. Strong relationships are noted between economic indicators and nutrient inputs; land holdings, gross returns and milk production are positively correlated to compost and fertilizer use. Significantly greater inputs are applied to owned versus shared cropped land, and high caste groups (Brahmins) apply more fertilizer and pesticides, and typically own better quality land.

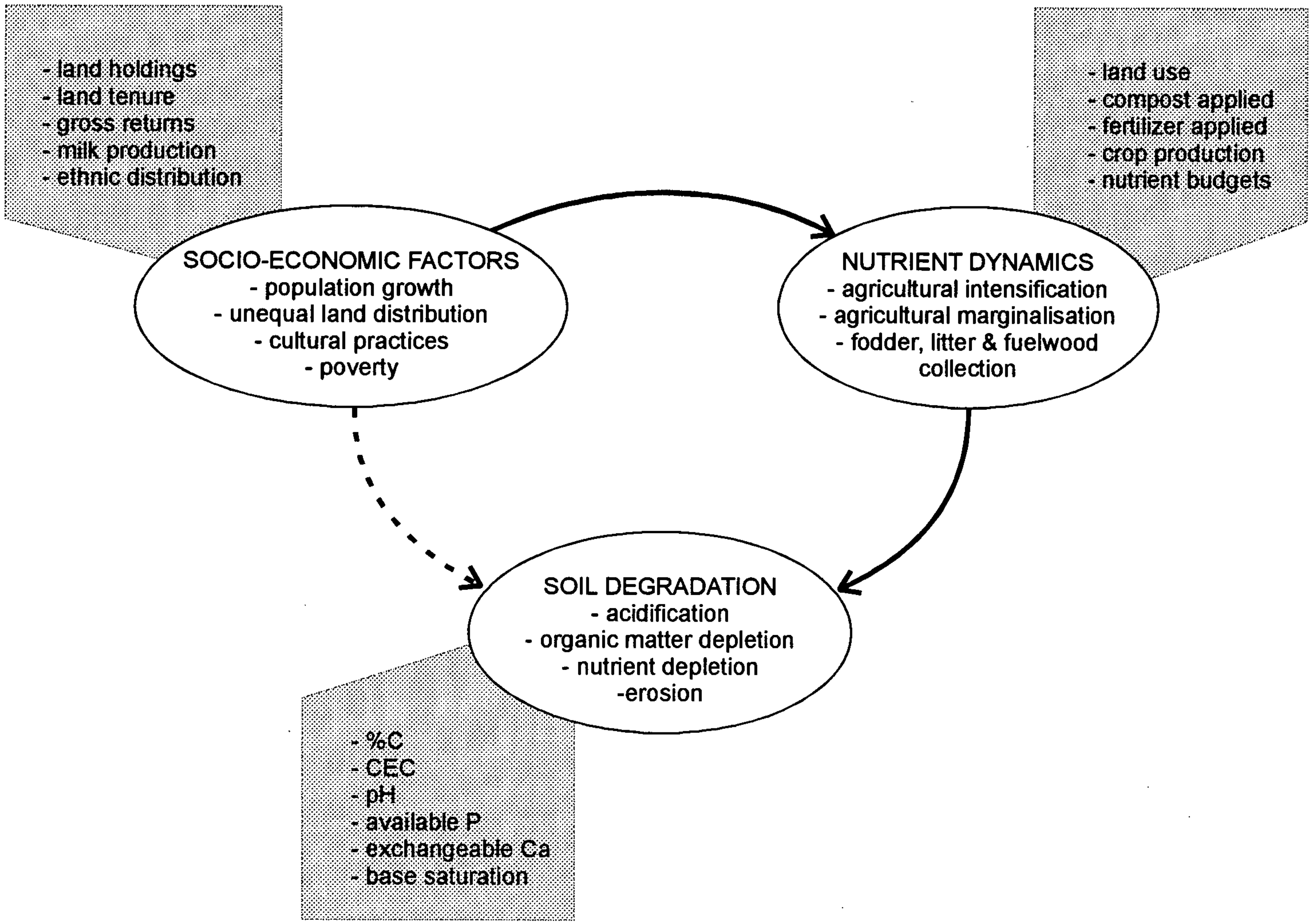


Figure 6.12. Contextual framework and quantified relationships (shaded) linking social factors, nutrient dynamics and soil degradation.

Farm management, particularly nutrient management, impacts crop productivity, nutrient budgets and soil fertility conditions. Soil acidification, organic matter depletion, nutrient depletion and erosion are degradation processes supported by plot studies and nutrient budget modelling. Crop yield under dryland and irrigated production is correlated with both nutrient inputs and soil fertility (Figure 5.11). Nutrient fluxes under irrigated cultivation appear to be sustainable, but are dominantly negative under dryland cultivation. Nutrient budgets for cultivated fields are dependent on compost and fertilizer inputs, and crop yield, while budgets on forest, shrub and grasslands are related to biomass collection. Relationships between nutrient budgets and soil fertility are poor reflecting the low overall fertility conditions and high site specific variability, but correlations are noted between compost and fertilizer use, and soil fertility (Figures 5.4 and 5.7).

Indirect relationships between socio-economic factors and soil fertility provide verification of the more direct linkages. Households owning moderate amounts of land (1-2 ha) typically own a mix of bari and khet land, apply the most fertilizer and compost to their fields, and display the best soil fertility conditions (Table 6.2). High caste groups own land with significantly better soil fertility conditions (Table 6.5), and households with higher returns to khet land and milk production appear to farm fields with higher soil fertility (Figure 6.11).

The socio-economic factors driving nutrient dynamics and consequently impacting soil fertility are not isolated, but interrelated and these factors may be influenced by soil fertility degradation. Population growth, access to land and cultural practices are closely tied to poverty. Poor families own smaller land holdings, typically own poorer quality land, and will be impacted most by soil degradation. Population growth is driving land use change and thus altering nutrient flows within and between land uses. To meet the demands of a growing population agriculture has been intensified and marginalized, and evidence of renewed deforestation is beginning to appear.

Access to land is a key factor driving nutrient management and influencing economic well-being. Land is the main agricultural asset of households in the study area, and khet land is more productive and provides greater opportunities for cash crop production than bari land. The poorest soil fertility conditions are found on common property lands (grassland, shrub and forest). Share cropped land is less intensively managed, receiving lower inputs of chemical fertilizer, organic matter and pesticides. Khet land receives the most nutrient inputs per ha, shows the best nutrient budgets and has the best overall soil fertility conditions.

Culture plays a subtle but important role by influencing the division of labour and access to resources. Women are central in soil fertility maintenance through their role in fertility management and livestock care, but time constraints may hamper rehabilitation efforts if the impact on women is not considered. Under the feudal land tenure system, land was granted to the local aristocracy and the resulting unequal distribution of land is evident today. While caste / ethnic distribution is not equivalent to class structure, differences are noted between Brahmins and other groups in the study area. Brahmins tend to use more agrochemicals, own more land and own land with better soil fertility.

The economic well-being of households in the study area is strongly tied to the quantity and quality of land owned, and reflects traditional versus market oriented agriculture (vegetable and milk production). Households with lower production returns, lower agricultural assets and lower cash income tend to apply less nutrients to their fields. Alternatively, households growing vegetable crops (which have higher gross margins) may still negatively impact soil fertility due to the high nutrient demands of these crops. Farm management and nutrient dynamics are influenced by a combination of socio-economic factors, but within this study area population growth and access to land are two key components indirectly impacting soil fertility conditions.

7. SUMMARY AND IMPLICATIONS

Soil fertility, nutrient dynamics and socio-economic interactions in a Middle Mountain watershed have been studied using soil surveys, plot studies, nutrient budget modelling, household questionnaires and GIS mapping techniques. The study area located approximately 40 km east of Kathmandu is intensively utilized and experiencing population growth, agricultural intensification and shortages in forest products. A 200 site soil fertility survey of cultivated and grass lands was conducted in 1993/94 which isolated topography, soil type and land use. Forest soil fertility was examined through a series of plot studies initiated by Fiegl in 1989 and re-sampled in 1994. Phosphorus dynamics were assessed by evaluating P sorption in relation to extractable Fe and Al, and a nutrient budget model was developed for the dominant cropping systems to assess the impact of management practices on soil fertility. Nutrient cycling examined as part of the Jhikhu Khola Watershed study was used to assess rates of change in soil fertility induced by land use.

A short questionnaire summarizing the crops grown, yields and nutrient inputs was conducted for each of the 200 fields sampled. Detailed questionnaires were collected from a subset of 85 households to gather information about the household farming system. Paired male-female interviews were conducted simultaneously and separately to illicit open responses. Changes within the farming system were quantified by repeating 27 household surveys originally conducted by Kennedy and Dunlop in Baluwa in 1989, and key informant questionnaires were used as a cross check.

Geographic Information System (GIS) techniques were used for data compilation and integration, using a 1:5,000 scale topographic basemap. Elevation, slope and aspect themes were generated using terrain modelling. Soil types delineated on aerial photographs were transferred to digital format. A historical comparison of land use was compiled for 1972 and 1994 using land use maps and aerial photographs. Population dynamics were evaluated for 1972, 1990 and 1995 using house counts and family size data.

All soil sample, plot study and household survey locations were georeferenced and transferred to the GIS database for analysis.

7.1 Soil Fertility Status

The overall soil fertility conditions of the study site are poor. Soil carbon to one standard deviation (0.99 $\pm$ 0.47%) and pH (4.8 $\pm$ 0.4) are particularly problematic, and available P (16.6 $\pm$ 18.9 mg kg^{-1}) is a concern given the low pH values. Land use is the most important factor influencing soil fertility, followed by soil type. Khet sites show the best overall soil fertility (pH 5.2, Ca 5.3 cmol kg^{-1}, available P 21.6 mg kg^{-1}), followed by bari and grassland, while forest soil fertility is the poorest (pH 4.2, Ca 0.9 cmol kg^{-1}, available P 0.7 mg kg^{-1}). Red soils have a greater clay content and higher CEC, but lower available P than non-red soils (9.8 versus 22.1 mg kg^{-1}). A site factor approach based on relationships between soil fertility and site characteristics facilitated the extrapolation from point data to a spatial coverage and was useful in assessing the extent of soil fertility problems. The composite soil fertility map indicates that only 14% of the classified regions have adequate pH, available P and exchangeable Ca.

Phosphorus sorption studies indicate the high P fixation capacity of red soils. Sorption ranged from 2-4 g P_2O_5 per kg soil for the 16 red soil sites evaluated. Phosphate sorption calculated using Borggaard's model which includes AAO extractable Fe and Al, and CBD extractable Fe showed good agreement (r^2=0.85) with measured P sorption and was used to calculate P sorption under different land uses. The P sorption capacity on red soils is nearly one order of magnitude greater than calculated values for non-red soils, and forest sites sorbed significantly greater P than agricultural sites. A classified map of P sorption developed using a site factor approach indicates that 29% of the area has very high P fixation capacity (>1.5 g kg^{-1}) and 61% has a P fixation capacity >0.5 g kg^{-1}. The high P fixation capacity of these soils has important implications for phosphorus management as fertilizer P will quickly be converted to insoluble or complex forms.

7.2 Soil Fertility Dynamics

The direction and rate of change of soil fertility impact both current and future biomass production. Plot studies and nutrient budget modelling indicate declining soil fertility on bari, forest, shrub and grasslands, and marginal conditions on khet land subject to intensive cultivation. Fertility characteristics of soils originating from the same parent material but subject to different land uses show that forest sites have the lowest N, available P, exchangeable bases and pH values resulting from nutrient removal through biomass collection. Bari sites which receive the highest organic matter inputs have the highest C and N levels. Khet lands enriched by irrigation water and suspended sediments have the largest available P, Ca and Mg. Rates of soil fertility depletion estimated from differences in soil fertility between land uses indicate substantial N and Ca losses from forest land (94 and 57 kg ha^{-1} furrow slice respectively). Annual losses from bari lands are small due to additional inputs from organic sources, suggesting that losses from agriculture are strongly influenced by management.

Nutrient budget modelling of N, P and Ca levels for the dominant crops and cropping patterns is used to estimate nutrient depletion from the soil pool and identify management practices contributing to soil fertility degradation. Practices related to maize production result in large deficits in N, P_2O_5 and Ca (118, 38 and 32 kg ha^{-1} furrow slice respectively). Rice and rice-wheat cultivation on irrigated land appear to have limited impact on the soil nutrient pool, but the addition of premonsoon maize in the rotation results in deficits of 106 kg N and 12 kg P_2O_5 per ha furrow slice. The collection of forest biomass results in annual nutrient losses of 56 kg N ha^{-1}, 16 kg P_2O_5 ha^{-1} and 34 kg Ca ha^{-1}, and is comparable to nutrient depletion determined from plot studies. Biomass removal from grasslands results in nutrient losses roughly estimated at 60 kg N ha^{-1}, 20 kg P_2O_5 ha^{-1} and 20 kg Ca ha^{-1}, while soil erosion on degraded grass and shrub lands results in comparable losses (34 kg N and 23 kg Ca per ha furrow slice).

7.3 Management Factors and Options

Land use change and soil nutrient budget modelling are useful in assessing the impact of management factors on soil fertility and identifying management options which may reduce nutrient deficits. Key factors influencing soil fertility degradation include forest litter removal, agricultural marginalisation, erosion and agricultural intensification. Potential options to reduce nutrient deficits include improved organic matter management, water management, lime, integrated nutrient management, *Azolla* and on-farm fodder production.

7.3.1 Management Factors

Litter Removal

Forest soils show the lowest overall soil fertility and largest annual nutrient losses. The collection of fodder, litter and fuelwood results in significant nutrient removal (56 kg N, 7 kg P and 72 kg total bases ha^{-1}) and disrupts the natural nutrient cycling. Historical forest cover data suggest a cyclical decline in forest cover with at least two cycles of deforestation followed by efforts of rehabilitation. Biomass removal contributes to a low soil organic matter content and soil acidification through the removal of bases from forest land, and pine litter inputs to agricultural fields are likely acidifying cultivated land.

Marginalization

The nutrient status on bari lands is generally poor and nutrient modelling indicates that N, P and Ca inputs are insufficient to maintain the soil nutrient pool under maize-wheat production. Bari soils are acidic with pH values ranging from 4.1 to 4.9, acidification from chemical fertilizer use is a concern and P availability is limited on red soils due to their high P fixation capacity. Rainfed agriculture has expanded onto former grazing, shrub and abandoned lands located on steep slopes and at high elevations. These marginal lands have inherently lower soil fertility and are less favourable for intensive nutrient management.

Erosion

Erosion from upland bari fields and degraded lands result in substantial nutrient transfer to lowland agricultural fields. Erosion on bari land removes an average of 25 kg N and 13 kg Ca per ha furrow slice, and marginal upland agricultural sites are prone to higher erosion rates. Nutrient losses through erosion on forest land are small when understorey vegetation is maintained, but litter removal leaves the forest floor unprotected to the monsoon rains. Degraded shrub and grasslands (>50% soil exposure) cover 5% of the study area and are a significant source of sediments, removing an estimated 34 kg N and 23 kg Ca per ha furrow slice.

Intensification

Khet fields act as a nutrient sink receiving inputs from compost, fertilizer, sediment, water and biological fixation. Soil fertility conditions on khet are adequate and nutrient modelling suggests that inputs are sufficient to maintain a rice-wheat cropping system. The amount of irrigated land has remained relatively constant over the last 25 years but cropping has intensified and shifted toward cash crop production. Nutrient budgets under triple cropping are N and P_2O_5 depleting (-106 kg N and -12 kg P_2O_5 per ha furrow slice), and cash crops such as tomatoes and potatoes require higher N, and P_2O_5 levels than staple grain crops. Vegetable production and the use of high yielding varieties has resulted in an increased dependence on agrochemicals, and water quality problems are associated with heavy fertilizer and pesticide use.

7.3.2 Management Options

Organic Matter Management

Organic matter inputs have many beneficial effects on soil chemical, physical and biological properties; providing macro- and micro-nutrients, reducing acidification, maintaining soil structure and enhancing microbial activity. Best management practice and deficit elimination scenarios identified improved composting as a practical option for improving nutrient budgets on bari land. Pit composting nearly doubles the N and P_2O_5 content of compost, and improved composting reduced estimated N deficits on bari fields by 17%.

Water Management

The diversion of stream floodwaters through the irrigation system carries suspended sediments and nutrients onto khet fields. Sediments are enriched in Ca, P and C, and an average accumulation of 4 mm per year supplies an additional 11 kg N and 28 kg Ca per ha furrow slice. In addition to nutrient enrichment from sediment accumulation, irrigation water is alkaline, contains moderate quantities of NO_3 and contains substantial Ca. While additional work is required to quantify nutrients supplied through irrigation waters, enrichment associated with irrigation and sediment deposition appears to be key to maintaining soil fertility conditions on khet land.

Lime

Bari, forest, shrub and grasslands all have median pH values <5.0, and further acidification is a concern with the increasing use of chemical fertilizers on bari land and biomass removal from forest, shrub and grasslands. Calcium and magnesium based rocks provide a source of liming materials that are locally available in limestone and marble deposits distributed in the lower Jhikhu Khola Watershed. Rehabilitation studies with lime and manure have shown increased fodder production and a slight increase in soil pH. However, detailed soil testing and analysis is required to determine the soil buffering capacity, lime requirements and yield response.

Integrated Nutrient Management

Nutrient deficit elimination scenarios suggest chemical fertilizer use would need to be quadrupled to meet crop N requirements under a triple crop rotation. The high cost of fertilizer constrains application rates and the associated soil acidification would be detrimental to crop productivity. Many farmers already report that soils are becoming 'hard' due to continued chemical fertilizer use. Integrated nutrient management, combining chemical fertilizers and compost is critical to maintaining soil fertility. Compost alone will be insufficient to meet crop nutrient demands with increasing cropping intensities and vegetable production, but organic matter additions improve soil structure, provide slowly available nutrients, and are less prone to nutrient losses through leaching.

Azolla

N fixation by blue-green algae and *Azolla* may provide sufficient N to meet the requirements of rice grown on khet fields. *Azolla* production of 15-20 t ha^{-1}, with a N concentration of 4.5%, incorporated into the soil would supply some 135 kg N if 20-30% is taken up by the first rice crop, and residual organic matter would supply nutrients to subsequent crops. Given the success of *Azolla* cultivation in countries such as the Philippines, it provides a viable management option.

On-Farm Fodder Production

Eighty-five percent of the households surveyed report fodder trees on their private land, but fodder shortages are common during the dry season. Additional fodder may be produced by planting species such as napier grass on terrace risers and 'waste' lands. Regular cutting would minimise rodent problems, provide a source of fodder close to the house, and reduce pressure on forest resources. Nitrogen fixing fodder trees such as sissoo and sirus planted as hedgerows are able to grow on N deficit sites, and litter adds organic matter to the soil. Regular cutting would provide fodder and firewood, and minimise the shading effect on agriculture.

7.4 Socio-Economic Factors and Options

Population growth, land tenure, culture and poverty are key socio-economic factors influencing nutrient management and driving soil fertility degradation. Potential options which may counter the negative impact of socio-economic influences on soil fertility include off-farm employment, community forestry, cash cropping and population stabilisation.

7.4.1 Socio-economic Factors

Population Growth

Population growth rates estimated at 2.6% are placing additional pressure on soil resources. The per capita availability of land has decreased to 0.17 ha, and double and triple crop rotations are required to meet the increased demand for food. Agricultural marginalisation in response to population pressure has brought steeply sloping and low soil fertility lands under cultivation, and recent declines in forest cover are indicative of continuing pressure on forest resources. Population growth is a dominant factor driving land use dynamics within the study region, and the increased demand for food, animal feed and fuelwood results in increased nutrient removal.

Land Tenure

Land ownership varies dramatically with 15% of the surveyed households owning 36% of the agricultural land, and 53% of households owning only 25% with total holdings <1 ha per household. Share cropping is practised by approximately one-third of the households, and 47% of households report that the land they farm does not generate enough food and income to meet their family's basic needs. The poorest soil fertility conditions within the study region are found on forest and grasslands, which are primarily under government ownership. Agricultural land holdings are positively correlated with total fertilizer and compost applications, and significant differences in nutrient budgets and soil fertility are noted with farm size. Share cropped land receives significantly lower compost, fertilizer and pesticide inputs, and grasslands are largely unmanaged.

Culture

Ethnic distribution, the role of livestock, and women as resource users and managers are three components of Nepali culture related to soil fertility in the study region. High caste farmers (Brahmins) typically own the most khet land, and apply more fertilizer and pesticides to their land. Livestock are important in Nepali culture, particularly cows and goats, and impact soil fertility through manure inputs. Female buffalo are obtaining economic importance with increased commercial milk production. Women are central in soil fertility management due to their responsibilities for livestock care, litter collection and compost application, and the commercialization of milk production is dramatically increasing the workload of women farmers.

Poverty

Agricultural assets (land and livestock), farm gross margins (total returns less variable costs), and sources of cash income (crop sales, milk production and off-farm employment) are used as indicators of household economic well-being. Access to land and land quality assessed by local land values is highly skewed and ranges from \$0-\$53,000 Cdn. Livestock values are highly variable between households, ranging from \$0-\$3,000 Cdn and 50% of household livestock assets are accounted for by female buffalo. Vegetable crops involve higher levels of resources (labour, pesticides, fertilizer, compost and water), but farmers have an economic incentive to adopt vegetable crops. Total returns and household gross margins are greatest for households growing vegetable crops as part of their rotation, but 47% of households have gross margins <\$100 Cdn per year. Farmers sell a variety of crops, but only a small minority systematically produce for the market. Forty-five percent of the households surveyed sell milk, and 40% of these households have been selling milk for less than five years. Off-farm activities are an important source of family income for 60% of the households with a median gross income of \$439 Cdn. per year. Households with higher agricultural assets and gross returns apply more compost and fertilizer to both khet and bari land, and households with higher returns and milk sales appear to farm sites with better soil fertility conditions.

7.4.2 Socio-economic Options

Off-farm Income

Off-farm activities provide cash income to households which may be used to purchase chemical fertilizer, thereby reducing nutrient deficiencies associated with intensive cultivation. If one-half of the current median off-farm income (\$220 Cdn) was used to purchase chemical fertilizer, some 500 kg of complex©

could be purchased, supplying 100 kg N and P_2O_5. The nutrient deficit estimated for an early maize-rice-wheat rotation could be eliminated by such input levels. Male out-migration in pursuit of wage employment however, negatively impacts the household farm by increasing the workload of women farmers and increasing their responsibility for farm decision making. The workload placed on women farmers is particularly problematic given parallel increases in demand for their labour associated with agricultural intensification, vegetable crop production and commercial milk production.

Community Forestry

Community forestry initiatives have been successful in increasing biomass through restocking and restricted access, but long term investments are required. Local farmers now have incentives to manage common forest land, but the necessary capital resources to initiate community forestry projects require outside subsidies. Community grassland initiatives which establish access rights and aid in pasture management, similar to the forest user groups, are an option for increasing fodder production but long term capital investments are required to establish productive grasslands on currently degraded sites.

Cash Cropping

Market oriented production provides a source of income which may be used to purchase commercial inputs. If farmers were to invest one-half of the gross margin of tomatoes grown on 0.25 ha of khet land ($264 Cdn) in chemical fertilizer, some 625 kg of complex© could be purchased providing 125 kg N and P_2O_5, far in excess of the nutrients required by the tomato crop. Vegetable production, however, increases water and pesticide requirements, and increased chemical fertilizer use is associated with soil acidification and water quality problems. Integrated nutrient management is required to minimise the negative effects of agrochemical use and water use efficiency issues need to be addressed.

Population Stabilisation

Reducing the demand on land resources may be obtained through population stabilisation. Family planning is a long term solution, while outmigration provides a short term option. Male outmigration in search of off-farm income reduces the supply of farm labour and places additional responsibilities on women farmers. Problems of population size and growth, resource utilization and depletion, and soil degradation must be considered jointly.

7.5 Sustainability of Farming Systems

Farms in Nepal need to be viewed as systems, integrating forest, livestock and cultivation activities. Biomass collected from forest, shrub and grasslands provide nutrients to the agricultural system with livestock, through manure, playing a central role in nutrient redistribution. Erosion is an important natural process but water and sediment regimes are modified through a complex irrigation system. Off-farm employment, cash crop production and milk sales provide income to the farm household which is partially used to purchase agrochemicals impacting agriculture. Nutrient flows must be evaluated within and between components as nutrient fluxes are interlinked. Pressure on one component will impact the entire system and alter the transfer of nutrients.

The traditional farming system appears to have been sustainable. Despite high rates of erosion, nutrients were recaptured on khet land, and compost was used to replace nutrients lost from bari lands. But triple cropping and increased vegetable production are now threatening sustainability. Both require more fertilizer, pesticides, water and labour. As a result nutrients on khet land are being depleted and bari land receives less compost. Cultivation of low soil fertility sites leads to low productivity, low returns to human and capital inputs, and the inefficient use of scarce nutrient resources. Forests are cleared of understorey vegetation, short circuiting the natural nutrient cycle and more erosion results. Social sustainability is also being threatened, given the increased demands particularly on female labour required for triple cropping and vegetable production. Although milk production provides more manure, it increases labour demands for fodder collection, feeding and milking, which are tasks mostly fulfilled by women. Increasing off-farm employment and schooling remove male and child labour from the system. Some 25% of the farmers cannot provide for their families. They will have no choice but to take a short run view and use up the capital stock of soil nutrients rather than investing in soil fertility.

7.6 Implications for Methodology

The biophysical and socio-economic data collected as part of this study, their analysis and its interpretation are not without limitations. Potential sources of error are associated with survey variability, sampling density, positional accuracy, laboratory analysis, historical records and the subjectivity of interview interpretation. A number of techniques were used to minimize errors during data collection and to validate the results. Soil sampling used a composite approach with ten samples bulked for each field, ten fields were sampled for each of the factors analyzed, and duplicate laboratory analysis was conducted for 10% of the samples. The nutrient budget model indicates the relative changes in soil nutrient fluxes under different management regimes and sensitivity analysis was used to identify key model variables. Biophysical processes need to be monitored over a long time period to determine rates of changes in soil fertility, but changes induced by land use are indicative of the general trends.

The accuracy of spatial data collection is implied in the map scale, but aerial photo interpretation, data transfer and digitizing are potential sources of error. Ground truthing was used to validate and update the interpretation of recent (1990) air photographs, but land use data derived from historical photographs could not be validated.

Obtaining accurate and consistent socio-economic data can be challenging. Bias may be introduced by poor question design, interviewer interpretation or respondent interpretation. Data were collected at different times, by different interview teams. Farmers are often illiterate, do not keep records and farm a series of small plots. Interview results were cross checked by comparing male and female farmer responses and key informant questionnaires.

Recognizing these limitations, this study contributes to the understanding of soil fertility issues in the Middle Mountains by showing the dominant trends in nutrient and soil fertility dynamics in one-subwatershed. While the Bela-Bhimsenthan study area is somewhat atypical of the Middle Mountains due to the Aranico Highway and its proximity to Kathmandu, the results are indicative of future conditions in many regions of the Middle Mountains. As market oriented economies develop in other areas of the Middle Mountains similar soil degradation issues may arise. There is a need to consider both biophysical and socio-economic factors, and while these factors may be similar in other areas of the Middle Mountains, their interactions will likely be different.

7.7 Implications for Future Research

Understanding how soil fertility is changing, and why, requires the integration of biophysical and socio-economic factors. Farmers' perceptions of soil fertility are useful in identifying past trends. However, given the nonlinearly of relationships between soil parameters (e.g. pH and P fixation), farmer perceptions do not indicate the proximity to threshold values. Long term research on soil fertility and nutrient dynamics are necessary to understand the physical processes. While soil fertility research provides an index of soil resilience and an understanding of the agronomic processes, it does not indicate the underlying socio-economic factors driving nutrient management. Household, farm and off-farm activities need to be viewed in terms of their interactions with natural and socio-economic environments. Interdisciplinary efforts that seek to integrate our understanding of these subsystems are needed to more fully comprehend soil fertility issues in the Middle Mountains of Nepal.

PLATES

PHOTOGRAPHS

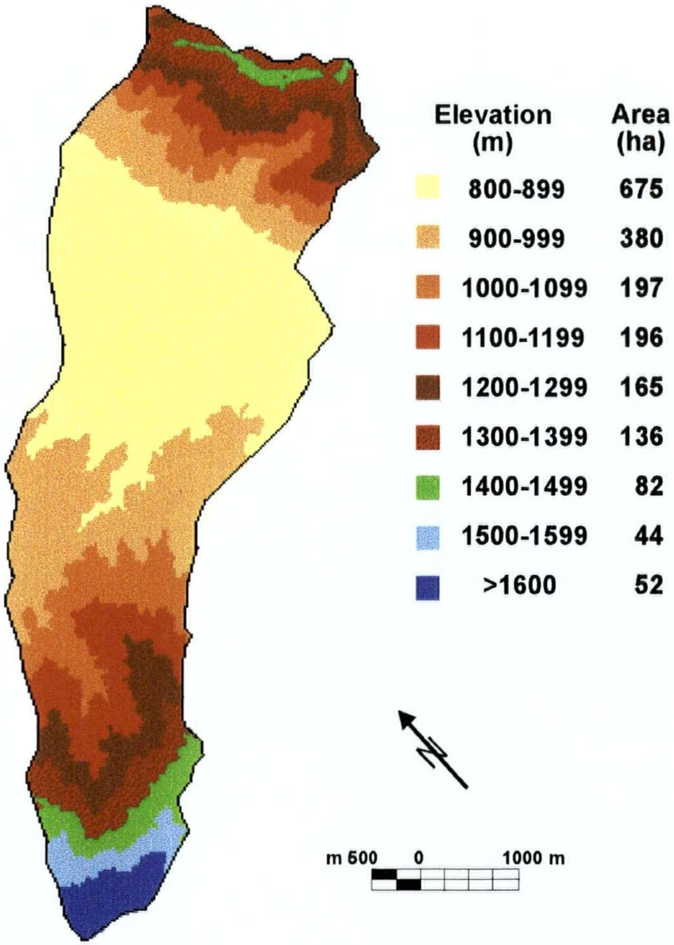


Plate 1. Elevation ranges.

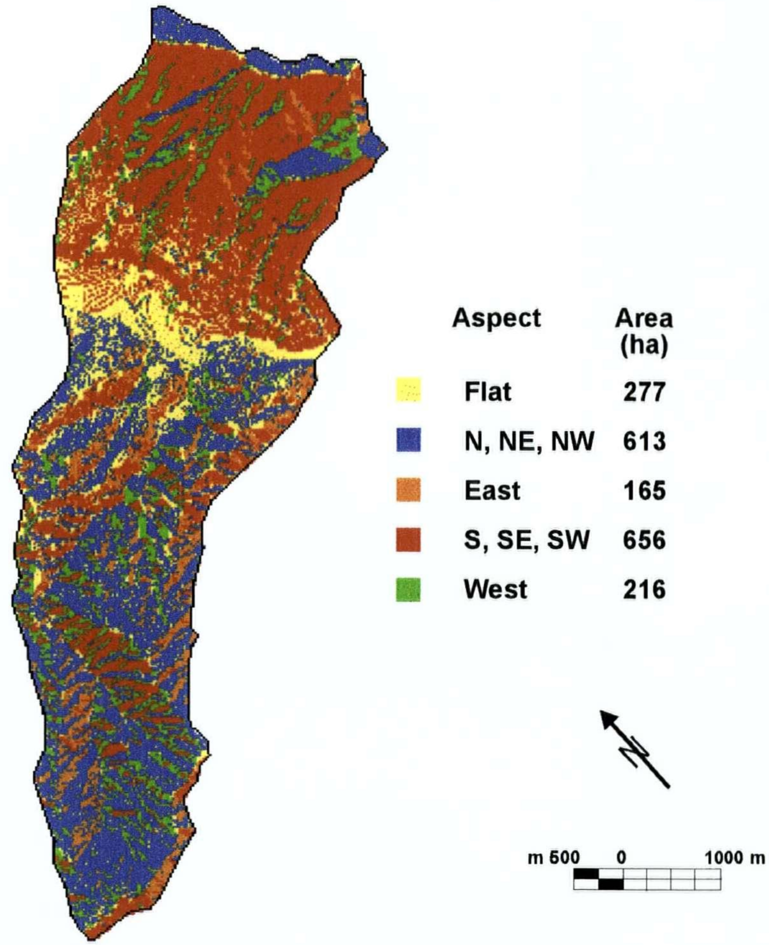


Plate 2. Aspect.

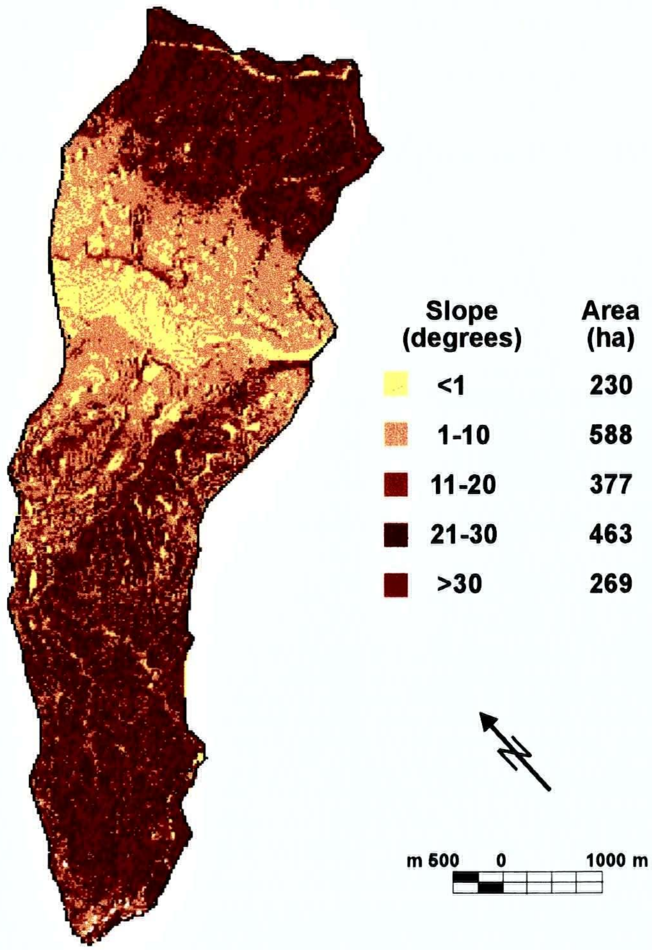


Plate 3. Slope classes.

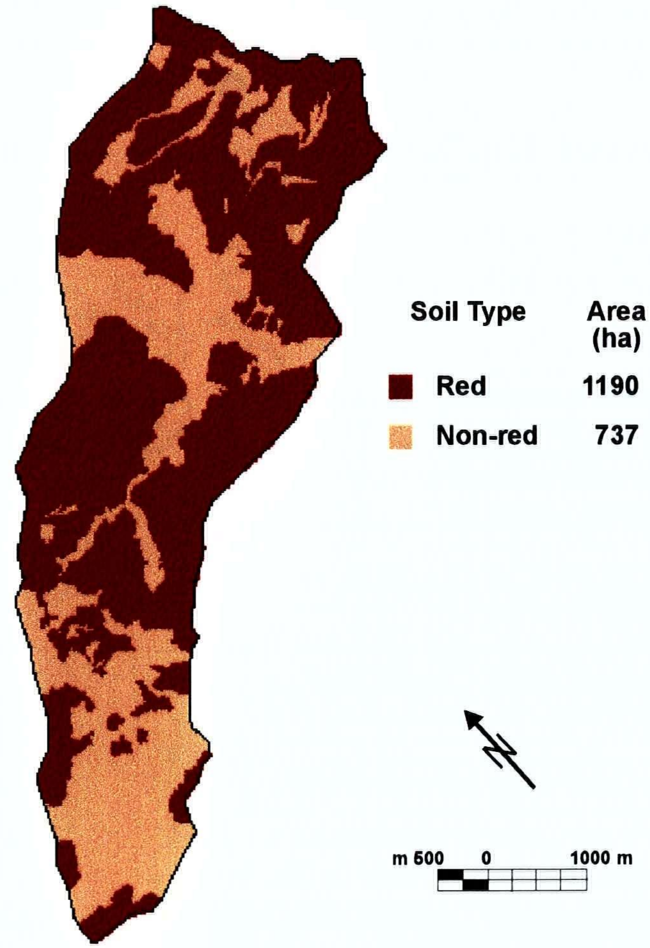


Plate 4. Soil type.

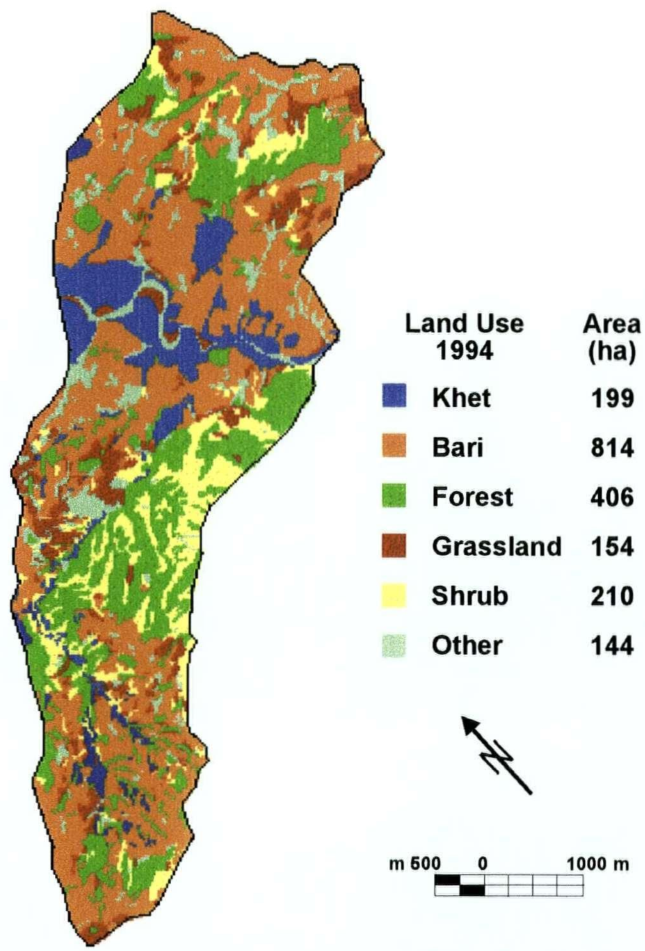


Plate 5a. Land use 1994.

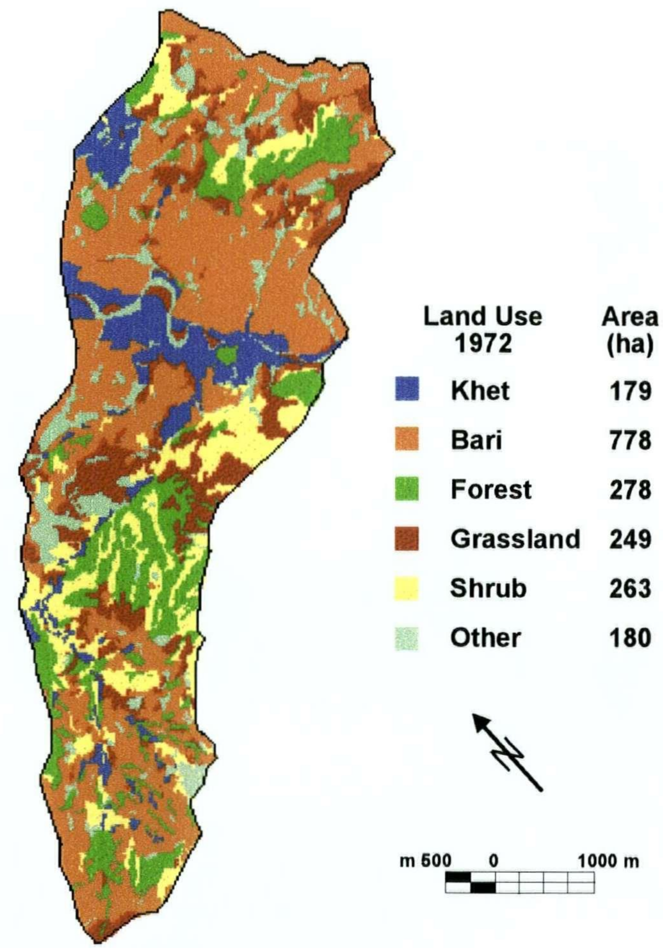


Plate 5b. Land use 1972.

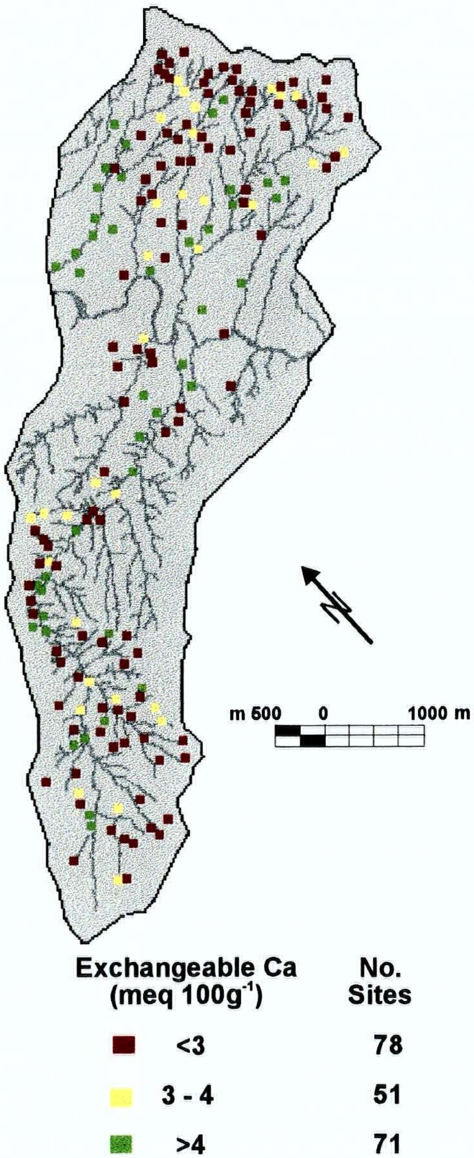


Plate 6. Exchangeable Ca 200 soil sites.

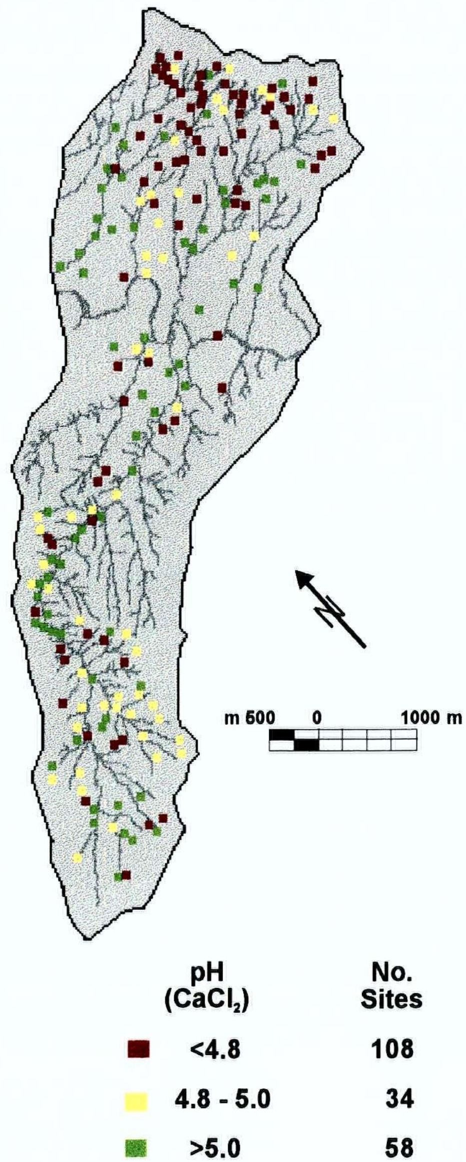


Plate 7. Soil pH 200 soil sites.

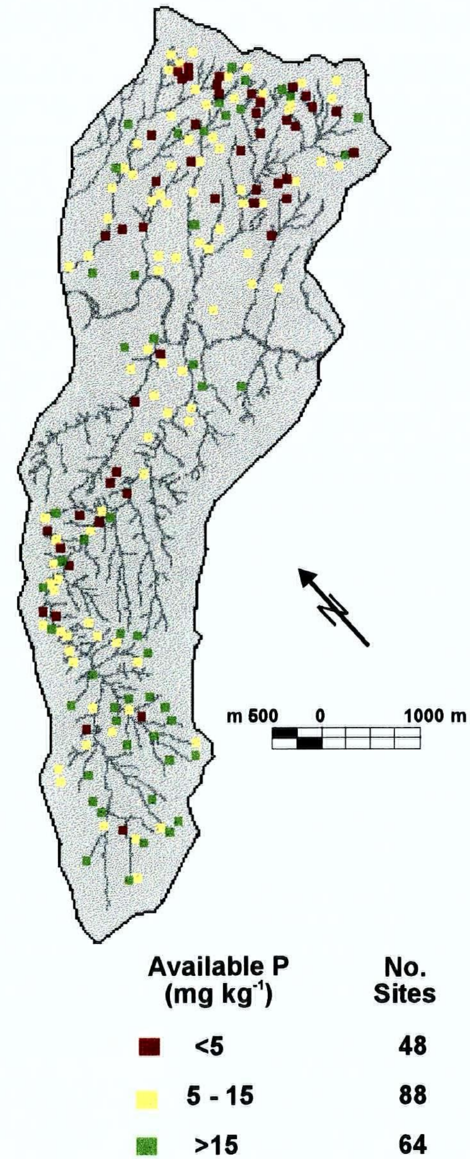


Plate 8. Available P 200 soil sites.

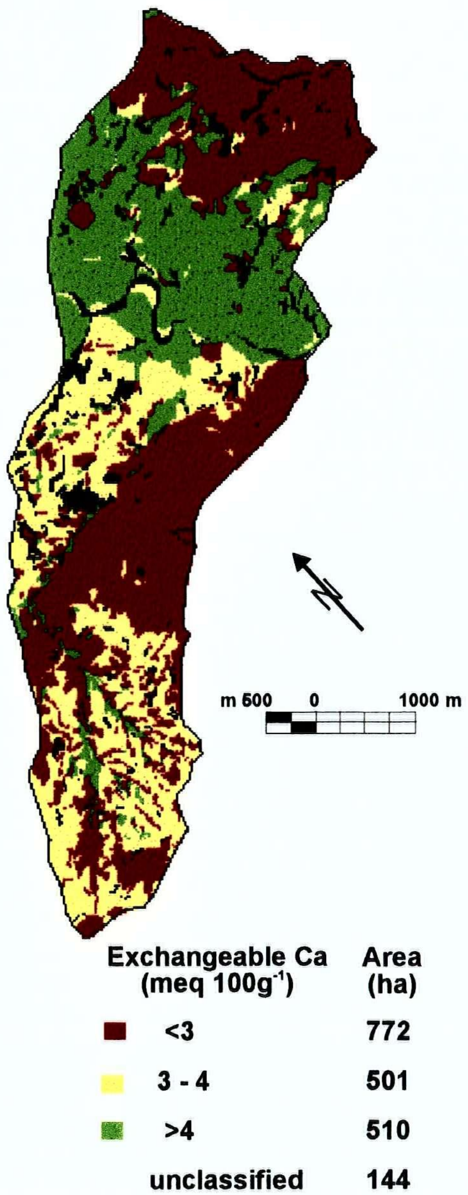


Plate 9. Exchangeable Ca soil classification.

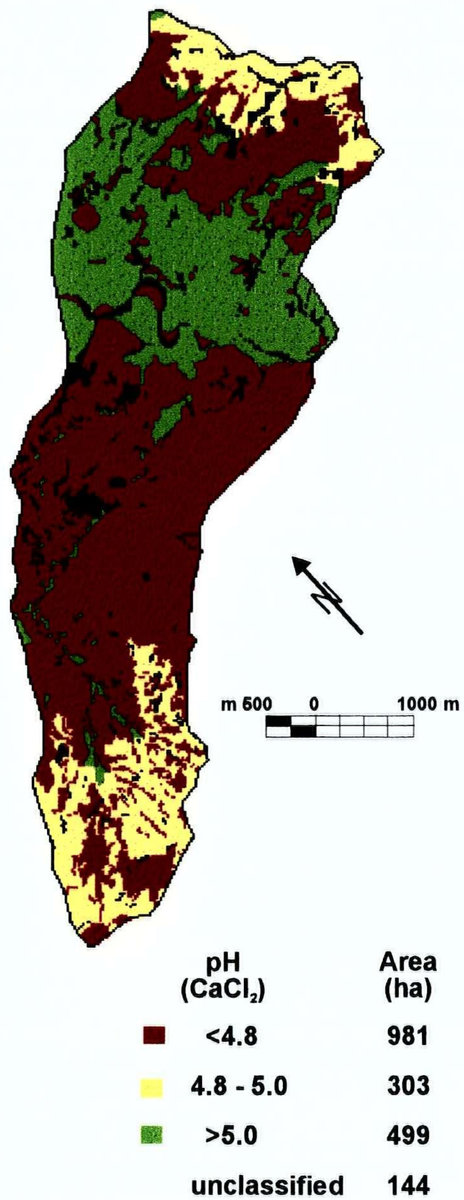


Plate 10. Soil pH classification.

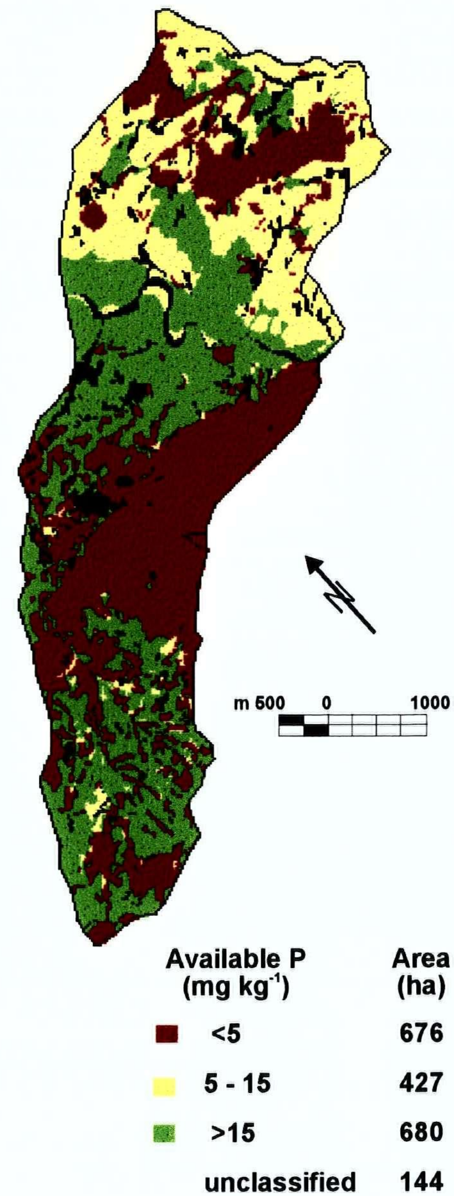


Plate 11. Available P soil classification.

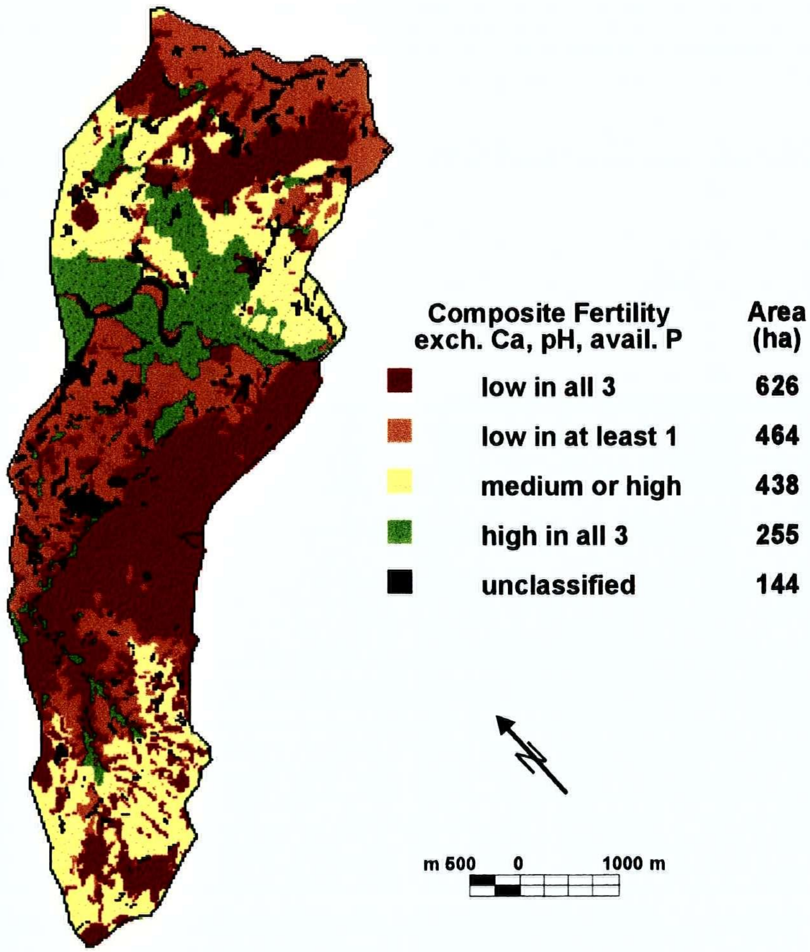


Plate 12. Composite soil fertility classification

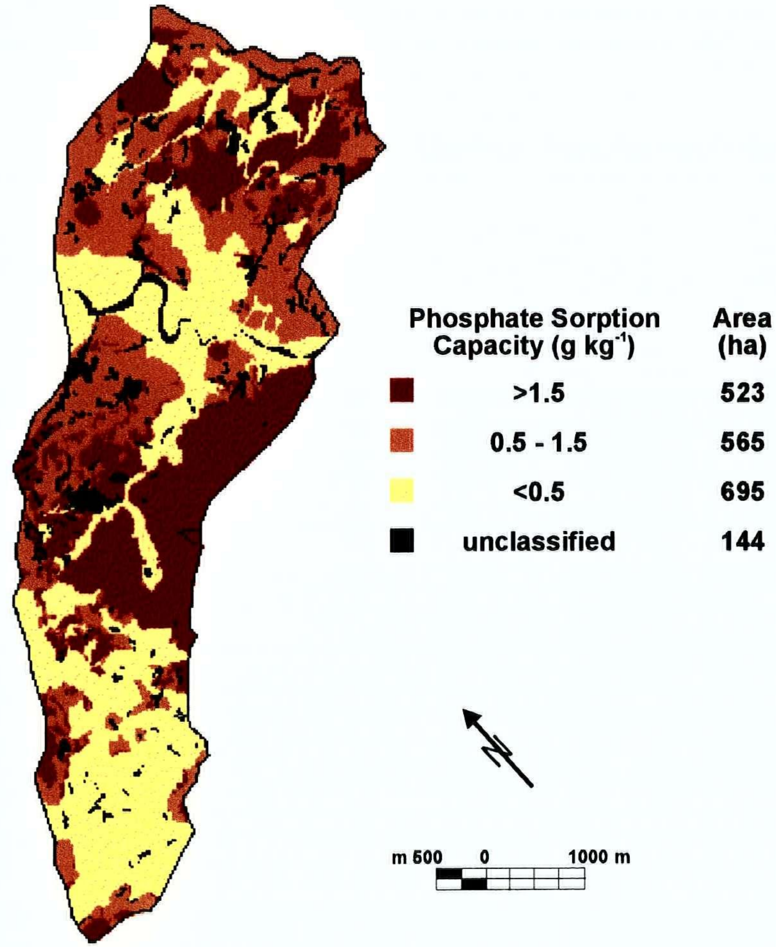


Plate 13. Classification of P sorption capacity.

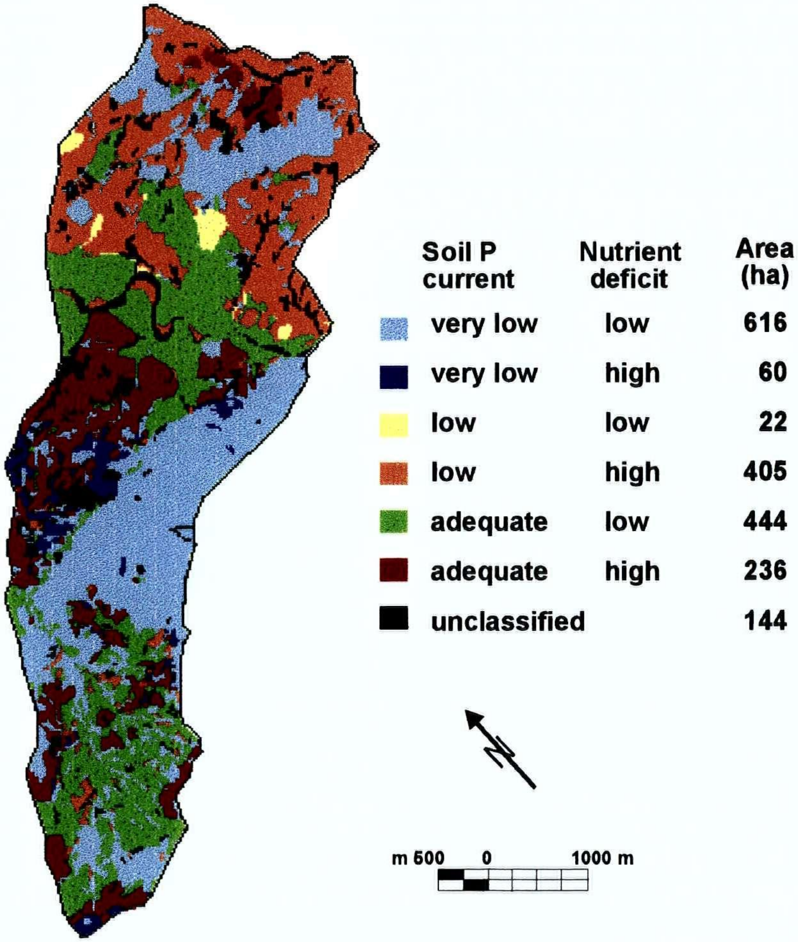


Plate 14. Spatial distribution of interpreted P degradation.

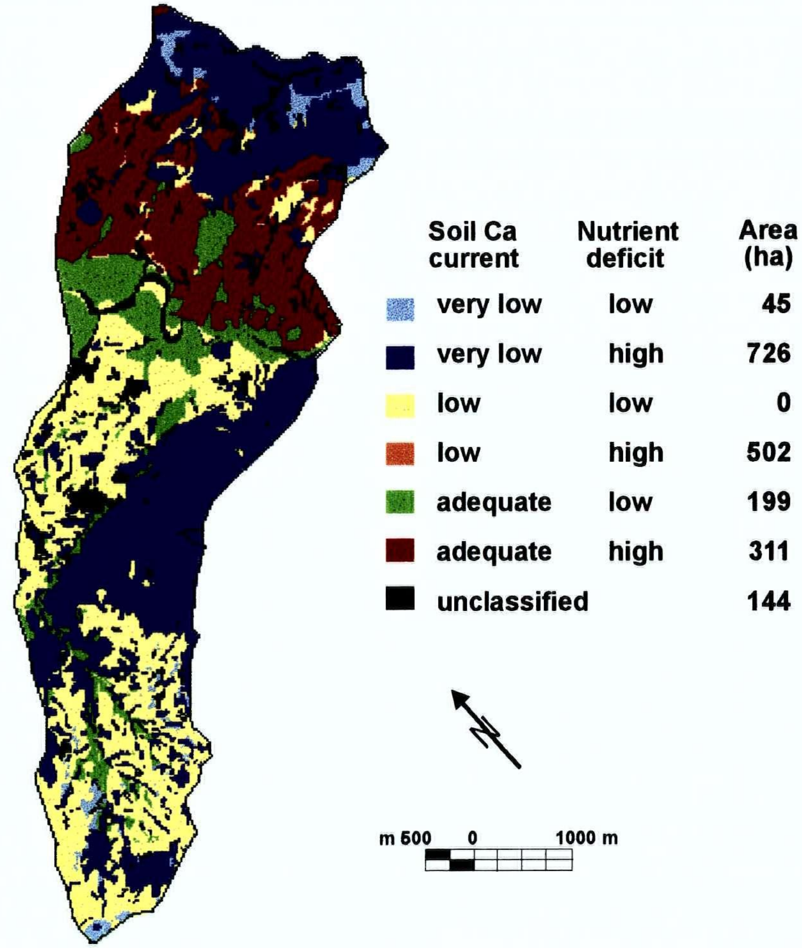


Plate 15. Spatial distribution of interpreted Ca degradation.

Photo 1. Women transplanting rice.

Photo 2. Women collecting litter.

Photo 3. Pine plantation on red soils.

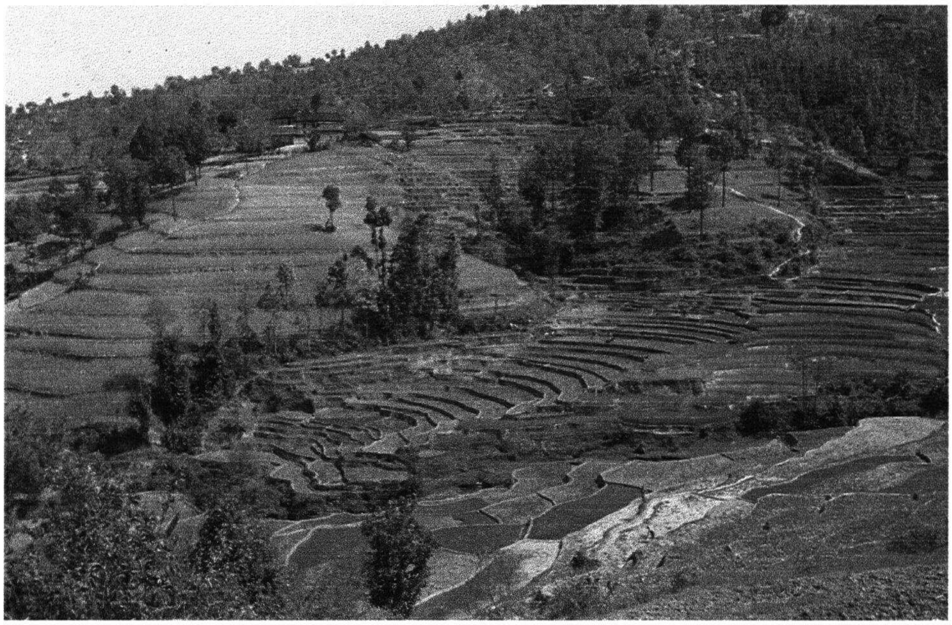


Photo 4. Intensively used agricutlural land.

Photo 5. Bari expansion onto shrub lands.

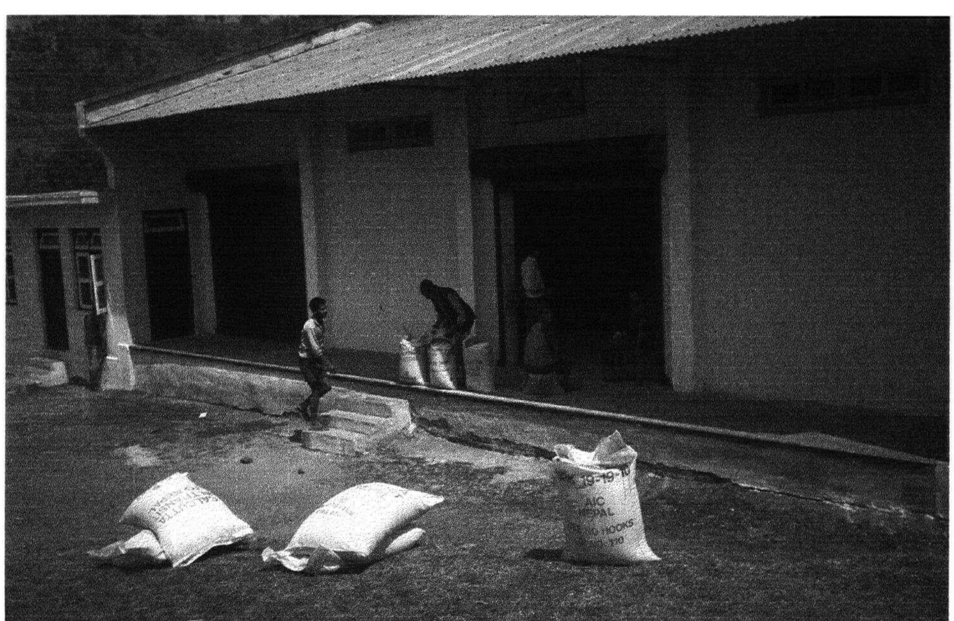


Photo 6.Farmers purchasing chemical fertilizer.

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APPENDIX A. QUESTIONNAIRES

A.1 Bela-Bhimsenthan Soil Fertility Site Description

Sample # .... Aerial Photo # .... Date ....
Location .... VDC .... Ward # ....
Elevation .... Aspect .... Slope ....

Local Land (khet/bari) Classification Types by:

Land Type .... Climate ....
Soil Texture, colour, depth .... Yield .. ..
Field Size .... Slope .. ..
Ownership ....Years Owned.... ....Total Khet ....Bari ....
Farmer's Name ....Ethnic Group ....

Crop Rotation/Variety	**Yield** (kg/ha)	**Fertiliser Application** (kg/ha)	
		Chemical	Organic
A			
B			
C			
D			

Workability ....Penetrometer Reading .. ..
Irrigation ....Years of Mineral Fertiliser Use ....
Yield Trends with Mineral Fertiliser ....
....
Occurrences of Disease and Pest ....
Control Measures ....

Grazing Land

Ownership	**Species Composition & %**	**Ground Cover %**
Government		
Communal		
Private		

Farmer's Comments:

A.2 Bela-Bhimsenthan Detailed Household Survey

Site Description (to match soil survey) Date: 1994

Sample # ....Farmer's Name ....
Mark the house location on the air photos (sample # + H)

What could be done to improve your situation (prioritise)

1.

2.

3.

General Comments

Goals
If you had some extra money, what would you buy? (prioritise)

1.

2.

3.

Family

How many people live in this household? .... people

What is their position in the household and their ages?
What percent of their time do they spend working on the farm?
What percent of their time do they spend working on off farm activities, what are the activities by season (Premonsoon, Monsoon, Winter) and what are the wage rates ($ and food)?

Position	Age (yrs)	On Farm Work (% Time)	Off Farm Work				
			% Time	Activity	Season	Wage per day	
						Rupees	Food
Father					P M W		
Mother					P M W		
Husband					P M W		
Wife					P M W		
Son I					P M W		
Son II					P M W		
Son III					P M W		
					P M W		
Daughter I					P M W		
Daughter II					P M W		
Daughter III					P M W		
Daughter In Law					P M W		
Daughter In Law					P M W		
					P M W		

Are there any family members who live outside of the house and send money home?

Yes .... No...............

If yes, how much money do they send/ bring home per year ? .... rupees

Production

How much land do you own?

Khet .... (ropani) Bari ....(ropani)

Forest .... (ropani) Grazing ....(ropani)

Other ....

For the land you own, what crops are grown and how much land is cultivated for each crop?
What amount of seed, fertiliser and compost do you apply to each crop?
What are you oxen and labour requirements (days per crop)?
What is your current production and compared to 5 years has it increased, stayed the same or decreased?

Area (ropani)	**Crop**	**Inputs**					**Production**	
		Seed (kg)	**Fertiliser** (kg)	**Compost** (kg)	**Oxen** (days)	**Labour** (days)	**Current** (kg)	Yield **5 yrs ago**
Khet	Early Rice							
	Monsoon Rice							
	Maize							
	Wheat							
	Tomato							
	Potato							
	Mustard							
Bari	Maize/Beans							
	Potato							
	Wheat							
	Mustard							
	Tomato							

Share Cropping

Is any land rented or share-cropped? Yes .... No ....

If yes, how many ropani? Khet........ Bari........

If yes, are you tenant .... or landlord .... ?

What are the rental arrangements (share percentage or amount paid in rupees)?

For the land you share-crop, what crops are grown and how much land is cultivated for each crop?
What amount of seed, fertiliser and compost do you apply to each crop?
What are you oxen and labour requirements (days per crop)?
What is your current production and compared to 5 years has it increased, stayed the same or decreased?

Area (ropani)	**Crop**	**Inputs**					**Production**	
		Seed (kg)	**Fertiliser** (kg)	**Compost** (kg)	**Oxen** (days)	**Labour** (days)	**Current** (kg)	Yield **5 yrs ago**
Khet	Early Rice							
	Monsoon Rice							
	Maize							
	Wheat							
	Tomato							
	Potato							
	Mustard							
Bari	Maize/Beans							
	Potato							
	Wheat							
	Mustard							
	Tomato							

Cropping System

Have you recently changed the type of crops you are growing? Yes .... No. ....

If yes, which crops, when and why?

Current Crop	Previous Crop	Year of Change	Reason

Is your cropping system the <u>same</u> each year or do you <u>rotate</u> crops? In which season and why?

	Premonsoon	Monsoon	Winter

Khet ....

Bari ....

What is the biggest problem preventing you from increasing your yield per ropani? (one only)

Food and Income

Does the land that you farm generate enough food and income to meet your family's basic needs?

Yes .... No ....

Do you sell any of your crops? Yes .... No ....

If yes, which crops, what amount is sold, at what price, in which season (Premonsoon, Monsoon, Winter) and how long have you been selling each crop?

Crop	**Sold** (per year)	**Price**		**Season**	**# Years**
	kg	rupees	per unit	Sold	Sold
Rice				P M W	
Wheat				P M W	
Maize				P M W	
Potato				P M W	
Tomato				P M W	
				P M W	

Do you buy additional food for your family members? Yes ...... No ......

If yes, what food do you buy, how much (per year) and at what cost?

Food	**Bought** (per year)		**Cost**	
Type	Amount	Unit	Rupees	per unit
Rice				
Wheat				
Maize				
Potato				
Salt				

Are there any other crop that you have considered growing? Why are you not growing these crops?

Pesticides

Do you apply any pesticides, herbicides or insecticides? Yes .... No ....

What type do you apply, to which crops, how much and at what cost?

Crop	**Pesticide**	**Diseases**	**Quantity**
Rice	Malathion		
	Dithane M45		
	Metacide		
	Fen Fen		
	Nuvan		
Wheat			
Maize	Furadol		
	Fen Fen		
Potato	Dithane M45		
	Fen Fen		
	Nuvan		
Mustard	Dithane M45		
	Fen Fen		
Tomato	Dithane M45		
	Fen Fen		
	Nuvan		

Trees

What type of trees do you currently have on your farm? How many of each type? Compared to 5 years ago has the number of trees increased or decreased? By how many?

Type of Tree	**Number Now**	**# 5 years ago**
Fodder	a Kutimiro..... b Gayo..... b Bakaino.... d Kabro...... e Koeralo...... f Tanki.... g Timilo...... h Gogan.....	a...... b...... c..... d....... e...... f....... g..... h.......
Fuelwood		
Fruit	a Mango..... b Lichhi..... c Anar........ d Guava....... e Banana..... f Aaru...... g Lemon...... h Nibuwa.....	a.......b.......c.......d...... e.......f........g.......h......
Timber		

Forest Products

Who goes to the forest to collect fuelwood, fodder and litter (e.g. daughter in law and mother)? How often? How long does the entire trip take?

Product	**Person**	**Frequency** (per week)	**Amount** (kg)	Easy or Difficult **5 years ago**	**Season**	**Time/ Trip** (hours)	**Location**
Fuelwood					P M W		
Fodder					P M W		
Litter					P M W		

Compost

What type and amount of forest litter do you incorporate in compost?
Is litter collection easier, the same or more difficult than 5 years ago? What type of litter do you prefer?

Litter Type	**Amount** (%)	Easy or Difficult **5 years ago**	**Comments** (Preferred litter type)
Sal			
Katus			
Kangiyo			
Pine Sallo			
Pithauli			

Livestock

What animals do you own now? How many?
Have your livestock numbers increased or decreased compared to 5 years ago? By how many?

Animal	**Number Now**	**# 5 years ago**
Cattle - Bull		
Cattle - Cow		
Cattle - Calf		
Buffalo - Bull		
Buffalo - Female		
Buffalo - Calf		
Goat		
Pig		
Chicken		
Duck		
Total		

Fodder

Are there fodder shortages? Yes .... No ....

When? Premonsoon .... Monsoon .... Winter ....

What are the sources of fodder that you feed your livestock through out the year?
Compared to 5 years ago is collection easier now, the same or more difficult?

Fodder	**Source** (%)	Easy or Difficult **5 years ago**
Crop Residues		
Terrace Risers		
Your own Trees		
Buying Fodder		
Forest		
Concentrated Feed		
Total	100 %	

Milk

How many animals do you milk?
How much milk is produced in the monsoon (6 months) and in the dry season (6 months)?
What is the fat content of the milk produced?
How much milk do you consume? How much milk do you sell and at what price?

Animal	#	**Milk Produced**		**Fat Content**		**Price**	Production	**Consumed**	**Sold**
		Monsoon (litres/d)	Winter (litres/d)	Monsoon (/litre)	Winter (/litre)	(/litre)	**5 yrs ago**	(%)	(%)
Cow									
Buffalo									
Goat									

Energy

What are the sources of fuel that you use through out the year?
Compared to 5 years ago is collection easier now, the same or more difficult?

Fuel Source	**Fuel Sufficiency** By Months	Easy or Difficult **5 Years ago**
Crop Residues		
Your Own Trees		
Forest		
Kerosene		
Buying Fuelwood		

Is there enough fuel for your household? Yes......No ......

If yes, It is Excess.........Sufficient.........Barely Enough.........

Have you considered any alternative source of fuel? Why are you not using them?

A.3 Balawa Socio-Economic Questionnaire - Women Farmers

Area ______________________ Village ________________________

Ward No. __________ Household No. (same as George's) ______

Farmer's Name __________________________ Years Lived Here ______

Position in Household ______________________ Age ________

Caste / Ethnic Group ______________________

1. How many people live in this household? How many years of schooling has each person completed?

	How Many	Years of Schooling														Remarks
		1	2	3	4	5	6	7	8	9	10	SLC	IA	BA	MA	If no schooling, why?
Girls																
Boys																
Women																
Men																

TOTAL: __________

(girls / boys: under 16 years old) (women / men: 16 years and older)

2. Does your household sell any cottage industry products?
   No _______ Yes ________ → What Products?

   Price? Quantity?

   Where are the products sold? Market for the raw materials?

3. Do any household members work for wages or outside income?
   No _______ Yes ________ → Who? Gender?

   Proportion of time?

   What type of work?

   Wages / income? (Rs./day)

4. Which household members carry out the following activities?
(M = man W = woman B = both M & W C = child * = hired labourer)

Land Preparation
ploughing
terrace repair
irrigation

Fertilising
gathering forest litter / manure
composting
applying compost / organic fertiliser
applying chemical fertiliser

Planting
deciding what to plant
nursery
transplanting
throwing seed

Harvesting
cutting
threshing

Livestock Care
gathering fodder
grazing
stall feeding
Dhana making
watering
milking

Household Care
gathering fuelwood
fetching water
keeping household money
deciding what to buy
deciding what to sell

Farm Management Activities
management of farm labourers
purchasing seeds
purchasing chemical fertiliser
purchasing livestock
storage

5. What animals are kept by this household? How many?
_____Cows M
_____Cows F
_____Cows Y
_____Bullocks A
_____Bullocks Y
_____Buffalo M
_____Buffalo F
_____Buffalo Y
_____Goats M
_____Goats F
_____Goats Y
_____Sheep
_____Pigs
_____Chickens
_____Other

(M = male F = female Y = young A = adult)
Are any of these animals not owned by you?
(indicate with a * next to the number NOT owned e.g.) 4 Cows F *2)

6. Compared to five years ago, have your livestock numbers changed?
No____________ Yes _____________ → More or less animals now?

By how many? Why?

7. Are your animals mainly stall-fed (S) or grazed (G)?
during the dry season ___________ during the wet season ___________

8. Compared to five years ago, has the availability of grazing areas for your animals changed?
No____________ Yes _____________ → More or less areas now?

Why?

9. When your animals are stall-fed, what do you feed them during the different seasons?

Type	% of Total	Season (circle)
Crop Residue		PMW
Grass		PMW
Dana		PMW
Tree Fodder		PMW
Buying Fodder		PMW
Other		PMW
TOTAL	100%	

10. Compared to five years ago, has the availability of grass and fodder changed?
No ____________ Yes ___________→ More or less now?

Why?

11. What kinds of tree/shrubs do you use for fodder? Distance from your house? Which ones do you prefer to use for fodder (indicate with ranking of 1,2,3...) Why do you prefer these fodder trees/shrubs?

Name of Tree / Shrub	**Distance** (hours walking)	**Rank**	**Why preferred**

12. Do you think your animals are currently getting enough to eat?
Yes _______ No __________→ What solution do you suggest?

13. Compared to five years ago, has the amount of organic fertiliser you put on your fields changed?
No ________ Yes ___________→ More or less organic fertiliser now?

How much?

Why?

14. What type of fuel does your household use? Where is the fuel from?
    If the fuel is purchased, what is the price?

Fuel Type	**% of Total** (100%)	**Source (%)**			
		Own Land	**Forest**	**Purchased**	**Price**
cut wood					
small branches					
crop residues					
manure					
banmara					
kerosene					
other					

15. Compared to five years ago, has the availability of fuel in this are changed?
    No ___________ Yes _______ → More or less fuel now?

    Why?

16. If you had some extra money, what would you do?

17. What are the biggest problems in your personal life, on the farm and in your village?

    personal life

    farm

    village

Farmer quotes and remarks:

A.4 Balawa Socio-Economic Questionnaire - Men Farmers

Area ______________________ Village ________________________

Ward No. __________ Household No. (same as George's) ______

Farmer's Name __________________________ Years Lived Here ______

Position in Household ______________________ Age ________

Caste / Ethnic Group ______________________

1. What type of khet land do you farm? What crops do you grow on each type? How many ropani of each?

Khet Type	Pre-monsoon Crop	Monsoon Crop	Winter Crop	# of ropani

Total ropani ___________

2. What type of bari land do you farm? What crops do you grow on each type? How many ropani of each?

Bari Type	Pre-monsoon Crop	Monsoon Crop	Winter Crop	# of ropani

Total ropani ___________

3. Which of the above crops do you grow on share cropped land? (circle crops)

4. Do you share crop out any land?
   No _______ Yes _________ → How many ropani? Khet _______ Bari __________

5. If you use share cropping (either in or out), what are the arrangements?
   What % of the output do you keep? ________%
   Do you buy the seeds and fertiliser? Yes ______ No ________

6. If you do not use sharecropping, what are the reasons?

7. Why did you choose this mix of crops?

8. Is your cropping system the same each year?
   Yes _______ No _______→ Why do you rotate crops?

9. Are there any other crops you have considered growing? What are they and what are their advantages? Why aren't you growing these crops?

10. What type of commercial fertiliser do you use on your khet and bari land?

Type	**Khet**	**Bari**
Complex		
Urea		
Ammonium Sulphate		
Other		
None		

11. When buying chemical fertiliser do you have difficulty in:
    - Getting the right type Yes _____ No _____
    - Getting it at the right time Yes _____ No _____
    - Being able to pay for it Yes _____ No _____

12. Compared to five years ago, has the amount of commercial fertiliser you put on your fields changed?
    No _______ Yes _______---> More or less commercial fertiliser now?

    How much?

    Why?

13. What are the biggest limitations (constraints) to increasing your yields?

14. What do you sell from your farm and at what price? (e.g. crops, livestock, milk, fruit, vegetables etc.)

Products	Quantities	Prices

15. Does your farm generate enough income to support your family?
Yes _____ No _____→ Explain:

16. Do you work for wages or outside income?
No_____ Yes _____→ What type of work?

Proportion of time?

Wages/income?

Where?

17. What type of trees do you have on your own land?

Type	Nepali Name	Number of Trees
Fodder		
Fuelwood		
Timber		

18. Compared to five years ago, has the number of trees on your land changed?
    No _____ Yes_____→ More or less now?

    Number of trees different?

    Source of seedlings?

19. If you had some extra money, what would you do?

20. What are the biggest problems in your personal life, on the farm and in your village?

    personal life

    farm

    village

Farmer quotes and remarks:

A.5 Bela-Bhimsenthan Key Informant Questionnaire

Area ______________________ Village ________________ Ward No.__________

Farmer's Name ______________________________ Age _________

Caste/Ethnic Group ____________ Years Lived Here _____

1. Critical Problems

What could be done to improve the situation in your region? (prioritise)

1.

2.

3.

General Comments:

2. Cropping Pattern

What are the common cropping patterns in this region?

Khet land

Bari land

What were the common cropping patterns 5 years ago?

Khet land

Bari land

2. Yields

Overall are yields increasing, decreasing or staying about the same within this region?

What are average yields, fertiliser use, and labour requirements for commonly grown crops in the region?

5 years ago were yields and fertiliser use less, the same, or more than now?

Khet Land Crops	Average Yield		Typical Fertiliser Use			Ave. Labour
	per ropani	5 yrs ago	type	amount	5 yrs ago	days per crop
pre-monsoon rice						
pre-monsoon maize						
monsoon rice						
potatoes						
wheat						
tomatoes						
mustard / tori						
others						

Bari Land Crops	Average Yield		Typical Fertiliser Use			Ave. Labour
	per ropani	5 yrs ago	type	amount	5 yrs ago	days per crop
maize						
wheat						
mustard / tori						
millet						
beans						
tomatoes						
potatoes						
others						

3. Market Oriented Production

Within this region, what is the relative importance of market oriented production compared to the production of crops for consumption?

Typically, what % of the crops grown is consumed and what % is sold?

5 years ago was the % sold more, the same or less than now?

Crops Grown	% Consumed	% Sold	5 yrs ago
rice			
wheat			
maize			
potatoes			
tomatoes			
mustard			
others			

Typically, what % of the crops consumed is from the farm and what % is purchased?

5 years ago was the % bought more, the same or less than now?

Crops Grown	% From Farm	% Bought	5 yrs ago
rice			
wheat			
maize			
potatoes			
tomatoes			
mustard			
others			

4. Water Availability

Overall is water availability a major production constraint in the region?

Within this region describe water shortages for the common crops.

5 years ago were there less water shortages, the same or more water shortages?

Crop	Water Shortages			5 yrs ago
	yes / no	when PMW	how long (days)	less, same, more
rice				
maize				
potatoes				
tomatoes				
others...				

5. Population

Of the new houses built in the region in the last 5 years, what % are local residents versus families from outside the region? __________% local __________% from outside

Where did the families moving into the region come from? (e.g. Kathmandu, Dhulikhel, Panchkhal etc.)

6. Land Ownership

For the families immigrating to the region (last 5 years) what type of land did they purchase?

Land Type	% of new families
mostly khet	
mostly bari	
mixed khet and bari	
degraded	
other...	
total	100%

What % of the farms are absentee land owners? __________%

What % of the absentee land owners have purchased land in the last 5 years? __________%

APPENDIX B. SUPPLEMENTAL DATA

Table B.1 Nutrient uptake by rice.

Yield	Component	Nitrogen N		Phosphorus P_2O_5		K_2O		Ca		Mg		Reference
kg ha^{-1}		kg ha^{-1}	(%)	kg ha^{-1}	(%)	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%	
2500	grain											Carson 1992
	whole plant	30	0.5	15	0.3	45						
1323	grain											Suwal et al. 1991
	whole plant	54	1.8	7	0.2	74						
1500	grain											LRMP 1986b
	whole plant	42	1.2	18	0.5	29						
5040	rough rice	67		27		13		4		6		U.S. Borax, 1979
6720	straw	40		13		90		12		7		
	whole plant	107	0.9	40	0.3	103	0.9	16	0.1	13	0.1	
3360	grain											Landon 1984
	whole plant	54	0.7	60	0.8	46	0.6					
1500	grain	35		16		12		1.4		0.3		Sanchez 1976
1500	straw	7		2		22		2.6		2.2		
3000	whole plant	42	1.4	18	0.6	34	1.1	4.0	0.1	2.5	0.1	
7900	grain	85										Olson and Kurtz 1982
10000	straw	40										
	whole plant	125	0.7									
9800	rough rice		1.5		0.6		0.3		<0.1		0.1	DeDatta and Mikkelsen 1985
8300	straw		0.9		0.1		2.8		0.3		0.2	
	whole plant		1.2		0.4		1.4		0.2		0.1	
2430	rough rice	23		12		12		1		3		Grist 1986
4930	straw	22		11		52		10		3		
	whole plant	45	0.6	23	0.3	64	0.8	11	0.1	6	0.1	
4030	rough rice	56		23		11		3		4		Foth 1990
5600	straw	34		13		78		10		6		
	whole plant	90	0.9	36	0.4	89	0.9	13	0.1	10	0.1	
ave.	**whole plant**		**1.0**		**0.4**		**1.0**		**0.1**		**0.1**	

Table B.2 Nutrient uptake by maize.

Yield	Component	Nitrogen N		Phosphorus P_2O_5		K_2O		Ca		Mg		Reference
kg ha^{-1}		kg ha^{-1}	(%)	kg ha^{-1}	(%)	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%	
1600	grain											Carson 1992
	whole plant	75	2.1	25	0.7	50						
1560	grain											Suwal et al. 1991
	whole plant	53	1.5	23	0.7	12						
6270	cob											Landon 1984
	whole plant	165	1.2	55	0.4	135						
11760	cob	151		60		44		17		25		U.S. Borax 1979
10080	stover	113		40		161		30		20		
	whole plant	264	1.2	100	0.5	205	0.9	47	0.2	45	0.2	
1000	grain	25		14		18		3.0		2.0		Sanchez 1976
1500	stover	15		7		22		4.5		3.0		
2500	whole plant	40	1.6	21	0.8	40	1.6	7.5	0.3	5.0	0.2	
6272	grain	109		49								Western Canadian Fertilizer Association 1992
	stover	63		21								
	whole plant	171	1.2	71	0.5	31						
5000	cob			34								Hanway and Olson 1980
	stover			13								
	whole plant			47	0.4							
10000	grain											Olson 1978
	dry matter	170	0.8	75	0.3	210	0.9	40	0.2	45	0.2	
	grain	129		71		47		1		11		Olson and Sander 1988
	stover	62		18		188		39		33		
9450	dry matter	191	2.0	89	0.9	205	2.5	40	0.4	44	0.5	
9400	grain	151		59								Foth 1978
10080	stover	112		41								
	whole plant	263	1.4	100	0.5							
9000	dry matter	115	1.3									Russelle et al. 1983
8400	grain											Miller and Donahue 1900
	whole plant	246	1.3	90	0.5	218	1.1	65	0.3	56	0.3	
ave.	**whole plant**		**1.4**		**0.6**		**1.4**		**0.3**		**0.3**	

Table B.3 Nutrient uptake by wheat.

Yield	Component	Nitrogen N		Phosphorus P_2O_5		K2O		Ca		Mg		Reference
kg ha^{-1}		kg ha^{-1}	(%)	kg ha^{-1}	(%)	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%	
1415	grain											Carson 1992
	whole plant	30	1.0	15	0.5	30	1.0					
2310	grain											Suwal et al. 1991
	whole plant	54	1.1	23	0.4	32	0.6					
4804	whole plant	64	1.3	11	0.2	28	0.6					Sherchan et al. 1991
1675	grain											Sherchan et al. 1995
	whole plant	45		10		20	0.5					
2425	grain											LRMP 1986b
	grain + straw	42	0.8	8	0.1							
1675	grain											Landon 1984
	whole plant	54	1.5	26	0.7	13	0.3					
600	grain	12		5		3		0.3		1.0		Sanchez 1976
1000	straw	3		1		17		2.0		2.0		
1600	whole plant	15	0.9	6	0.4	20	1.2	2.3	0.1	3.0	0.2	
3360	grain	58		29								Western Canadian Fertilizer Association 1992
	straw	17		6								
	whole plant	75	1.0	35	0.5	19						
5000	grain											Olson 1978
	whole plant	110	1.0	50	0.5	70	0.6	15	0.1	20	0.2	
7300	grain											Halvorson et al. 1987
	whole plant	176	1.1	47	0.3	133	1.8					
4030	grain											Miller and Donahue 1990
	whole plant	140	1.6	56	0.6	123	1.4	18	0.2	20	0.2	
3600	grain	84		43		26		2		10		U.S. Borax 1979
4500	straw	34		9		59		10		6		
	whole plant	118	1.5	52	0.6	85	1.0	12	0.1	16	0.2	
2690	grain	56		28		17		1		7		Foth 1990
3360	straw	22		8		39		7		3		
	whole plant	78	1.3	36	0.6	56	0.9	8	0.1	10	0.2	
ave.	**whole plant**		**1.2**		**0.5**		**0.9**		**0.1**		**0.2**	

Table B.4 Nutrient uptake by cash crops.

Crop	Yield		Nutrient Uptake (kg ha^{-1}) for whole plant					Source
	kg ha^{-1}	component	N	P_2O_5	K_2O	Ca	Mg	
tomato	5000	fruit	15	5	24	12	2	von Uexkull 1978
	10000	fruit	29	9	48	24	5	
	25000	fruit	73	23	120	59	11	
	27800	fruit	54	15	83			Splittstoesser 1990
	17920	fruit	134	45	179	8	12	U.S. Borax 1979
	30000	fruit	100-150	65-110	160-240			Landon 1984
		average	79	39	122	26	8	
potato	40000		200	75	270	20	25	Olson 1978
	44800	tubers	143	41	242			Western Canadian Fertiliser Assoc. 1992
	44,000	tubers	77	32	269	4	9	Sanchez 1976
	20000	tuber	68	29	98			Splittstoesser 1990
	26800	tuber	224	62	348	56	17	Miller and Donahue 1990
	50,000	tuber	180	50	240	10	15	Simpson 1986
	15000	tuber	52	10	71			Russell 1973
	24000	tuber	90	34	168	3	7	Foth 1990
	40300	tuber	134	50	252	6	10	U.S. Borax 1979
		average	130	43	218	17	14	
onion	21955	bulb	49	5	24			Splittstoesser 1990
	16800	bulb	50	23	44	12	2	Foth 1990
	36000	bulb	86					Broadbent 1978
	15000	bulb	60-100	25-45	45-80			Landon 1984
		average	69	24	48	12	2	

Table B.5. Nutrient uptake by tropical grasses.

Type		Dry matter	Nutrient Uptake (kg ha^{-1}) for whole plant										Source
Common Name	Scientific Name		N		P_2O_5		K_2O		Ca		Mg		
		(t ha^{-1})	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%	
Elephant, Napier	*Pennisetum purpureum*	10	107	1.1	62	0.6	434	4.3	78	0.8	49	0.5	Sanchez 1976
Elephant, Napier	*Pennisetum purpureum*	25	288	1.1	101	0.4	875	3.5	148	0.6	99	0.4	Sanchez 1976
Elephant, Napier	*Pennisetum purpureum*	28	338	1.2	165	0.6	678	2.4	107	0.4	71	0.3	Sanchez 1976
Pangola grass	*Digitara decumben*	10	120	1.2	50	0.5	432	4.3	36	0.4	28	0.3	Sanchez 1976
Pangola grass	*Digitara decumben*	23	299	1.3	108	0.5	859	3.7	106	0.5	67	0.3	Sanchez 1976
Pangola grass	*Digitara decumben*	26	335	1.3	121	0.5	481	1.9	122	0.5	75	0.3	Sanchez 1976
Guinea grass	*Panicum maximum*	10	107	1.1	62	0.6	434	4.3	78	0.8	49	0.5	Sanchez 1976
Guinea grass	*Panicum maximum*	23	288	1.3	101	0.4	875	3.8	149	0.6	99	0.4	Sanchez 1976
Guinea grass	*Panicum maximum*	25	322	1.3	115	0.5	487	1.9	167	0.7	110	0.3	Sanchez 1976
Para grass	*Panicum purpurascens*	8	80	1.0	39	0.5	386	4.8	28	0.4	16	0.2	Sanchez 1976
Para grass	*Panicum purpurascens*	24	307	1.3	98	0.4	923	3.8	115	0.5	79	0.3	Sanchez 1976
Stylo	*Stylosanthes humilis*	3		2.4		0.1							Humphreys 1987
Stylo	*Stylosanthes humilis*	5		2.7		0.1							Humphreys 1987
Stylo	*Stylosanthes humilis*			0.2		0.6							Humphreys 1987
Desmodium	*Desmodium intotum*					0.2		0.7					Humphreys 1987
Desmodium	*Desmodium uncinatum*					0.2		0.7					Humphreys 1987
Blue grass	*Poa pratensis*	2	60	3.0	21	1.0	60	3.0	16	0.8	7	0.4	Foth 1990
Bermuda grass	*Cynodon dactylon*	8	185	2.3	71	0.9	269	3.4	59	0.7	24	0.3	Foth 1990
Bermuda grass	*Cynodon dactylon*	6	150	2.5	60	1.0	180	3.0	33	0.6	22	0.4	Miller and Donahue 1990
average				1.5		0.5		3.1		0.6		0.4	

Table B.6. Nutrient content of compost and animal manure (% dry weight basis).

Nutrient Source	**N (%)**	**P_2O_5 (%)**	**K_2O (%)**	**Ca (%)**	**Mg (%)**	**Source**
Middle Mountains						
Traditional Compost	0.6	0.06	0.6			Suwal et al. 1991
Pit Compost	1.1	0.11	1.4			Suwal et al. 1991
Farm Yard Manure	0.5	0.2	1.2			Sherchan and Gurung 1995
Maize stubble + 10% dung	0.7	0.01	1.1			Suwal et al. 1991
60% FYM + soyabean, maize stubble	0.9	0.11	1.5			Suwal et al. 1991
General						
Dairy Manure	0.7	0.2	0.5			Landon 1984
Dairy Manure	3	0.4	2	1.3	0.3	Sommers and Sutton 1980
Cattle Dung (India)	0.4	0.2	0.3			Suwal et al. 1991
Cattle Dung (India)	1.7	1.7	0.6	0.4	0.5	Jain and Kumar 1995
Cattle Manure	2.3	0.9	0.7	2.0	0.6	Kirchmann 1994
Cattle Manure	0.6	0.3	0.5	0.8	0.2	Simpson 1986
Beef / Dairy Manure	2	0.5	1.2		1	Miller and Donahue 1990
Beef Manure	2	0.5	2	0.6	0.4	Sommers and Sutton 1980
Beef Manure + bedding	1.0	0.9	1.3	0.8	0.4	Follett et al. 1981
Poultry Manure (India)	2.2	2.0	4.2	2.3	1.4	Jain and Kumar 1995
Poultry Manure	1.6	1.1	0.8			Landon 1984
Poultry Manure	5.1	1.9	1.8	6.7	0.6	Kirchmann 1994
Poultry Manure	5	2	1.2		2.4	Miller and Donahue 1990
Poultry Manure	1.6	0.9	0.5	3.7	0.3	Follett et al. 1981
Pig Manure (India)	2.2	2.0	4.2	2.3	1.4	Jain and Kumar 1995
Goat Manure (India)	0.6	0.5	0.03			Jain and Kumar 1995
Goat Manure	2.8	1.4	2.4			Landon 1984
average for Cattle	**1.5**	**0.6**	**1.3**	**1.0**	**0.5**	

Table B.7. Nutrient content of litter.

Nutrient	Litter Composition	
	g/kg	%
N	9.6	1.0
P_2O_5	2.06	0.2
K_2O	6.6	0.7
Ca	13.9	1.4
Mg	3.1	0.3

source: Schmidt 1992

Table B.8. Nutrient inputs from organic and chemical fertiliser sources.

System	n	Mean Organic Matter Inputs[1]			Mean Chemical Fertiliser Inputs[1]		
		Application (kg/ha)	N Input (kg/ha)	P_2O_5 Input (kg/ha)	Application (kg/ha)	N Input (kg/ha)	P_2O_5 Input (kg/ha)
premonsoon							
early rice (khet)	5	2290	14	1	480	145	45
early maize (khet)	12	3686	22	2	202	60	35
monsoon							
rice (khet)	49	5555	33	3	301	109	45
maize (bari)	65	16389	98	10	214	80	38
winter							
wheat (khet/bari)	51	977	6	1	137	42	25
wheat (khet)	30	1662	10	1	153	48	30
wheat(bari)	21	0	0	0	112	33	20

[1] source: 200 site soil survey, male farmers

Table B.9. Variable Costs - Seed

Crop	Seed Rate[1]		Price[1]	
	per ropani	kg/rop.	Rs/kg	$/kg
Khet				
rice	1 pathi	2.4	12	0.28
wheat	3 pathi	10.5	9	0.21
tomato	0.25 mana	0.25	450	10.83
potato	6 dharni	14.0	28	0.67
maize	5 mana	2.5	16	0.39
mustard	2 mana	1.0	16	0.39
Bari				
maize	3 mana	1.5	16	0.39
wheat	1.5 pathi	5.2	9	0.21
tomato	0.25 mana	0.25	450	10.83
potato	8 dharni	18.0	28	0.67
mustard	2 mana	1.0	16	0.39
barley	1.5 pathi	5.2	9	0.21
niger	2 mana	5.2	12	0.29

[1] Source: MRM 1996

Table B.10. Variable Costs - Fertiliser

Fertiliser Type			Unit[1] (kg)	Price[1] (Rs)	Price ($/kg)
Urea		46 - 0 - 0	50	400	9.6
Complex	(Gede)	20 - 20 - 0	50	850	20.5
Ammonium Sulphate	(Chimi)	21 - 0 - 0	50	400	9.6
Di-Ammonium Phosphate	(DAP)	20 - 46 - 0	50	850	20.5
Triple Super Phosphate	(TSP)	0 - 46 - 0	50	425	10.2

[1] Source: MRM 1996

Table B.11. Variable Costs - Pesticides

Pesticide Type		**Unit**[1] (kg)	**Price**[1] (Rs)	**Price** ($)
Dithane M45	(mancozeb)	500 g pack	175	8.42
Fenvalerate	(fen fen)	100 ml bottle	80	1.92
Parathion methyl	(metacide)	100 ml bottle	75	1.81
Dichlorvos	(nuvan)	100 ml bottle	70	1.68
Malathion	(cythion)	100 ml bottle	38	0.91
Edifenphos	(hinosan)	100 ml bottle	150	3.61
Deltamethrin	(decis)	100 ml bottle	115	2.77
Phorate	(thimet)	kg	85	2.05
Carbofuran	(f uradane)	kg	85	2.05
BHC dust	(kanpure)	50 kg	350	8.42

[1] Source: MRM 1996

Table B.12. Variable Costs - Labour

Crop	**Labour Rate**[1] (days/ ropani)	**Price** ($/ropani)
rice	15	18
wheat	8	10
tomato	30	36
potato	15	18
maize	10	12

[1] Source: Kennedy and Dunlop 1989, Srivastava 1996