Module 3.3

# Resource Dynamics: Complex Problems, Complex Solutions

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## Objectives

- To describe and discuss the methodology used by ICIMOD in its natural resource management projects
- To share the experiences gained and lessons learned in identifying the problems and the various efforts made for solving them

## What are the major findings of the project?

A multi-media CD-ROM entitled *Complex problems-complex options: preservation, degradation and rehabilitation in a Nepalese watershed* was produced as part of the 1997 Annual Report. The People and Resources' Dynamics Project (PARDYP) grew out of the Mountain Natural Resources' Management Project (formerly Jhikhu *Khola* Watershed Project).

The main goal of the Jhikhu *Khola* Watershed Project was to quantify the status and changes in the water, soil, agricultural and forest resources in the watershed over the past 20 years and to determine the socioeconomic conditions and dynamics that shape the lives of the inhabitants. The integration of socioeconomic conditions with biophysical conditions was of key importance and a special effort was made to link soil fertility and degradation with gender and socioeconomic conditions.

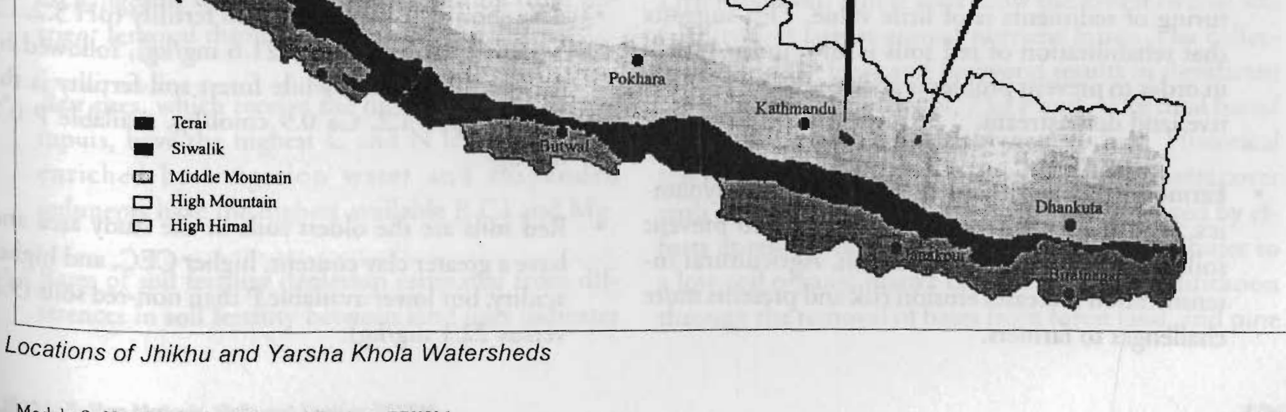
The main findings in the Jhikhu *Khola* Watershed covered research activities between 1989 and 1997 and are summarised below.

## How is rainfall, erosion and sediment transport affected?

Rainfall, erosion and sediment transport are key issues to consider when determining resource management and sustainable farming in mountain environments. The research findings over the past years are as given in the following passages.

*Rainfall*

- There are on average 77 storms annually, of which 3.5 per cent have a peak 10-min rainfall intensity of




*Locations of Jhikhu and Yarsha Khola Watersheds*

>50 mm, a critical level for erosivity. About one third of all storms occur during the pre-monsoon season.

- Total rainfall during the monsoon represents about 70 per cent of the annual total.

- Most of the rainfall delivery is highly variable and local rather than regional-pattern dominated.

*Erosion*

- Annual losses were highly variable ranging between 0.1 and 40 t/ha/yr on rainfed agricultural sites.

- Pre-monsoon losses were over one order of magnitude greater than monsoon losses and were attributed to a lack of vegetative cover during the pre-monsoon period. Unfortunate timing of cultivation during the pre-monsoon results in the greatest losses, and farmers have little warning or predictive power to prevent such events. Planting a cover crop that can survive the dry season is one of the options considered to reduce the erosion risk during this period.

*Sediment properties and behavior*

- Silt and clay is dominant in sediment yield during the premonsoon season, and silt and fine sand are dominant during the monsoon season.

- Because of differences in parent materials, soil age and weathering intensity, red soils produce sediments with significantly lower nutrient content than non-red soils (particularly phosphorus and calcium). Since red soils only occur below 1,700m, sediment colour and associated P content can be used as a fingerprint trace to determine the origin of storm-source materials and possible nutrient benefits derived from recapturing sediments.

- Red soils are more difficult to manage and once such sites are degraded sediment production is high (significantly higher than on *bari* land) (dryland cultivation), downstream impacts are large and re-capturing of sediments is of little value. This suggests that rehabilitation of red soils is an important task in order to prevent problems affecting more productive land downstream.

- Farmers have a profound effect on sediment dynamics. Management practices are designed to prevent soil loss and sediment production. Agricultural intensification increases erosion risk and presents more challenges to farmers.

- Sediment yield is highly dependent on season, scale and land use. Of the total annual sediment production, 30 per cent is recaptured on *bari* and *khet* (irrigated rice field) fields. In larger watersheds, up to 60 per cent of sediment is put into long-term storage within the basin.

- Average annual sediment yield was found to be in the range of 10-20 t/ha/yr at all basin scales investigated (75-11,000 ha), and degraded land produces sediments in direct proportion to the total event rainfall independent of season and scale.

- Individual events were most damaging on the field or terrace scale and declined rapidly as scale increased.

**What are the soil fertility status and dynamics?**

Overall soil fertility conditions were examined over the past five years using four different survey methods: soil mapping evaluation covering the entire watershed; soil comparison between forest and upland agriculture in the headwater area; detailed soil fertility analysis in the subwatershed to identify the key factors that affect soil fertility declines; and selective soil analysis in long-term forestry monitoring plots (11 forests). Farmers were consulted in all surveys, but a special effort was made to relate farmers' inputs and experiences to soil fertility (200 sites were analysed), and information on inputs, yields, and constraints was obtained through farm interviews. The findings of these surveys are summarised in the following passages.

*Soil fertility status*

- The overall soil fertility conditions are poor. Soil carbon (0.99 ± 0.47% average), pH (4.8 ± 0.4) and available P (16.6 ± 18.9 mg/kg) are particularly problematic.

- Land use is the most important factor influencing soil fertility, followed by soil type, topography and micro-climatic conditions (elevation and aspect).

- *Khet* shows the best overall soil fertility (pH 5.2, Ca 5.3 cmol/kg, available P 21.6 mg/kg), followed by *bari* and rangeland, while forest soil fertility is the poorest (pH 4.2, Ca 0.9 cmol/kg, available P 0.7 mg/kg).

- Red soils are the oldest soils in the study area and have a greater clay content, higher CEC, and higher acidity, but lower available P than non-red soils (9.8 versus 22.1 mg/kg).

- A site-factor approach based on relationships between soil fertility and site characteristics facilitated extrapolation from point data to a spatial coverage and was useful for assessing the extent of soil fertility problems. The composite soil fertility map produced with GIS overlay techniques indicates that only 14 per cent 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 $P_2O_5$/kg soil for the 16 red-soil sites. Phosphate sorption calculated using Borggaard's model, which includes AAC extractable Fe and Al and CBD extractable Fe, showed good agreement ( .. =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 phosphorus sorption map was developed using GIS techniques and a site-factor approach. The results indicate that 29 per cent of the area has very high P-fixation capacity (>1.5 g/kg) and 61 per cent has a P fixation capacity >0.5 kg. 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.

*Soil fertility dynamics*

- The direction and rate of change of soil fertility influence 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* subject to intensive cultivation.

- Fertility characteristics of soils originating from the same parent material but subject to different land uses show that sites have the lowest N, available P, exchangeable Ca 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, and *khet* enriched by irrigation water and suspended sediments have the highest available P, Ca and Mg.

- Rates of soil fertility depletion estimated from differences in soil fertility between land uses indicates substantial N and Ca losses from forest land (94 and 57 kg/ha furrow slice respectively). Annual losses from *bari* are small due to additional inputs from organic sources suggesting that losses from agriculture are strong and are influenced by management.

- Nutrient budget modelling of N, P and Ca levels for the dominant crops and cropping patterns was 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 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 pre-monsoon maize in the rotation results in deficits of 106 kg N and 12 kg $P_2O_5$ /ha furrow slice.

- The collection of forest biomass results in annual nutrient losses of 56 kg N/ha, 16 kg $P_2O_5$/ha and 34 kg Ca/ha, which are comparable to nutrient depletion determined from plot studies. Biomass removal from rangelands results in nutrient losses roughly estimated at 60 kg N/ha, 20 kg $P_2O_5$/ha, and 20 kg Ca/ha while soil erosion on degraded range and shrublands results in comparable losses (34 kg N and 23 kg Ca /ha furrow slice).

## What are the key management factors and options?

Land-use change and soil-nutrient budget modelling are useful for assessing the impact of management factors on soil fertility and identifying management options that may reduce nutrient deficits. Data on soil inputs, yields, labour allocation and management practices were obtained by interviews and participatory surveys. Key factors influencing soil fertility degradation include forest litter removal, agricultural marginalisation, erosion and agricultural intensification.

*Key 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) and disrupts natural nutrient cycling. Historical forest cover data suggest a cyclical decline in forest cover with at least two cycles of deforestation followed by efforts at 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 to be acidifying cultivated land.

**Marginalisation:** The nutrient status on *bari* 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 on to former range-, 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* and degraded lands result in substantial nutrient transfer to lowland agricultural fields. Erosion on *bari* removes an average of 25 kg N and 13 kg Ca /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 from monsoon rains. Degraded shrub and rangelands (>50% soil exposure) cover 5 per cent of the study area and are a significant source of sediments, removing an estimated 34 kg Ca /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 causing N and $P_2O_5$ depletion ( 106 kg N and 12 kg $P_2O_5$ /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 have resulted in an increased dependence on agrochemicals, and water quality problems are associate with heavy fertilizer and pesticide use.

**Excess use of pesticides:** The introduction of high-yielding varieties of tomatoes and potatoes has resulted in the increased use of pesticides. The lack of extension services and appropriate education programmes are key reasons for the misuse of agrochemicals. The long-term health implications are severe and urgent action is needed to address the proper handling and use of these chemicals.

*Management options*

Potential options for reducing nutrient deficits include organic matter management, water management, lime, integrated nutrient management, *Azolla* and on-farm fodder production.

**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 micro-activity. Best management-practice and deficit-elimination scenarios identified improved composting as a practical option for improving nutrient budgets on *bari*. 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 per cent.

**Water management:** The diversion of stream floodwater through the irrigation system carries suspended sediments and nutrients on to *khet* fields. Sediments are enriched in Ca, P and C, and an average accumulation of 4 mm/yr supplies an additional 11 kg N and 28 kg Ca /ha furrow slice in addition to nutrient enrichment from sediment accumulation.

**Lime:** *Bari,* forest, shrub- and rangelands all have median pH values <5.0 and further acidification is a concern with the increasing use of chemical fertilizers on *bari* and biomass removal from forest, shrub- and rangelands. Calcium- and magnesium-based rocks provide a source of liming materials that are locally available in limestone and marble deposits. Rehabilitation studies with lime and manure have shown increased fodder production and a slight increase in soil pH.

**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 available nutrients gradually, 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.

**On-farm fodder production:** Eighty-five per cent 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 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 fuelwood and minimise the shading effect on agriculture.

**Extension service for fertilizer and pesticide use:** There is an urgent need for improved agricultural extension services. With the introduction of cash crops, new management techniques are needed and, without professional advice from agricultural staff, the indiscriminate use of fertilizers and pesticides is leading to water-quality problems (eutrophication and toxicity) that have long-term health consequences.

## What are the key socioeconomic factors and options?

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

**Population growth:** Up to 1995, population growth rates were estimated at about 2.6 per cent. However, recent analysis (1996 surveys based on aerial photo work) indicates that the rate is significantly higher in part due to immigration and natural growth. This is placing additional pressure on soil resources. The per capita availability of land had decreased to 0.17 ha, and double and triple crop rotations are applied in an attempt to meet the increased demand for food. Agricultural marginalisation in response to population pressure has brought steep slopes under cultivation and is indicative of continuing pressure on forest resources. Population growth is a dominant factor driving land-use dynamics and the increased demand for food, animal feed and fuelwood results in increased nutrient removal.

**Land tenure:** Land ownership varies dramatically with 15 per cent of the surveyed households owning 36 per cent of the agricultural land and 53 per cent of the households owning only 25 per cent with total holdings <1 ha per household. Share cropping is practised by approximately one third of the households, and 47 per cent 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 rangelands, 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 rangelands 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. Rich farmers typically own the most *khet* 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 buffaloes 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 commercialisation of milk production is dramatically increasing the workloads 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 are highly skewed. Livestock values are highly variable between households, and some 50 per cent of household livestock assets are accounted for by female buffaloes. 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 per cent of households have gross margins <US$ 70 /yr. Farmers sell a variety of crops, but only a small minority systematically produce for the market. Households with higher agricultural assets and gross returns apply more compost and fertilizer to both *khet* and *bari* and households with higher returns and milk sales appear to farm sites with better soil fertility conditions.

*Socioeconomic options*

Potential options for reducing socioeconomic pressure on resources include off-farm income, community forestry, cash cropping, and out-migration and population stabilisation.

**Off-farm income:** Off-farm activities provide cash income that may be used to purchase chemical fertilizer, thereby reducing nutrient deficiencies associated with intensive cultivation. However, male out-migration in pursuit of wage employment negatively impacts the household by increasing the workloads 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.

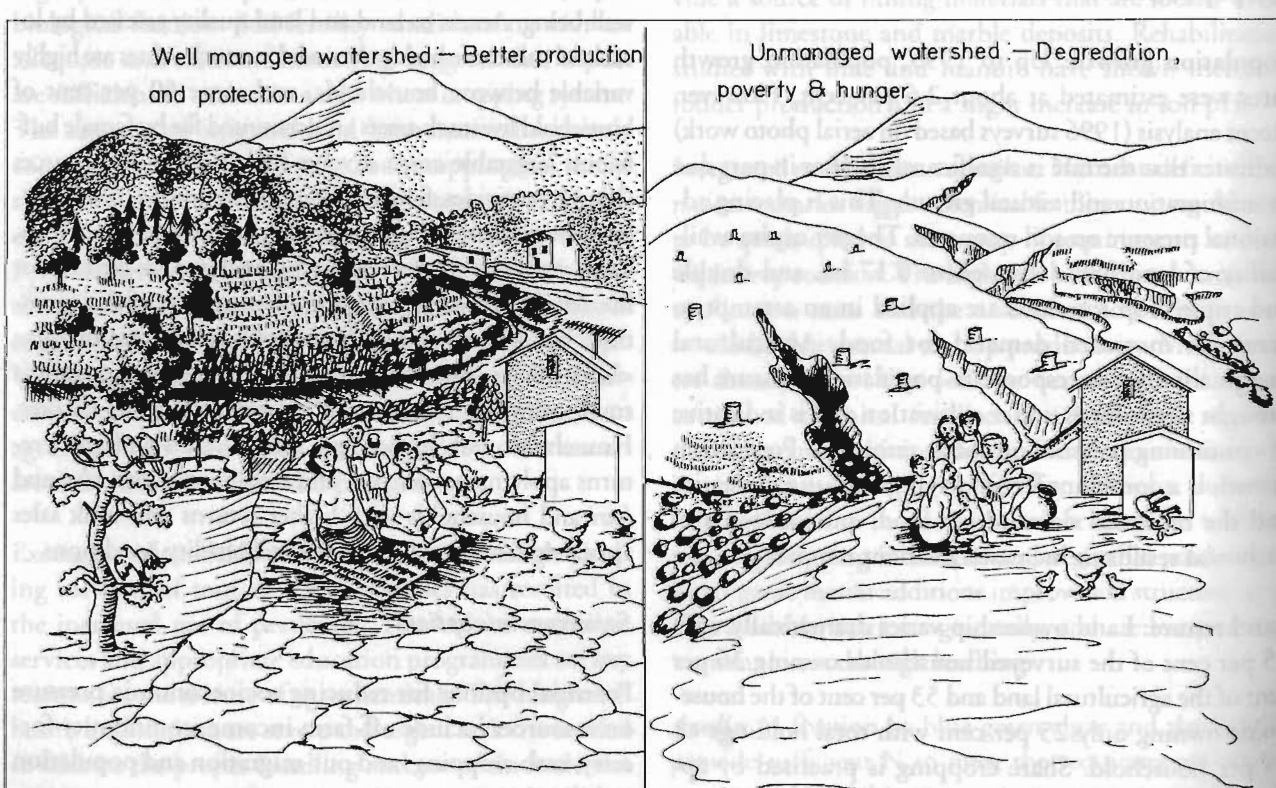
**Community forestry:** Community forestry initiatives have been successful in increasing biomass through restocking and restricted access, but long-term investments are required. Local farmers now have incentives to manage common forest land, but the necessary capital resources to initiate community forestry projects require outside subsidies.

**Cash cropping:** Market-oriented production provides a source of income that may be used to purchase commercial inputs. 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.

## Are traditional farming systems sustainable? What are the implications for future research?

Farms in Nepal need to be viewed as systems that integrate forest, livestock and cultivation activities. Biomass collected from forest, shrub- and rangelands 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 complex irrigation systems. Off-farm employment, cash-crop production and milk sales provide income to farm households that is partially used to purchase agrochemicals impacting on agriculture. Nutrient flows must be evaluated within and between components as nutrient fluxes are interlinked. Pressure on one component will impact on 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*, and compost was used to replace nutrients lost from *bari*. However, triple cropping and increased vegetable production are now threatening sustainability. Both require more fertilizer, pesticides, water and labour. As a result nutrients on *khet* are being depleted and *bari* 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 buffalo numbers to provide more manure, milk production 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 per cent of the farmers cannot provide for their families. They will have no choice but to take a short-term view and use the capital stock of soil nutrients rather than investing in soil fertility.

## Implications for future research

Understanding how resources are changing, and why, requires the integration of biological, physical and socioeconomic factors. Farmers' perceptions of soil fertility are useful in identifying past trends. However, given the nonlinear charactersitics 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 socioeconomic factors driving nutrient management. Household, farm and off-farm activities need to be viewed in terms of their interactions with natural and socioeconomic environments. More interdisciplinary efforts that seek to integrate our understanding of these subsystems are needed to fully comprehend resource issues in the Middle Mountains in Nepal.

For more information consult the CD-ROM.

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