Efficient Management of Natural Resources: A Way to Sustain Food Security in the Rainfed Sloping Lands of Northern Vietnam

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Abstract

Rainfed sloping lands occupy one-third area of northern Vietnam and are threatened with destruction of natural resource base due to improper land use practices. Current production practices are exacerbating soil loss and destruction of the natural habitat as the soils are deeply weathered, poor in nutrients, and highly vulnerable to erosion. These ecosystems have much lower carrying capacity and respond to crop intensification by rapid decline in productivity, even total collapse if not managed properly.

Remoteness and inaccessibility, low biological productivity, environmental degradation, disease and health problems, population increase, and lack of a development paradigm tailored to the special conditions are the key constraints for development. Sustainable farming on these lands in the perspective of a seriously deteriorated ecology and environment is not an easy task. Proper understanding of constraints and development of appropriate technologies with focus on soil, water, and nutrient management help optimize food production and combat resource degradation. Research and application of watershed based integrated natural resource management technologies offered excellent opportunities for crop diversification to meet market orientation, sustaining food production at higher levels, improving soil health, recharge of aquifers, and enhancing household incomes for better rural livelihoods in the sloping land ecoregions of northern Vietnam.

In Vietnam, uplands cover three-fourth of the territory and shelter one-third of the population (28 out of 84 million people) of the entire nation. The uplands are a fragile environment characterized by sloping lands that are prone to erosion, with low natural soil fertility and declining forest cover. They are currently threatened with ecological degradation, which is already severe in some areas. Substantial areas of cultivated land have been seriously affected by soil erosion and land degradation, resulting from improper land use practices. More than 11 million ha (33%) is barren land as a result of deforestation and inappropriate land use.

As increasing population expand to steeper, more fragile areas in the uplands, more catchments are affected by severe soil erosion, declining soil productivity, and environmental degradation. Watershed land degradation now poses a threat to the economies of Vietnam, and to the livelihoods of the ever-growing population that depend on these resources.

On-site soil loss reduces soil fertility in terms of chemical, physical, and biological degradation. These soil changes will in due course reduce crop yields and hence income and household food security. The off-site effects of soil erosion often have broader economic and environmental implications including sedimentation, flooding, and reduced water quality resulting in poor living conditions of the people.

The Integrated Watershed Development Program, a new paradigm for research, has been promoted under the Asian Development Bank (ADB)/International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) initiative since 1999 to address the above constraints. This program focuses on:

- Simultaneous development of land, water, and biomass resources in the light of the symbiotic relationship among them.

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- Integrated farming systems approach.
- Meeting food, fodder, and fuel requirements of the human and livestock population that depend on these resources.
- Ensuring environmental sustainability along with economic viability by promoting low-cost technologies.
- Improving land productivity by promoting improved agronomic practices and input use.
- Releasing population pressure on land by creating non-farm employment.
- Development of local institutions for future management through participatory approach.

The central thrust of our research is to enhance productivity of land and water resources on the basis of a scientifically defined watershed that connotes a geographical unit rather than economic administrative units (like household or village). It is also ensured that whole range of stakeholders, from land users to policy makers, are involved in the generation and promotion of improved land use practices.

The approach we have taken was to ensure maximum participation of farmers in planning and execution of all our activities. All the watershed interventions, viz., introduction of new crops and cropping systems, soil and water conservation, integrated nutrient management (INM), integrated pest management (IPM), etc. are thoroughly discussed and decided by the farmers. Researchers and extension workers aid in decision-making process and facilitate agreed activities by providing technical support.

Micro-watershed is used as a demonstration block for appreciating the benefits in terms of reduced runoff and soil loss through scientific measurements. Farmers in rest of the watershed are evaluating improved soil, water, and nutrient management options and cropping systems along with IPM and integrated disease management (IDM) for efficient use of natural resources and sustainable productivity gains. Studies on nutrient budgeting and response to micronutrients are being conducted with close cooperation and involvement of farmers.

The partnership research at the benchmark watershed was conducted under three sub-projects and the results are presented.

Sub-project 1: Socioeconomic Surveys

Purpose

Target the group of farmers for exchange of improved watershed natural resources management (NRM) technologies and monitor the impact of interventions made in the watershed.

Objectives

- Conduct surveys and enlist present practices.
- Quantify economic benefit and household income due to improved technologies.
- Assess adoption pattern and constraints to the adoption of watershed technologies.

Survey

Secondary data and survey of the target zone provide basis for the choice of representative “benchmark research location”. More detailed information on the benchmark area will be needed in order to define research priorities and can be collected by means of rapid rural appraisal (RRA) or participatory rural appraisal (PRA) by the on-farm research team. The survey consisting of direct observations and interviews bring to life the problems faced as well as the opportunities, which exist for improvement. The RRA or PRA survey technique is a good tool for developing the necessary insights into how integrated system operates. The technique lays increased emphasis on farmer participation in the collection and interpretation of information over the diagnostic surveys.

We conducted a socioeconomic survey using a schedule carved out from the schedules used by the Asian Grain Legumes On-farm Research (AGLOR) and the Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), India. The survey covered the watershed as a whole for general description of macro-economics, population, infrastructure, institutions, and other aspects. But most of the work concentrated at village and household levels. The main areas covered were:

- Demography, manpower, skills, and education.
- Rural sociology with emphasis on traditions and values, constraints to development, land tenure, participation, power structure, and leadership.

- Agro-economy: commodities, yields, farming systems, inputs, technology, income, and cash flow.
- Household survey of selected target groups.
- Institutions and basic social services.

Information on physical (rainfall, temperature, solar radiation, topography, and soil) and biological (natural vegetation, pests, and diseases) elements were obtained to determine what crops can be grown in an area, given a suitable human environment (economic, institutional, and social elements). A checklist to keep track of the topics for discussion and exploration was developed. For recording physical information on individual fields, a simple data sheet was used.

Natural and socioeconomic conditions

Out of 1522 ha, although 53% area is suitable for agricultural purposes only 28% is being cultivated. Again most of these lands were brought recently under arable cropping. The average family size is small with 58% of the population in the age group of 17 to 55 years. Since majority of the population is young and engaged in agricultural production, adoption of labor-intensive new production technologies and farming systems should not pose any problem.

Cropping patterns and land use

Major crops in terms of cropped area are maize (83%), sugarcane (8%), legumes (13%), and watermelon (6%). Groundnut was grown in the past but is not cultivated now due to severe problem of pod rot. Cereal monocropping (maize-maize) is predominant and occupies 77% of the cultivated area followed by watermelon-maize cropping system (11%). Cereal-legume cropping is practiced in only 2–3% cultivated area.

Input usage

High quantity of inorganic fertilizers is used (Table 1). Usage of organic manure (39–46 t ha^{-1}) is limited to watermelon and sugarcane crops. Insecticide usage is limited to sugarcane alone.

Crop yields

The average yields are low to moderate (maize 0.9–7 t ha^{-1}; watermelon 10–36 t ha^{-1}; and mung bean 0.3–1.2 t ha^{-1}) with low benefit-cost ratio (maize 0.4, watermelon 0.7, and mung bean 0.9) (Table 2). Discussions with the farmers revealed that production potential is high if appropriate crops and production technologies are used. Improved seed and cultural practices are being adopted only in maize.

Constraints to production

The survey has brought out the following important constraints faced by the farmers in the benchmark landscape watershed.

Farmer perceived

- Lack of water for crop intensification (97.9%).
- Unavailability of credit and complicated loan procedures (91.8%).
- Fertilizers are expensive (83.7%).

Table 1. Input usage in various crops.

Particulars	Maize	Watermelon	Sugarcane	Mung bean	Cowpea	Rice
Seed[1] (kg ha^{-1})	23	1	-	22	23	100
Urea (kg ha^{-1})	444	561	670	12	Nil	220
Super phosphate (kg ha^{-1})	525	579	554	500	500	500
Murate of potash (kg ha^{-1})	136	127	1467	Nil	Nil	85
Manure (t ha^{-1})	Nil	46	39	Nil	Nil	10
Labor (person-days)	198	552	414	190	215	200

1. Seed price (VND per kg): Maize 18100, watermelon 554700, mung bean 11180, cowpea 14000, and rice 2500 (US$ 1 = 14000 VND). Data for sugarcane not available.

Table 2. Yield and output of crops grown in Thanh Ha State Farm, Vietnam.

Crop	Yield (t ha^{-1}) Range	Yield (t ha^{-1}) Average	Price[1] (VND kg^{-1})	Output Average (VND ha^{-1})	Output CV (%)
Maize	0.9–7.0	3.4	1742	5923176	46.4
Watermelon	10.0–36.0	17.8	1582	28166666	48.0
Sugarcane	20.0–83.0	58.3	134	7839999	49.3
Mung bean	0.3–1.2	0.7	7600	5320000	21.8
Cowpea	0.6–1.2	0.8	5400	4320000	27.5
Rice	3.0–6.1	3.2	1900	6080000	15.6

1. US$ 1 = 14000 VND.

- Lack of capital to purchase inputs (80%).
- Lack of knowledge on plant protection and improved production practices (79.6%).
- Monopoly of market forces (75.5%).
- Non-availability of market facilities (71.4%).
- Lack of extension services and demonstration of new technologies (71.4%).
- Unavailability of farmyard manure (FYM) (67.3%).

Researcher perceived

- Soil erosion.
- Inappropriate soil, water, and nutrient management practices.
- Improper land use planning.
- Natural resource base degradation.

Constraints and opportunities

We examined the constraints (in the farming systems and the environment) that limit the systems productivity and made an attempt to focus on opportunities that increase systems productivity. A number of specific challenges were identified that need to be addressed for development to be carried out successfully in the sloping ecoregions of northern Vietnam. A distinction was made between the constraints that in principle can be addressed directly by the research team (‘*addressable*’) and those that cannot (‘*non-addressable*’). A priority list of constraints and opportunities identified is provided.

Constraints

- Physical constraints: broken terrain, steep slopes, and poor soils.
- Environmental constraints: deforestation, land degradation, moisture stress during critical stages of crop growth, and low biological productivity.
- Infrastructure constraints: inadequate communication, transportation, and production infrastructure; and unskilled agricultural force.
- Economic constraints: subsistence orientation; and inadequate development of market and trade.
- Cultural constraints: low levels of education and knowledge; and persistence of traditional pattern of behavior.
- Intellectual constraints: inadequate scientific knowledge of the sloping land ecoregions; and lack of suitable strategies to guide development and planning.

Opportunities

- The benchmark watershed has good potential for introduction of new crops and cropping systems since the current cropping systems are giving meager income and mining the soil fertility with associated erosion of natural resource base.
- Identification and/or introduction of appropriate technologies with focus on soil, water, and nutrient management at micro-level in a watershed context will help in optimizing food production and arresting further erosion of natural resource base.
- Farmers are currently relying on high doses of inorganic fertilizers with little or no application of organic fertilizers. Good scope exists for introduction of appropriate INM practices.
- Most farmers are unaware of improved production technologies. There is a need to demonstrate new crops/cultivars, integrated pest and disease management technologies, improved crop produc-

tion practices, and systems diversification for higher productivity and household incomes.
- A paradigm tailored to the special conditions of the sloping land ecoregions needs to be developed.

Farmers themselves are strongly aware of some of the constraints, while the team members perceived other constraints as important. The decision on which constraints to tackle first may be influenced by this difference in perception. For example, the researchers considered soil erosion hazard as the number one problem, while farmers did not regard it as being quite serious. Erosion hazard may be seen as a ‘strategic’ problem, i.e., one which is likely to increase in the future unless measures are taken immediately. To build up credibility, the team however, decided to first address those constraints, which the farmers consider urgent, even if they are not most important in researchers’ point of view.

From constraints to solutions

The following process was followed for analysis of constraints and project planning:

1. Analyze the causes underlying the major constraints.
2. Examine whether there is sufficient evidence for these causes, if not take up diagnostic research to find answers.
3. Analyze whether a constraint or cause can be tackled directly by on-farm testing with available technology or whether technology must be developed.
4. Choose specific, well-defined technologies for on-farm testing.

Choosing the most appropriate technology always requires a good knowledge of both the target system and range of available technological options. Knowledge of the target system and the farming environment was obtained from the diagnostic survey and through collection of information. Knowledge about the technology was obtained by means of systematic search for information from experts, literature, and existing databases. The examples of groundnut and soil fertility are given in Table 3.

Farmers’ involvement in the choice of innovations

The research team, after carrying out the ex ante analysis of possible innovations, met the cooperating farmers and discussed the proposed innovations and solicited farmers’ inputs. The average landholding in Vietnam is very small (1000 m^2 upland or 600 m^2 rice field) and production losses if any due to improper practices advocated need to be compensated. The

Table 3. Prioritization of constraints, likely causes, and research activity in Thanh Ha State Farm, Vietnam.

		Technology testing		
Constraint	Cause	On-farm	On-station	Additional diagnostic studies
Failure of groundnut due to pod rot	High disease pressure.	Introduction of high-yielding, disease resistant cultivars.	Screening of potential cultivars.	Quantify fungus buildup and disease relationships.
		Introduction of appropriate IPM technologies.		Identify hot spots and abandon fungus-infested fields.
Declining soil fertility and crop productivity	Continuous maize monocropping.	Integration of legumes.	Screening potential legumes.	Characterization of soil resource.
	Reduced fallow and soil erosion.	Introduction of integrated land, water, and nutrient management technologies.	Seed multiplication.	

approach adopted therefore, is to encourage maximum participation of farmers in planning and execution of all the activities. All the watershed interventions, viz., introduction of new crops and cropping systems, soil and water conservation, INM, IPM, etc. are thoroughly discussed and decided by the farmers. Researchers and extension workers aid in decision-making process and facilitate agreed activities by providing technical support.

Micro-watershed is used as a demonstration block for appreciating the benefits in terms of reduced runoff and soil loss through scientific measurements. Farmers in rest of the watershed evaluate improved soil, water, and nutrient management options and cropping systems along with IPM and IDM for efficient use of natural resources and sustainable productivity gains. Studies on nutrient budgeting and micronutrient requirements for different systems are underway with close cooperation and involvement of farmers.

Conclusions

The socioeconomic surveys helped us to identify the benchmark research location, which is the representative of a well-defined target zone. Target zones were delineated within the project's mandated region on the basis of similarities in climate, soil classes, dominant cropping systems, etc. Similar zones would be expected to face similar constraints to agricultural production, and to have similar opportunities to overcome them. The working hypothesis is that the performance of innovations will be similar across the target zone, and the chances that farmers will then adopt them will also be similar.

Sub-project II: Ecoregional Databases

Purpose

Assemble all available databases on soil, climate, crops, and input use for the targeted rainfed production system applicable in the ecoregion of northern Vietnam.

Objective

- Study spatial distribution of the constraints, analyze yield gaps, and examine opportunities for crop intensification in the target ecoregion(s).

Characterization of environment

Climate

The climate in the landscape watershed is monsoonal with hot, wet summers (April–August) and cool, cloudy, moist winters (December–February). The total annual rainfall is 1500–2000 mm. The average temperature is 25°C, with an average maximum of 35°C (in August) and an average minimum of 12°C (in January). The southwest monsoon occurs from May to October, bringing heavy rainfall. Temperatures are high. November to May is the dry season with a period of prolonged cloudiness, high humidity, and light rain. Weekly weather data for the past 15 years from the nearby weather station was collected (Fig. 1). All the meteorological parameters are being collected at regular intervals. Rainfall variability is measured with automatic rain gauge located in the watershed.

All available databases on soil, climate, crops, and input use for the targeted rainfed production of

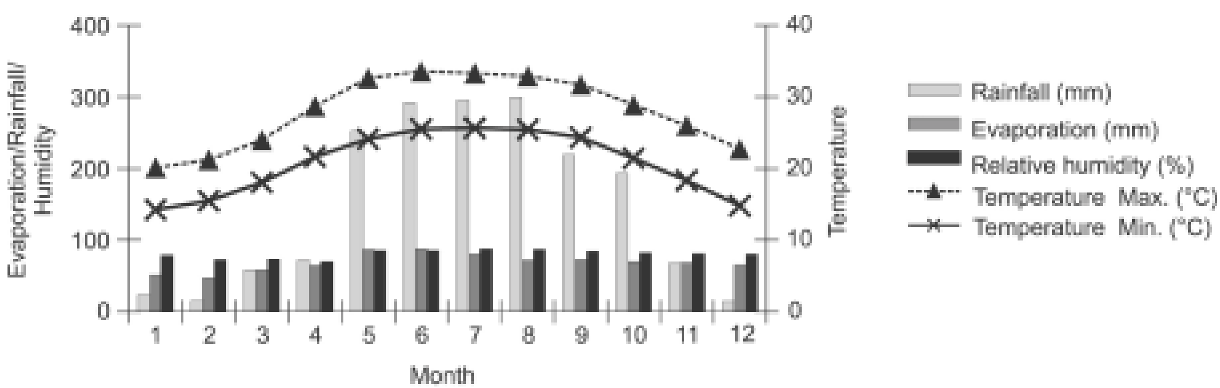

Figure 1. Climate of Hoa Binh Province, 1984–98.

northern Vietnam (7 provinces) were assembled to study spatial distribution of the constraints, analyze yield gaps, examine opportunities for crop intensification, and scale-up improved integrated watershed technologies.

Soils

The soil was sampled up to a depth of 1.5 m for detailed biological, chemical, and physical characterization and also based on the toposequence. Some salient observations are:

- Soil is medium loamy in texture, acidic in nature with very poor organic matter, medium in potassium, and very low in phosphorus (P) content.
- Soils need organic and inorganic supplements and particularly P fertilizer for good productivity. It is better to use thermo phosphate than super phosphate in these soils.
- Soil is rich in microbial population with large biodiversity and has good ability to develop biological activities with cultivation.

Yield gap analysis

We undertook the yield gap analyses for important crops grown in the target ecoregions of northern Vietnam using conventional approach of yield optimization trials conducted on research stations by comparing with the farmers' field plot yields. Data from experiment station and fields of 10 farmers each in 5 districts of a province for three years (1997–99) in five provinces for maize, groundnut, and soybean were collected. Yield gap analysis was undertaken for each province by computing the difference between average farmers' yields from 5 districts in a province and the crop yield from the experiment station in that province. The results showed that for maize mean yield from station trials was 4.9 t ha^{-1} and farmers' average yield was 2.8 t ha^{-1} indicating a yield gap of 2.1 t ha^{-1} (Table 4). The yield gap for maize in 5 provinces varied between 1.7 and 2.5 t ha^{-1}. The average yield gap was 2.1 t ha^{-1} and it varied between 1.1 and 3.6 t ha^{-1} in different provinces. The coefficient of variation for groundnut yield was 41.7% which indicated large variation in yield gap within the provinces. For soybean mean yield gap was 1.8 t ha^{-1} and within the provinces it varied from 1.6 to 2.0 t ha^{-1} with a coefficient of variation of 7.7%. Daily climate data for the period 1982 to 1997 was collected from Phu Tho, Vinh Phuc, Hoa Binh, Nam Ha, Nam Dinh, Ninh Binh, and Ha Tay provinces to undertake yield gap analysis using the CROPGRO model and to examine the opportunities for crop intensification in the target ecoregion.

Table 4. Maize yield gap between experimental plot yields and farmers' field yields.

Province	Experimental yield (t ha^{-1})	Farmers' yield (t ha^{-1})	Yield gap (t ha^{-1})
Hoa Binh	4.7	2.8	1.9
Ha Tay	5.4	3.1	2.3
Phu Tho	4.2	2.5	1.7
Vinh Phuc	5.5	3.0	2.5
Ninh Binh	4.6	2.8	1.8
Mean	4.9	2.8	2.1
SD	0.5	0.2	0.3
CV (%)	10.2	7.3	15.1

Sub-project III: On-farm Research

Purpose

Test, validate, and evaluate suitable natural resource management technologies in partnership with the farmers in farmers' fields in the benchmark watershed.

Objectives

- Introduce improved soil, water, nutrient, and pest management technologies for sustained increases in agricultural productivity.
- Reduce soil degradation and increase rainwater use efficiency through increased soil moisture, runoff water harvesting, and increased groundwater recharging.
- Evaluate suitable cropping systems based on the agroecological potential of the region to increase farm income.

Soil and water conservation

We have undertaken various measures for increased water and soil conservation in the benchmark watershed such as:

- Landform treatments (ridge and furrow, contour planting).

- Grassed waterways and drainage channels.
- Field bunding.
- Biological and mechanical barriers across the slope on contours.
- Trenches and silt traps to reduce the rainwater velocity and increase opportunity time for infiltration.
- Percolation tanks (40 m^3 capacity) to store excess water.
- Planting of *Gliricidia sepium* on the property bunds and contours.

Groundwater monitoring

Groundwater level in 10 open wells (8 inside and 2 outside the watershed) on the toposequence (top, middle, and lower part of the landscape watershed) was monitored at fortnightly intervals to observe water fluctuations and water yield to quantify the influence of improved soil and water conservation practices undertaken in the benchmark watershed. There was about 2.5–3 m increase in the water level in the benchmark watershed wells compared to those outside the watershed (Fig. 2). In addition, groundwater level fluctuations were less pronounced with stable water yield particularly in the dry season.

Moisture conservation

In northern Vietnam, the important production constraints for the groundnut crop are low temperature at maturity in autumn-winter, and low temperature at germination and moisture stress at maturity in spring season. Trials were therefore, initiated to evaluate the effect of straw and polyethylene mulch on soil moisture, temperature, and pod yields of groundnut. Polyethylene mulch increased soil temperature by 2–3°C in autumn-winter and 1–2°C in spring at 10 cm depth with associated conservation of soil moisture in the entire soil profile (Fig. 3). Increase in soil temperature in spring promoted early (about 2–3 days) and better germination with good seedling vigor while in winter, good pod development and early maturity was noticed.

Application of polyethylene mulch resulted in doubling the groundnut yield (1.5 t ha^{-1}) than the control (0.7 t ha^{-1}) treatment in autumn-winter season in 2000. The straw mulch treatment, which is environment-friendly and also economical, increased groundnut yields by 71% over the non-mulch control treatment (1.2 t ha^{-1}). Both the mulch treatments increased number of pods $plant^{-1}$, pod weight, and biomass. However, in spring 2001, significantly higher yields (3.23 t ha^{-1}) were recorded in polyethylene mulch treatment than in control (2.74 t ha^{-1}). The beneficial effects of straw mulch appeared to be masked by the increased incidence of fungal disease.

Land degradation

To quantify the effect of land degradation in terms of reduced productivity, we studied the effect of field location on a toposequence in the watershed on crop productivity. Soil samples up to a depth of 105 cm were collected for detailed biophysical and chemical characterization for identifying the suitable indicators of land degradation.

Soil biological activity parameters such as microbial biomass, soil respiration, dehydrogenase, alkaline and acid-phosphatase activities are the direct measures that indicate the soil health. These biological properties are directly associated with transformations of various elements in soil which are needed for plant growth. Soil biological parameters varied significantly on a toposequence. Biomass carbon (C) and respiration values for top 10 cm samples from top of the toposequence were similar to the values of the 10–20 cm samples from the middle of toposequence. Detailed analysis of parameters will enable us to relate the indicators of soil degradation with the crop productivity for estimating the productivity losses due to degradation.

Variation in biological soil quality attributes along the toposequence and soil depths were studied in detail (Table 5). The results indicated a wide variation for all the parameters along the location on a toposequence. The organic C content was high (8517–9633 mg C kg^{-1} soil). Similarly, soil respiration also showed the same trend. Further, analysis of results reveal that the samples from top of the toposequence showed more soil C, microbial biomass C and nitrogen (N), and respiration than the samples from middle and lower positions on a toposequence. These results point out that as the farmers grow fruit trees on top of the toposequence

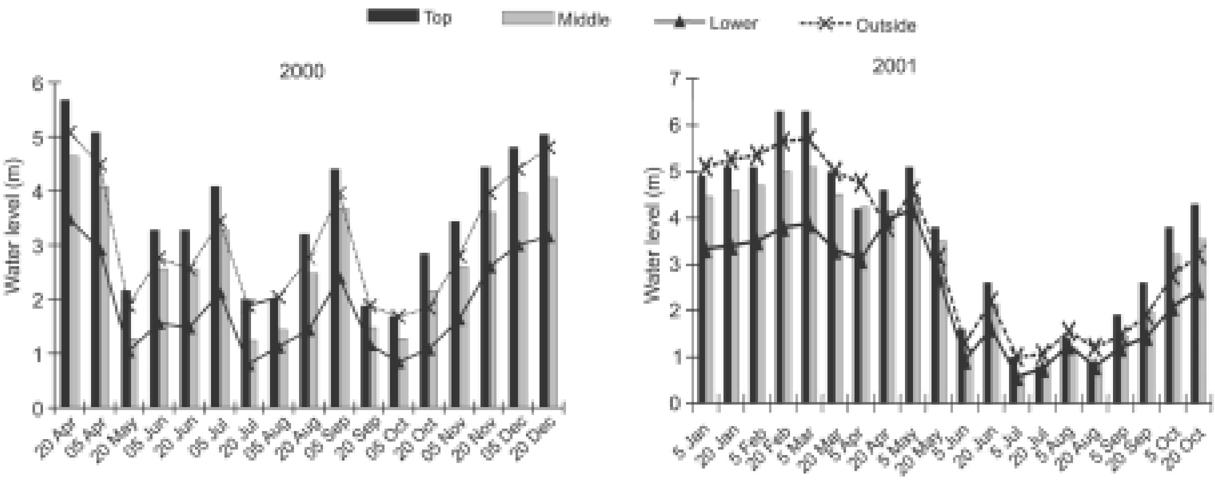

Figure 2. Groundwater level in the open wells along the toposequence in the benchmark watershed.
(Note: 0 = Ground level.)

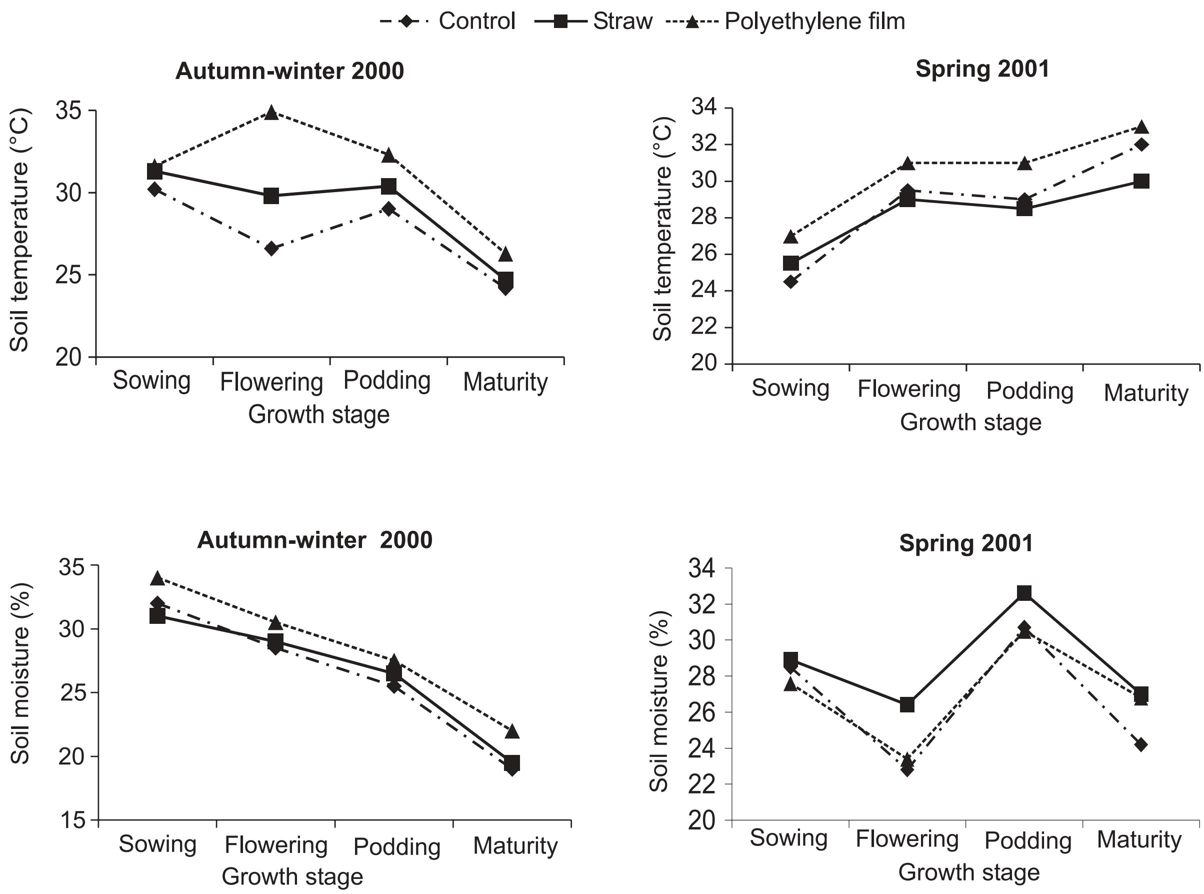

Figure 3. Changes in soil temperature and moisture in mulch and normal cultivation of groundnut.

Table 5. Variation in soil biological properties along the toposequence at 0–105 cm soil depth.

Soil property	Lower	Middle	Top
Microbial biomass C ($mg\ kg^{-1}$)	108	112	125
Microbial biomass N ($mg\ kg^{-1}$)	11	10	16
Mineral N ($mg\ kg^{-1}$)	19	18	12
Net N mineralization ($mg\ kg^{-1}$ soil $10d^{-1}$)	9	8	10
Organic C ($mg\ kg^{-1}$)	8517	8233	9633

the soils were not degraded on top, whereas, the agricultural systems followed on middle and lower positions of a toposequence which are cultivated have caused degradation. The results also suggest a direct relationship between rainfall and soil organic C content. Further analyses of these data sets will reveal detailed understanding of relationships between environmental management factors and land degradation.

Runoff and soil loss

The two micro-watersheds were equipped with digital recorders to monitor runoff and sediment samplers to measure soil loss and nutrient loss in runoff as well as in soil sediment. In 2000, annual rainfall of 1349 mm and runoff of 29.5% rainfall was recorded. Total soil loss from the developed watershed in 2000 was 6.8 t ha^{-1}.

Nutrient management

Improved nutrient management in maize

Farmers in the benchmark watershed over the years have increased the quantity of nitrogenous fertilizer (600 to 750 kg urea ha^{-1}) in maize crop to maintain the yields. This has resulted in increased incidence of pests and diseases and decline in household incomes. Improved nutrient management practice (180 N:90 P_2O_5:90 K_2O; 10 t FYM; and 400 kg lime) was compared with farmers' practice (275–300 N:80 P_2O_5:45 K_2O) in maize to wean the farmers away from high dependence on inorganic fertilizers, encourage balanced fertilization, and reduce cost of cultivation. Higher grain yields were obtained with improved practice in all the three years and the results have clearly indicated good scope for savings of 95 to 120 kg ha^{-1} of N fertilizer (Table 6).

Evaluation of micronutrient requirements

Soil analysis indicated that the soils in the benchmark watershed are deficient in micronutrients like boron, zinc, sulfur, and molybdenum. Trials were initiated on groundnut and soybean to quantify advantages of micronutrient application with and without *Rhizobium* inoculation. Micronutrient application resulted in 27% higher pod yield over farmers' practice (2.75 t ha^{-1}). The results, however, indicated limited scope for reduction of N fertilizer and urgent need to identify appropriate *Rhizobium* strains and/or effective application methods for added advantage.

Green manure, compost, and mulching

Farmers have planted 40,000 *Gliricidia* saplings on farm bunds and near the mechanical structures in the benchmark watershed. The growth was very fast with

Table 6. Influence of improved nutrient management practices on grain and biomass yields (t ha^{-1}) of maize.

	1999 Autumn		2000 Spring		2000 Autumn		2001 Spring	
Practice	Grain	Biomass	Grain	Biomass	Grain	Biomass	Grain	Biomass
Farmers' practice	4.50	8.84	5.32	11.80	4.90	8.80	5.57	9.58
Improved practice	4.81	9.67	5.70	11.85	5.37	11.82	6.62	11.26
SE±	0.12	0.20	0.13	0.16	0.12	0.21	0.25	0.28
CV (%)	9.00	17.00	10.00	5.70	9.80	10.70	5.00	9.00

ample biomass production. In Vietnam, *Gliricidia* can be cut 5 times in a year with an estimated biomass production of 25–50 t ha^{-1}. This rich organic matter containing 3–5% N can meet 100 to 200 kg N requirement of crops when applied in situ.

Due to limited turn around time, farmers in Thanh Ha watershed used to burn maize straw after spring season to get the fields quickly prepared for autumn-winter cropping. Demonstrations were held to discourage straw burning and farmers were given training on minimum cultivation, mulching, in situ soil incorporation, and composting.

Integrated pest and disease management

Integrated pest and disease management studies were conducted during 1999 to 2001 with 7 farmer groups in the benchmark watershed. Regular monitoring of disease and insect buildup, appropriate selection of variety (resistant), seed treatment, cultural practices (lime application, land configuration, timely sowing, *Rhizobium* inoculation, etc.), and need-based chemical application are some of the measures that were followed and compared with farmers' practice to quantify the benefits and economic suitability.

Bacterial wilt, collar rot, and root rot are important diseases in groundnut, while stem borers in maize and *Maruca testulalis* and *Helicoverpa armigera* in mung bean and soybean appear to be most devastating pests. Manganese toxicity (appears like virus infection) is widespread in spring season. Mulching reduced soilborne fungi significantly but led to increased incidence of leaf spots due to luxuriant crop growth. Increased incidence of rust, damping-off, and early leaf spot was noticed on top of the toposequence in groundnut while late leaf spot and root rot were more severe in the middle part of the toposequence.

Introduction, evaluation, and seed multiplication of novel crops

A decade of renovation policy (*Doi moi*) implementation has changed the agricultural production model in Vietnam from community oriented to household based. Abolition of government managed and sponsored production system and establishment of new system has led to scarcity of improved varieties. It has, therefore, become very important to take up varietal improvement and seed multiplication to ensure that appropriate varieties are identified/developed and produced in sufficient quantities to meet the production demands.

More than 75% area was under maize (spring maize-autumn maize) before our intervention in the watershed. This has resulted in decline in soil fertility and increase in input costs over the years. Trials to evaluate novel crops (soybean, groundnut, and mung bean) and improved cultivars were taken up under the aegis of the National Legume Research and Development Program and funding support from the Australian Centre for International Agricultural Research (ACIAR). Technical backstopping and seed multiplication of these remunerative crops resulted in reduction in maize area by about half in the benchmark watershed (Fig. 4). Many farmers are interested in groundnut cultivation in large areas but non-availability of seed and seed storage facilities are the major constraints.

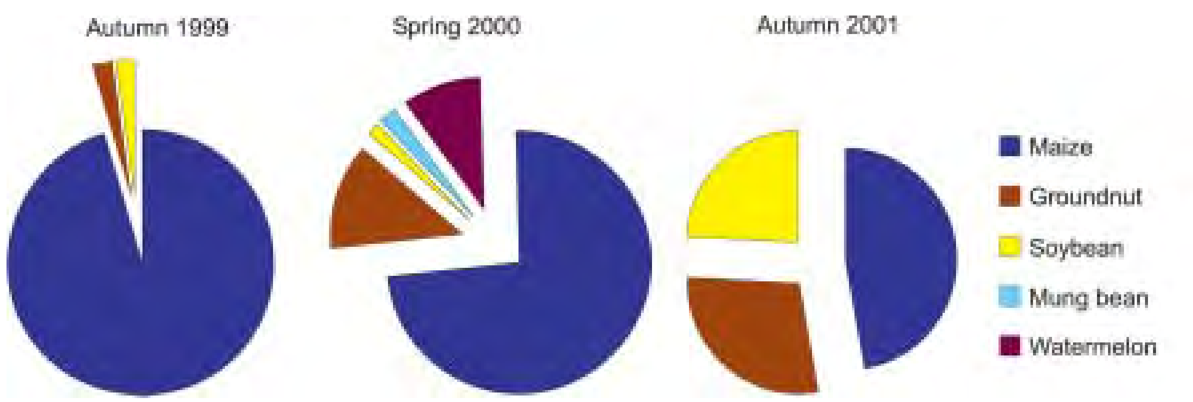

Figure 4. Proportion of land under various crops in Thanh Ha watershed.

Large-scale on-farm demonstrations

On-farm demonstrations were conducted with mung bean, soybean, groundnut, and watermelon. Improved mung bean cultivar T 135 was assessed for its suitability as a catch crop in watermelon-maize cropping system. T 135 produced 1.12–1.24 t ha^{-1} and did not pose any problem for normal maize cultivation.

An early-maturing soybean cultivar TN 12 (70–75 days) was introduced to increase cropping intensity and system productivity. The new cropping system allows four crops, i.e., watermelon-soybean-groundnut-sweet potato/vegetables in one year, if water is made available during the dry season. Improved groundnut cultivars LO 2 and MD 7 with high yield potential (3–4 t ha^{-1}) and tolerance to bacterial wilt and pod rot were introduced. Farmers were highly impressed with the crop and showed interest in planting in large areas.

Improved production practices

Farmers in the watershed were following traditional cultural practices due to technological inaccessibility. Improved production practices (integrated nutrient, pest, and disease management; and agronomy) were compared with farmers' practice in maize. Improved production practices increased maize grain yields by 8–18% over the years with 38% reduction in N fertilizer (90–120 kg ha^{-1}) usage. Improved production practices were also introduced in soybean, groundnut, and mung bean.

Land use planning for increased household incomes

Unlike other Asian countries, the landholdings of Vietnamese farmers are very small. The average family holding in drylands is around 0.5 to 1 ha. It is, therefore, important that the farm is utilized in most prudent way for higher household income and food security. Efforts have been made to identify appropriate crops and crop combinations in various seasons for enhanced household income. For example, maize, groundnut, and soybean combination gave higher income in spring while the traditional maize monocropping system was not at all economical (Fig. 5). Also, crop performance differed significantly across seasons.

Soils in the sloping lands were highly vulnerable to erosion when cleared of vegetative cover and were subjected to various forms of land degradation. Loss of humus rich topsoil left behind the subsoil devoid of vital plant nutrients leading to rampant infertility and poor water-holding capacity. It is, therefore, important to identify crops that not only perform well on these soils but help improve soil health over the years. To find out the influence of land degradation on crop productivity and profitability we have delineated the grain yields of soybean, groundnut, mung bean, and maize based on the location on the toposequence in the watershed (Figs. 6 and 7).

In general, higher grain yields and farm incomes were obtained in the lower and middle part of the toposequence compared to that of top due to less degradation and better soil fertility. Farmers are incurring higher expenditure due to increased fertilizer usage on top of the toposequence. Groundnut can be grown successfully on top, middle, and lower part of the toposequence while mung bean and soybean need high level of management on top of the toposequence for obtaining good yields. This kind of information would assist in appropriate land use planning and development of targeted nutrient management technologies for system resilience and increased household incomes.

Technology Exchange and Human Resource Development

Human resource development and technology exchange were important components of the project and consistent efforts have been made to provide on the job training to large number of national staff and disseminate integrated watershed technologies widely as natural resource management is still an unexplored research area in Vietnam.

On the job in-country training

Several in-country training courses were organized for researchers, extension workers, and farmers during the last three years with the help of faculty from both national and international organizations. These include (i) recent concepts in integrated participatory watershed management; (ii) improved soil and water management in watershed context; (iii) integrated pest

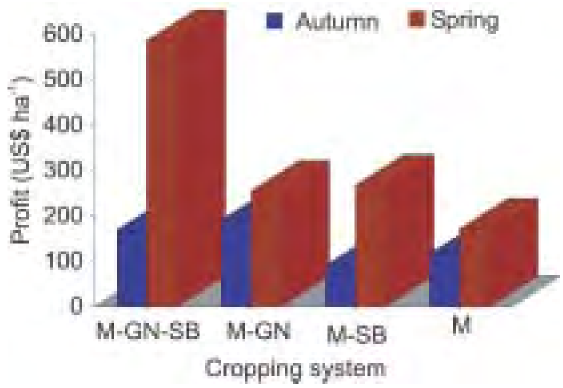

Figure 5. Influence of land use planning on household income, Thanh Ha, 2000.
(Note: M = maize, GN = groundnut, SB = soybean, and MB = mung bean.)

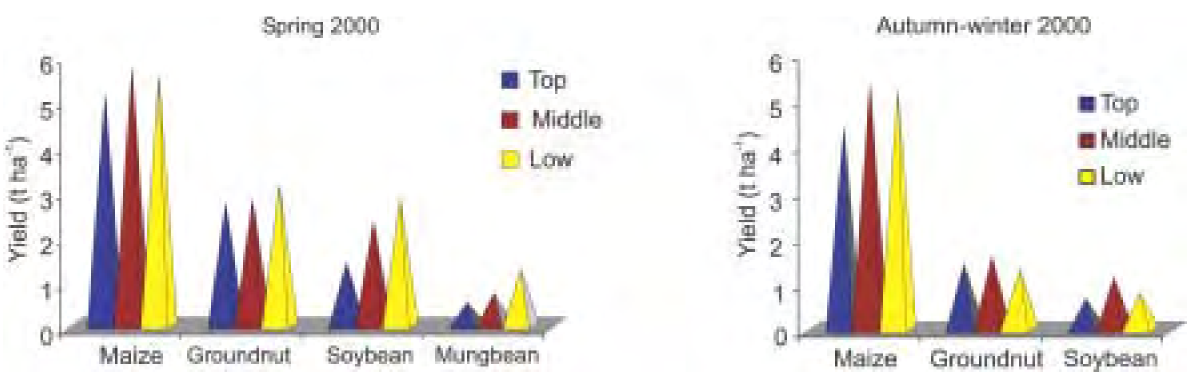

Figure 6. Influence of toposequence on crop productivity in Thanh Ha.

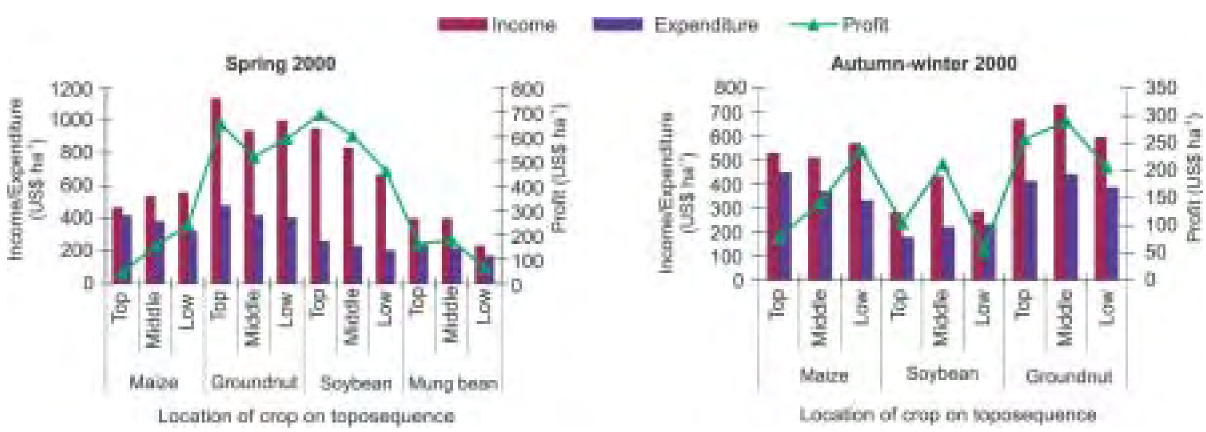

Figure 7. Influence of toposequence on crop profitability in Thanh Ha.

and disease management; (iv) improved production practices of groundnut, soybean, and mung bean; (v) INM; (vi) *Rhizobium* inoculation; and (vii) *Gliricidia sepium* nursery management. Also, many national program scientists received informal training in design and development of efficient land and water management technologies at watershed scale.

Regional training courses and traveling workshops

Scientists of the Vietnam Agricultural Science Institute (VASI) benefited greatly from these activities as they were provided excellent opportunities to visit other benchmark watersheds of the project, interact with peers, and exchange views and experiences.

Training at ICRISAT

Three young and two senior researchers from VASI visited ICRISAT and received training on integrated watershed management, data collection, and modeling.

Public awareness programs

Farmers' days were conducted in each cropping season in the landscape watershed and all the farmers in the Thanh Ha State Farm were invited to get aquainted with different components and technologies of integrated watershed. Field days proved to be very efficient in getting the message across as several provincial and district authorities, technology exchange departments, research managers, and policy makers were invited and were highly impressed with the technological innovations. Videos and brochures on improved production practices and watershed development were prepared for use by extension agencies for wider dissemination and adoption of technologies.

Looking Ahead

Watershed based integrated natural resource management technologies provided an excellent opportunity for efficient management of rainwater, i.e., controlling runoff to reduce erosion, increase infiltration, enhance moisture levels in the soil, canalizing and harvesting surplus water for life saving irrigation and summer cropping, and recharging groundwater for sustaining the production at higher levels to meet the growing food demands in the uplands. Crop diversification with legumes and oilseed crops helped in improvement of soil health and opened up new opportunities for enhanced household incomes and rural employment in the hitherto malnourished and poverty-stricken sloping lands. In the coming years the strategic goal should be to scale-up improved technologies to other sites in the target ecoregion to capitalize the benefits achieved in the benchmark watershed and consolidate the gains of improved soil, water, and nutrient management technologies and cropping systems through wider adoption for sustaining agricultural production in the sloping land ecoregions of northern Vietnam.