Improving Management of Natural Resources for Sustainable Rainfed Agriculture in Asia: An Overview

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Abstract

Limiting natural resources, erratic rainfall, land degradation, soil erosion, poverty, and burgeoning population characterize the dry regions in Asia. Over-exploitation of natural resources in these areas to meet the ever-increasing demand for food and fuel of rapidly growing population has led to environmental degradation and calls for initiation of immediate steps for optimal utilization of natural resources based on the potential and limitations. To develop sustainable natural resource management options for increasing the agricultural productivity and income of rural poor in these dry regions, a new integrated farmer participatory watershed management model was developed by ICRISAT along with NARS partners. This holistic approach includes new science tools, linking on-station research to on-farm watersheds, technical backstopping through consortium of institutions with convergence of livelihood-based activities. This new model was applied at selected benchmark locations in Asia by ICRISAT in partnership with NARS through execution of the project "Improving Management of Natural Resources for Sustainable Rainfed Agriculture in Asia". The broad objectives of the project were to enhance and sustain the productivity of medium and high water-holding capacity soils in the intermediate rainfall ecoregions of the semi-arid tropics of Asia and to develop environment-friendly soil and water resource management practices. On-station benchmark locations served as sites for strategic research and on-farm benchmark watersheds served as farmer-managed sites for farmer participatory refinement and evaluation of sustainable natural resource management options under varying socioeconomic and bio-physical situations. The on-farm watersheds were provided with technical backstopping from ICRISAT and other consortium institutions. The monitoring and impact assessment in these locations reflected a higher technology adoption of improved soil and water conservation practices, and nutrient and pest management with increased productivity and incomes.

Reduction in production capacity of land due to wind and water erosion, loss of soil humus, depletion of soil nutrients, secondary salinization, diminution and deterioration of vegetation cover as well as loss of biodiversity is referred as land degradation. Land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors including climatic vicissitudes and human activities is a cause of desertification. Though land degradation has been a problem in the past also, the pace of degradation has greatly increased in recent times due to burgeoning population and enhanced means of exploitation of natural resources. Seventy per cent of 5.1 billion ha (39.5% of land area) dryland areas worldwide is afflicted with one or the other form of land degradation. Permanently degraded lands are growing at the annual rate of 6 million ha globally, which are affecting livelihoods of millions of poor people in the developing and poor countries. The process of land degradation is seriously undermining their livelihood security leading to poverty, starvation, and migration.

A global assessment of the extent and form of land degradation showed that 57% of the total area of

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drylands occurring in two major Asian countries namely China (178.9 million ha) and India (108.6 million ha) are degraded (UNEP 1997). Accelerated erosion resulting in loss of nutrient rich top fertile soil, however, occurs nearly everywhere where agriculture is practiced and is irreversible. The torrential character of the seasonal rainfall creates high risk for the cultivated lands. Of the estimated 173 million t of sediment discharged into the oceans annually, Asia alone contributes nearly half of the load, even though the actual land area is just one-third (UNEP 1997). This is an eloquent testimony to the intensity of the process and the consequential damage to the producing ability of land. In India, erosion rates of 5 to 20 t ha^{-1} (up to 100 t ha^{-1}) are reported. In India alone some 150 million ha are affected by water erosion and 18 million ha by wind erosion (UNEP 1997). Thus, erosion leaves behind impoverished soil on one hand, and siltation of reservoirs and tanks on the other. This degradation induced source of carbon (C) emission contributes also to far reaching global warming consequences. If the current production practices are continued, the Asian countries will face a serious food shortage in the near future.

In India, 65% of arable land is rainfed and the increasing demand for food and feed has to be met from the increased production from the rainfed areas, as there is no scope for expansion of cultivable area as well as irrigation facilities. The policy shift towards rainfed lands is necessitated on social grounds as a large majority of the rural community has subsistence-level existence with a sizeable component of people below the poverty line. The incidence of poverty is 28% in the Asian developing countries, with high incidence of 35% poverty in India. The poverty index in India is high and is around 40%. Although poverty in India has shown a decline over time, the absolute numbers have increased substantially from 180 million in early 1950s to over 350 million by the end of 1990s (Ryan and Spencer 2001). The different facets of poverty are malnutrition, non- or underemployment, poor reproductive health care and associated infant mortality, high birth rates, illiteracy, and a feeling of helplessness.

To minimize land degradation in selected countries of Asia, the Asian Development Bank (ADB) has supported a project on “Improving Management of Natural Resources for Sustainable Rainfed Agriculture in Asia” through RETA 5812. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) executed this project during January 1999 to June 2002 in partnership with the national agricultural research systems (NARSs) of India, Thailand, and Vietnam. The broad objectives are to enhance and sustain the productivity of the medium and high water-holding capacity soils in the intermediate rainfall ecoregion of the semi-arid tropics (SAT) of Asia (parts of India, Vietnam, and Thailand) and to develop environment-friendly resource management practices that will conserve soil and water resources. The specific objectives of the project are to:

1. Characterize natural resource base and identify physical and socioeconomic constraints to increased sustainable cropping in the target ecoregion.
2. Apply and refine integrated cost-effective soil, water, and nutrient management (SWNM) practices based on the natural resource endowments of the farmers.
3. Rehabilitate degraded medium to high water-holding capacity soils and study effects of integrated SWNM strategies on profitability and sustainability of the system.
4. Integrate and evaluate techno-economic feasibility of promising strategies for crop intensification and reduction in soil degradation in the target Asian ecoregion, to identify indicators of unsustainability, and to learn lessons for extension/transfer of promising practices to other parts of the SAT.

Target Countries and Ecoregion

The project has targeted the assured rainfall ecoregion production systems in Asia for managing water at community-scale watersheds. It occurs principally in the eastern Deccan plateau in India and portions of central Myanmar, northeastern Thailand, northern Vietnam, and dry climatic areas of Indonesia and sloping lands of the Philippines. Thailand has its own share of land resource stresses; many of these are natural, but accelerated by human activities on the land. Some have been specifically created through mismanagement. About 30% of the land area is steep land. About 75% (386,000 km^2) of land is vulnerable to desertification. In Thailand the annual average soil erosion rate is 34 t ha^{-1} yr^{1} with more than 30% of the country affected by moderate to severe erosion. Approximately 45% of the land in the Philippines is moderately to severely eroded. About 41% of the area is cultivated and is on land with slopes greater than 18%. In Indonesia, one-third of the 57 million ha of upland soils is classified as in critical condition because of land degradation. Conservation technology will certainly contain some of these degradation processes but more work is required for it to be truly sustainable.

To develop sustainable natural resource management options for increasing the agricultural productivity and incomes of rural poor in this agro-ecoregion three target countries, India, Thailand, and Vietnam, were selected. Five on-farm benchmark watersheds were selected in the three target countries (Fig. 1).

The ecoregion constitutes the heartland of rainfed agriculture in Asia. The rainfall is dependable (800–1300 mm) and the soils are medium deep to deep (>1 m depth) with medium high (150–200 mm) water-holding capacity. This ecoregion is mostly suited for double cropping through intercropping or sequential cropping systems. It has a potential to become the green revolution area of rainfed drylands. Although land degradation and receding groundwater tables are commonly observed in semi-arid tropical environments, these are of particular concern in the intermediate rainfall ecoregion of central India, northern Vietnam, and northeastern Thailand. The soils in this ecoregion are prone to severe soil erosion because of their positional toposequence setting. Currently the rainfall use efficiency for crop production ranges between 30 and 45% and annually 300 to 800 mm of seasonal rain is lost as surface runoff or deep drainage (Wani et al. 2002a). If the

Figure 1. Benchmark on-farm watersheds in target ecoregion of the selected countries.

annual rainfall is properly utilized for crop production, it would be sufficient to sustain not only the double cropping but 200 to 300 mm of surplus rainwater would be available annually to recharge groundwater resource. The recession of groundwater levels in the Deccan Plateau in India has shown that in spite of high rainfall there is mismanagement of water.

New Integrated Watershed Management Model

A new model for efficient management of natural resources in the SAT has emerged from the lessons learned from long-term watershed-based research conducted by ICRISAT in partnership with NARSs (Wani et al. 2002b). The important components of this integrated watershed management model are:

- Farmer participatory approach through cooperation model and not through contractual model.
- Use of new science tools for management and monitoring of watersheds.
- Link on-station and on-farm watersheds.
- A holistic system's approach to improve livelihoods of people and not merely conservation of soil and water.
- A consortium of institutions for technical backstopping of the on-farm watersheds.
- A micro-watershed within the watershed where farmers conduct strategic research with technical guidance from the scientists.
- Low-cost soil and water conservation measures and structures.
- Amalgamation of traditional knowledge and new knowledge for efficient management of natural resources.
- Emphasis on individual farmer-based conservation measures for increasing productivity of individual farms along with community-based soil and water conservation measures.
- Minimize free supply of inputs for undertaking evaluation of technologies and farmers are encouraged to evaluate new technologies themselves without financial subsidies.
- Continuous monitoring and evaluation by the stakeholders.
- Empowerment of community individuals and strengthening of village institutions for managing natural watersheds.

Consortium partners

India

- Indian Council of Agricultural Research (ICAR):
  - Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad
  - Indian Institute of Soil Science (IISS), Bhopal
- State agricultural universities (SAUs):
  - Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Indore
- State Government Department:
  - Drought Prone Area Program (DPAP), Ranga Reddy, Andhra Pradesh
- Non-governmental organizations (NGOs):
  - M Venkatarangaiya Foundation (MVF), Hyderabad
  - Bharatiya Agro Industries Research Foundation (BAIF), Bhopal

Thailand

- Royal Thai Department of Agriculture (DOA), Bangkok
- Royal Thai Department of Land Development (DLD), Bangkok
- Khon Kaen University (KKU), Khon Kaen

Vietnam

- Vietnam Agricultural Science Institute (VASI), Hanoi

CGIAR

- International Water Management Institute (IWMI), Bangkok

Advanced research institutions

- Michigan State University (MSU), East Lansing, Michigan, USA
- University of Georgia, Griffin, Georgia, USA

Strategic Research

In this project three on-station benchmark micro-watersheds (catchments) (Table 1) served as field sites to undertake strategic research on integrated soil,

Table 1. Benchmark sites for on-farm and on-station work in Asia.

Watershed	Soils	Annual rainfall (mm)
On-station		
ICRISAT, Patancheru, India	Vertisols and Vertic Inceptisols	800
Indian Institute of Soil Science, Bhopal, India	Vertisols	1140
College of Agriculture, JNKVV, Indore, India	Vertisols	960
On-farm		
Adarsha watershed, Kothapally, Ranga Reddy, India	Vertic Inceptisols	760
Milli watershed, Lalatora, Vidisha, India	Vertisols and Vertic Inceptisols	1200
Ringnodia watershed, Solsinda, Indore, India	Vertic Inceptisols	1050
Tad Fa watershed, Khon Kaen, Thailand	Sloping mixed heavy soils	1300
Thanh Ha watershed, Hoa Binh, Vietnam	Deep Alfisols and sloping lands	1300

Table 2. Geomorphological characteristics of the on-farm watersheds.

	Watershed shape		Linear aspect of drainage network		Relief aspect of drainage basin	
Watershed	Form factor	Area-perimeter ratio	Bifurcation ratio	Drainage density	Relief ratio	Relative relief
Adarsha Watershed, Kothapally (India)	0.38	0.47	2.33	0.56	0.03	1.05
Milli watershed, Lalatora, Vidisha (India)	0.36	0.43	2.00	0.38	0.04	1.09
Ringnodia watershed, Indore (India)	0.66	0.47	1.33	0.66	0.52	1.77
Tad Fa watershed, Khon Kaen (Thailand)	0.22	0.32	1.50	1.37	0.05	3.33
Thanh Ha watershed, Hoa Binh (Vietnam)	0.64	0.39	1.50	1.36	0.06	3.33

Source: Pathak et al. (2002).

water, nutrient, and pest management and also for collection of necessary data for validating simulation models. The five on-farm benchmark watersheds (Table 2) served as farmer-managed sites for farmer participatory refinement and evaluation of sustainable natural resource management options under varying socioeconomic and bio-physical situations. These sites also provided insight into socioeconomic constraints for adoption and evaluation of techno-economic feasibility of different management options. At these sites researchers and farmers jointly monitored hydrological processes, soil loss, nutrient cycling, and increased productivity at watershed level. In this paper a brief overview of the progress in strategic and on-farm research at benchmark sites is given and detailed reports for individual sites are covered separately in subsequent papers.

Use of high-science tools for watershed planning, development, and impact assessment

Simulation modeling

Crop simulation models help in evaluating the performance of technologies under different agroclimatic situations through scenario analysis and in identifying the major constraints for sustaining productivity and also appropriate technology application domains. Integration of remotely sensed data in the geographic information system (GIS) along with simulation models would increase our ability to conceptualize, and develop strategies to manage the natural resources in the watersheds efficiently on sustainable basis.

Crop growth simulation models in an integrated watershed management approach provide an opportunity to simulate the crop yields in a given climate and soil environment. ICRISAT researchers have adopted DSSAT v 3.0, a soybean crop growth model, to simulate the potential yields of soybean crop in Vertisols grown at different benchmark locations. Mean simulated yield obtained for a location was compared with the mean observed yield of the last five years to calculate the yield gap. The results (Table 3) showed that there is a considerable potential to bridge the yield gap between the actual and potential yield through adoption of improved resource management technologies (Singh et al. 2001).

Table 3. Simulated soybean yields and yield gap for the selected locations in India.

Location	Mean simulated yield (kg ha^{-1})	Mean observed yield[1] (kg ha^{-1})	Yield gap (kg ha^{-1})
Primary zone			
Betul	2371	858	1513
Guna	1695	840	855
Bhopal	2310	1000	1310
Indore	2305	1122	1183
Kota	1249	1014	235
Wardha	2997	1042	1955
Secondary zone			
Jabalpur	2242	896	1346
Amaravathi	1618	942	676
Belgaum	1991	570	1421

1. Mean of reported yields of last five years (1997–2001).

All the previous data of BW7 watershed at ICRISAT, India from 1995 to 2000 on crop growth and soil water have been converted to formats suitable for testing of the Agricultural Production Systems Simulator (APSIM) models of soybean-chickpea sequential and soybean/pigeonpea intercropping systems. These models have been validated for soybean sole crop and soybean/pigeonpea intercropping systems, which required significant amount of time for understanding and fine tuning model parameters, particularly related to competition of light and genetic coefficients. Finally the model performs well, with few exceptions, to simulate crop growth, yields, and soil water dynamics. Water balance components and nitrogen (N) balance components (N uptake, N fixation, denitrification, leaching, and N mineralization) have been quantified for a few seasons.

To evaluate the effect of different SWNM practices on soybean intercropped with pigeonpea using the simulation model we have validated the APSIM model using the data sets generated from on-station watershed at ICRISAT. Using APSIM model, productivity and resource use of soybean/pigeonpea intercropping system were simulated. The model parameters for soybean and pigeonpea crops were determined by calibration using the observed data of phenology, crop growth, and soil water dynamics for 1998/99 and 1999/2000 seasons. The model simulated growth and development of both the crops satisfactorily; however, adjustments were needed to set competition parameters for light and water.

Simulated water balance and the observed data showed that significant amount of rainfall (25%) was lost as runoff during 1998/99 season. Simulated runoff matched the observed runoff data for both the flat and broad-bed and furrows (BBF) landforms (Table 4). Soil water dynamics for both the treatments during the entire growing season also matched the observed data satisfactorily (data not shown). Rainfall lost as deep drainage from the shallow soil during 1998/99 season was significant (292 to 303 mm). However, during 1999/2000 season, runoff and deep drainage were negligible (Table 4). Total water use by the crop (459 to 465 mm) was met by rainfall and soil water depletion.

Remote sensing

Over-exploitation of natural resources to meet ever-increasing demand for food and fuel of rapidly growing population has led to environmental degradation and calls for initiation of immediate steps for optimal utilization based on the potential and limitations. Information on the nature, extent, and spatial distribution of natural resources is a prerequisite for achieving this goal. Multispectral measurements made at regular intervals using satellites hold immense potential of providing such information in a timely and cost-effective manner,

Table 4. Simulated water balance of soybean/pigeonpea intercropping system on flat and BBF landforms on a shallow soil during 1998–2000 seasons, ICRISAT, India.

Water balance components (mm)	Flat shallow	BBF shallow
1998/99 season		
Rainfall	1035	1035
Runoff[1]	261 (266)	252 (250)
Deep drainage	292	303
Evapotranspiration	567	586
Soil water change	–73.8	–95.7
1999/2000 season		
Rainfall	436	436
Runoff[1]	0.11 (Nil)	0.11 (Nil)
Deep drainage	0.9	4.4
Evapotranspiration	459	465
Soil water change	–10.1	–20.9

1. Figures in parentheses are observed data.

and facilitates studying the dynamic phenomenon that helps in assessing the effectiveness of the interventions made in the watersheds.

In partnership with the National Remote Sensing Agency (NRSA), Hyderabad, India, we are using Indian Remote Sensing Satellites (IRS-1B/-1C and -1D) data for developing and managing watersheds efficiently as well as for monitoring the impact of various interventions made in the watersheds.

Soil conservation measures taken up in the area generally result in (i) arresting soil loss; and (ii) improving soil fertility and moisture status, which subsequently leads to establishment or improvement in vegetation/biomass. The changes in the terrain condition of the watershed monitored using satellite images are described.

The Milli watershed in Lateri Block is located in the northwest corner of Vidisha district in Madhya Pradesh in central India (Fig. 2). This watershed consists of 35 villages, which are grouped into 17 micro-watersheds. The Lalatora micro-watershed (725 ha) was selected for detailed monitoring of hydro-meteorological measurements.

The change in biomass is reflected in the agricultural land use. The agricultural land use of Milli watershed is portrayed in Figure 3. Since the soil and water conservation measures were initiated during 1997, IRS-1C LISS-III data for rabi (postrainy) season of 1997 was used to derive information on agricultural land use before the watershed activities were initiated in this area. To study the impact of the program on the land use, IRS-1C LISS-III data of rabi 2001 was used. The False Color Composite (FCC) derived from LISS-III data of 1997 and 2001 is shown in Figure 4. Red color in FCC indicates vegetation cover whereas bluish green or greenish blue indicates black soil bare/fallow. A comparison of the vegetation cover during the period 1997 to 2001 points to a significant increase of 269 ha in the vegetation cover (3,402 ha during 1997 versus 3,672 ha during 2001). Contrastingly, there has been shrinkage in the fallow/barren lands. This analysis using remotely sensed data by satellite provided direct evidence in increased cultivation during postrainy season. Such an increase in area during postrainy season is mainly due to increased water availability in soil or in wells, which helped the farmers to increase their cultivated area.

In partnership with NRSA we also studied the vegetation cover by generating the Normalized Difference Vegetation Index (NDVI), which is essentially the ratio of the differences of the response in the near infrared and red regions of the spectrum. Their sum values thus obtained range normally between 0 and 1.0. However, values of NDVI less than zero are also encountered which indicate barren or fallow land. The NDVI images generated from LISS-III data of 1997 and 2001 are shown in Figure 4.

A close look at the figure indicates a marginal increase in the vegetation cover supporting thereby the observation made on the agricultural land use. Whereas an estimated 31.5% of the geographic area of watershed has been found to be in the NDVI range of 0.10–0.55 in 1997, it has risen to 40.3% during 2001 demonstrating an increase of 9% in the greenery in the watershed. It is, indeed, interesting to note that in Lalatora micro-watershed where the soil and water conservation treatments have been imposed, the vegetation cover has improved tremendously. As against only 149 ha of vegetation cover during 1997–98, it has risen to 229 ha during 2000–01 registering thereby an increase of 80 ha during 3-year period (Fig. 4).

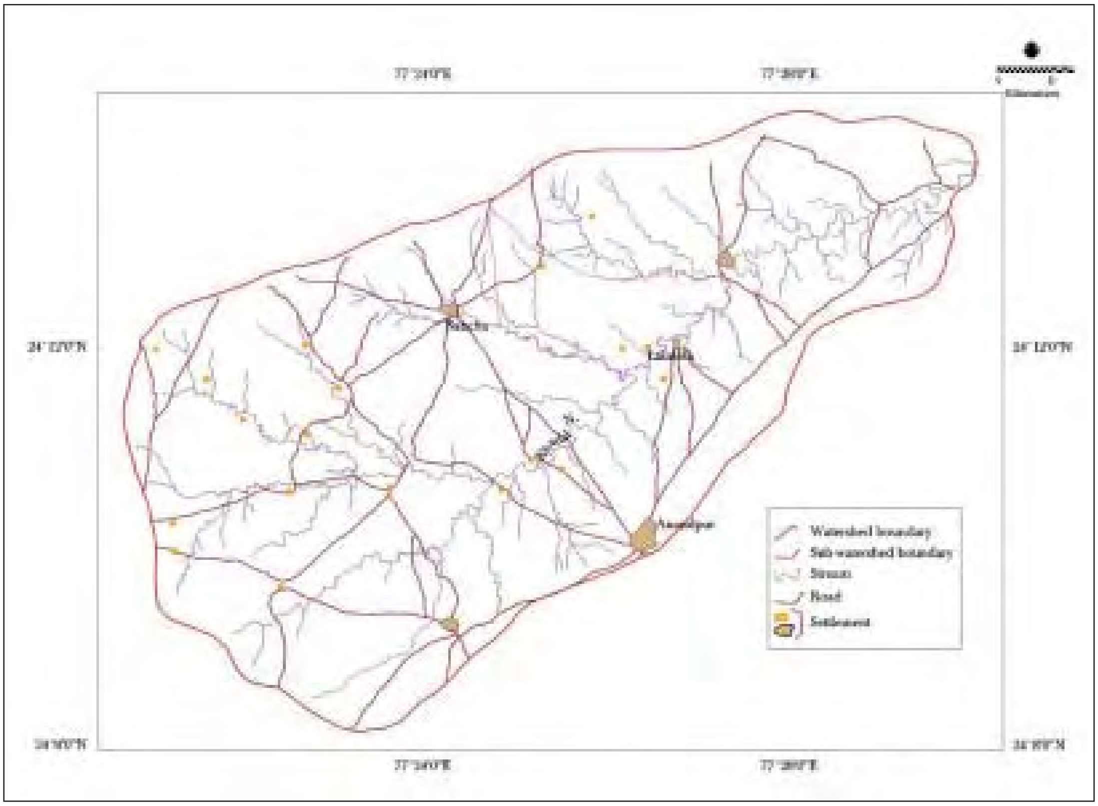

Figure 2. Map showing Milli watershed and Lalatora watershed in Madhya Pradesh, India.

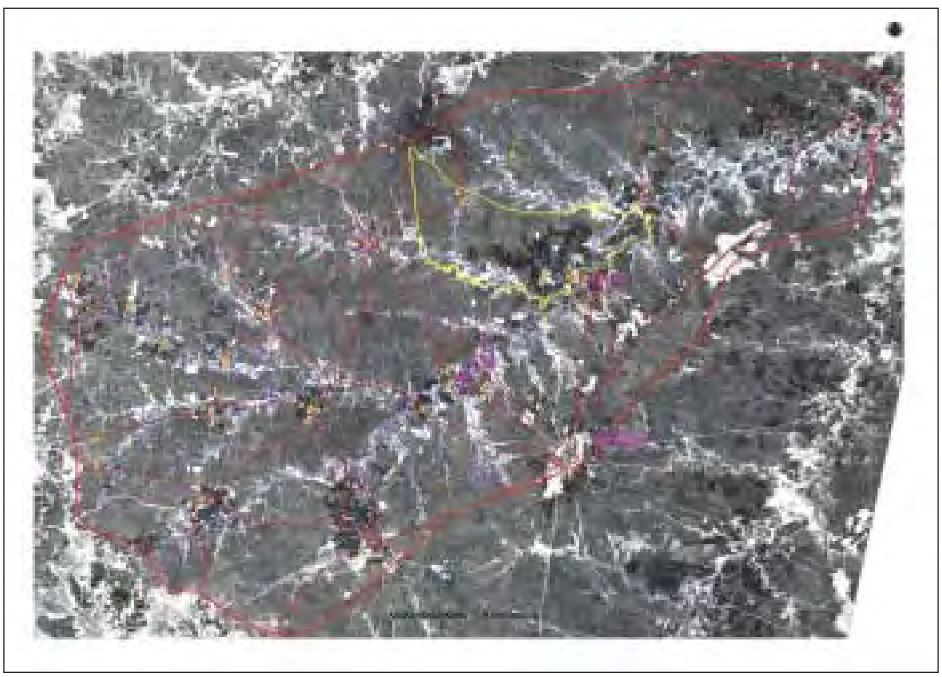

Figure 3. IRS-1C PAN image of Milli micro-watershed showing agricultural land use.

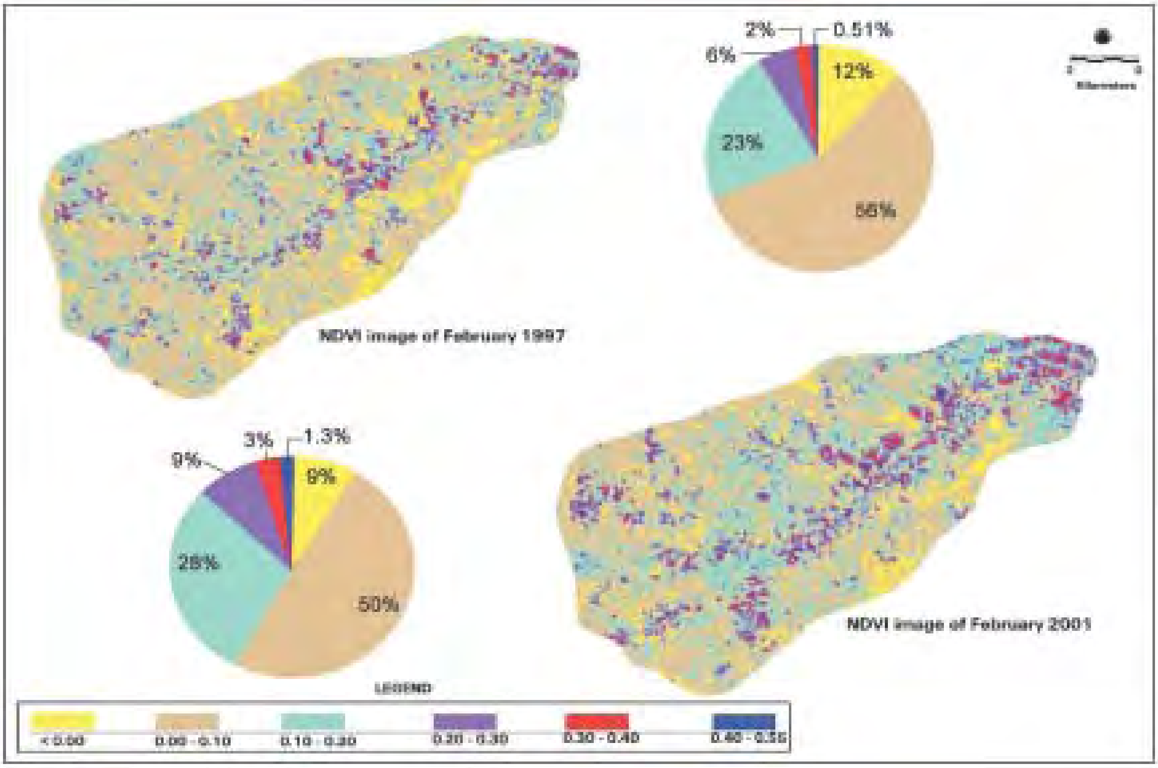

Figure 4. NDVI image of land use in Lalatora micro-watershed during postrainy season 1997 and 2001.

Impact of waterlogging on growth and yield of soybean

Waterlogging studies conducted at IISS, Bhopal on soybean-based systems revealed that waterlogging significantly influenced nodule number and dry biomass.

On-farm Farmer Participatory Research

Site selection

The process of site selection for on-farm research was done by a consortium of institutions, based on the dryland area, feasibility of the technology adoption (similar agroclimatic conditions), landholding size, socioeconomic conditions, and willingness of the farmer, etc. The site selection for Adarsha watershed, Kothapally, Andhra Pradesh, India was done by ICRISAT, DPAP, and MVF along with the involvement of the stakeholders.

ICRISAT, DPAP, and MVF together surveyed three watersheds in Andhra Pradesh and selected Adarsha watershed. The total irrigable area was very less. There was more dryland with a large area under rainfed farming in the village. There was not a single water harvesting structure for human or livestock use at the time of survey in 1998, i.e., before the initiation of the project. As no interventions were made to conserve soil and water in this watershed, it was selected to encompass the convergence. Adarsha watershed was selected after a committee meeting with villagers in a "Gram Sabha" and villagers participated in the proposed watershed activities.

Participating groups

Different committees and groups were formed in the village and the villagers themselves selected leaders. The committee members participated from the initiation of the watershed activity such as selection of the site, implementation of the activity, and execution and assessment of all the developmental activities within the watershed.

Baseline survey for constraint analysis in the watershed

After the selection process, necessary information on the environment and conditions of the village was collected. Baseline data collection was done by both the researchers and the stakeholders. The following information was collected:

- Socioeconomic status of the farmers and landless people, crop productivities, inputs, and livelihood opportunities.
- Soil, water, and nutrient management practices followed by the farmers.
- Soil, climate, cropping systems, and input use. The data was assembled and analyzed.
- Production constraints, yield gaps, and opportunities for crop intensification. GIS maps were prepared for different crops, soils, and cropping systems of the village.

The results of the survey indicated that in Kothapally village, dryland area was more (62.79%) compared to irrigated land (37.21%); literacy rate (35.74%) was low; and labor was scarce. There was inverse relationship between land size and fertilizer/pesticide use. Crop yields were very low (1070 kg ha^{-1} for sorghum, 1500 kg ha^{-1} for maize, 190 kg ha^{-1} for pigeonpea) and there was not a single water harvesting structure in the village. The villagers did not undertake any income generating activities.

Soil and water conservation activities

To control erosion and restore productivity of degraded soils in the benchmark watersheds selected, several soil and water conservation options were evaluated to conserve and harvest rainwater and increase the productivity of the crops. These activities are important in maintaining, improving, and enhancing productivity of the crops. Widespread adoption of improved practices is essential for desertification control and restoration of degraded soils. Engineering techniques of erosion control and runoff management can be made more effective when used in conjunction with biological control measures. In all the watersheds several soil and water conservation activities along with biological control measures were taken up both at farm and community levels.

Ex-situ conservation

- Grassed waterways
- Water storage structures
- Gully control structures
- Field bunding

In situ conservation

- Shaping of the land reduces runoff; hence, the land is made rough by BBF and other similar landform treatments.
- In the BBF method the beds of 1.05 m width and 45 cm furrows are prepared at 0.4 to 0.6% gradient. The BBF method reduces runoff, conserves more water in the soil profile, and drains excess water safely away from the crops.
- Contour planting on flat landform.
- Bullock-drawn tropicultor developed by ICRISAT is used by the farmers at Kothapally for planting, sowing, fertilizer application, and intercultivation practices.
- Planting of *Gliricidia* is done by farmers on field bunds for stabilizing the bunds to conserve the rainwater and soil. In addition these plants will generate N-rich organic matter for field application, which will augment the N supply for crop growth. This reduces the dependence on mineral fertilizer N.

Integrated nutrient management

Vegetative bunds

Gliricidia was planted on field bunds to conserve moisture. The loppings were incorporated into the soil to provide biologically fixed N and reduce the usage of chemical fertilizers. *Gliricidia* also adds valuable organic matter to soil.

Nutrient budgeting and balanced fertilization trials

To study nutrient budgets at watershed level, a stratified random sampling was done by dividing the watershed into three toposequences. As per the farm holding size, the farms were selected for nutrient budgeting studies. This approach enabled us to calculate the nutrient budgets at watershed level and also assisted in developing the balanced nutrient management strategies for sustaining the productivity in the watershed. This study involved detailed soil and crop analyses. In addition detailed accounts of nutrient inputs and outputs by the farmers were maintained. Pilot studies were conducted at Milli watershed, Lalatora and Adarsha watershed, Kothapally.

We selected a sample of 25 farmers of different farm sizes in Milli watershed, Lalatora. Five farmers having <1 ha (small), six farmers having 1–2 ha (medium), and 14 farmers having >5 ha (large) landholding were selected. These numbers were in proportion to the respective size category in the watershed. A field was identified in each selected farmer's holding and monitored for nutrient inputs and outputs. All information about various nutrient inputs to different crops in the same field was collected. At harvest, the crops were sampled for yield as well as for nutrient uptake (Table 5).

The data indicated that for all major crops and cropping systems the phosphorus (P) balance was positive, while the balance for potassium (K) was negative. This is because almost all farmers apply diammonium phosphate (DAP) while no farmer applied any K fertilizer. Since these Vertisols are rich in K, deficiency of K may not occur in the near future. We presume there is buildup of P in the soil and there is scope to reduce P application. It is quite interesting that both the legume crops, soybean and chickpea, are mining N from soil. The wheat crop is fertilized more than it takes N and P from soil. Poor farmers grow sorghum crop without any input and the yield as well as nutrient outputs are also very small.

In Adarsha watershed, Kothapally, balances for N, P, and K were computed in 15 farmers' fields wherein improved SWNM options along with conventional practices were followed. Balanced nutrient doses were used for sustaining productivity. In this study N inputs through rainfall and biological nitrogen fixation (BNF) by legumes have been computed. *Rhizobium* inoculation of pigeonpea and soybean seeds was done to increase BNF. Positive crop responses to specific nutrient amendments based on soil analysis, e.g., boron (B) and sulfur (S) applications were done and increased yields were observed. Higher grain yields were obtained with improved practices indicating considerable scope for savings on N fertilizer.

The nutrient uptake by maize/pigeonpea intercropping system was more in the improved systems with BBF as compared to that of flat landform treatment. The N-difference and ^{15}N isotope dilution methods were used to quantify N contribution of legumes through BNF using non-fixing control plants. Similarly, for the sole maize

Table 5. Nutrient budgets for selected crops and systems at Milli watershed, Lalatora, India.

	Input (kg ha^{-1})			Output (kg ha^{-1})			Balance (kg ha^{-1})		
Crop	N	P	K	N	P	K	N	P	K
Sole crop									
Soybean	8	20	0	91[1]	6	42	–37	14	–42
Wheat	59	15	0	51	6	34	8	9	–34
Chickpea	15	9	0	63[1]	4	41	–16	5	–41
Sorghum	0	0	0	16	2	26	–16	–2	–26
Soybean-wheat system									
Soybean	9	24	0	105[1]	8	52	–43	16	–52
Wheat	62	15	0	52	7	37	10	8	–37
Total	71	39	0	157	15	89	–33	24	–89
Soybean-chickpea system									
Soybean	10	23	0	102[1]	7	45	–41	15	–45
Chickpea	17	8	0	61[1]	4	43	–13	4	–43
Total	27	31	0	163	11	88	–54	19	–88

1. 50% of N uptake in soybean and chickpea is presumed to be from biological nitrogen fixation.

crop, uptake of nutrients was more in BBF system than in flat landform. The nutrient balances based on the available data sets showed that all the systems are depleting K from soils and more P is applied than removed by the crops. Crop yields as well as the nutrient removal was more in BBF than in the flat landform treatment. High negative N balance in maize/pigeonpea BBF system (–55 kg N ha^{-1}) indicates that the crop extracted more N from the soil when grown on BBF system than when grown on flat system (–48 kg N ha^{-1}). In sole maize on flat system N balance was only –24 kg N ha^{-1}. Similar trend was observed in all the cropping systems studied. Potassium balance was also influenced by landform. In BBF system (–40 kg K ha^{-1}) the crop could extract more soil K than in flat system (–29 kg K ha^{-1}) in maize/pigeonpea cropping system.

Best-bet options

The scientists from JNKVV, CRIDA, and ICRISAT put together a best-bet option for soybean-based systems. This consisted of use of improved variety of soybean JS 335, seed treatment with Thiram along with *Rhizobium* and phosphate solubilizing micro-organisms, application of DAP at 50 kg ha^{-1}, and integrated pest management (IPM). In the first year, 27 farmers evaluated this option for soybean covering 40 ha. Average increase in soybean yield was 34% above the baseline/control plot soybean yield of 950 kg ha^{-1}. Detailed analysis of benefit-cost ratio for the farmers who evaluated this option was worked out and the net profit was estimated at Rs 5575 ha^{-1}.

Micronutrient amendments

Balanced nutrient doses were used for sustaining productivity in these watersheds. *Rhizobium* inoculation of pigeonpea and soybean seeds was done to increase BNF. Positive crop responses to specific amendments based on soil analysis, e.g., B and S amendments were done at Kothapally and Lalatora watersheds, which proved to be a success as increased yields were observed.

Green manuring

The importance of leguminous green manures such as *Gliricidia* in maintaining soil and crop productivity has been widely accepted. Decomposition of *Gliricidia* loppings and nutrient release occur at a faster rate due to low C:N ratio. Most of the nutrients especially N and K are released within 5–10 days of decomposition.

Comparative evaluation of decomposition of *Gliricidia* and pigeonpea plant residues showed that leaves of *Gliricidia* decomposed faster than pigeonpea plant parts (leaves, stem, and roots). Highest N mineralization (119 mg N kg^{-1}) occurred with surface soil application of *Gliricidia* leaves compared to *Gliricidia* stems (93 mg N kg^{-1}) at 150 days of incubation.

Micro-enterprise: vermicomposting

Earthworms are used in vermicomposting as they are voracious feeders and can transform organic wastes into compost in a short span. Compost, which is processed by earthworms, makes good organic fertilizer as it contains auxins, a growth promoter for plants and also some natural antibiotics. Vermicomposting is a cost-effective pollution abatement technology. Women self-help groups (SHGs) in Adarsha watershed, Kothapally and individual farmers in Lalatora watershed have undertaken vermicomposting as an income generating activity. Farmers have evaluated response of vegetable crops to vermicomposting and have observed significant increases in yields of tomato in Kothapally.

Integrated pest management

Integrated pest management is the coordinated use of pest and environmental information to design and implement pest control measures that are economically, environmentally, and socially sound. Pesticides are used only when needed and when other control methods will not prevent economically important pest injuries. The outcome of a sound IPM program is usually increased profits due to savings from reduced pesticide application and increased protection of the environment. Insect pests continue to be the major problem in pulse production in Asia. Intensive use of pesticides leads to total crop loss. Complete dependency on chemical control for the past three decades has led to unsatisfactory pest management along with environmental degradation.

ICRISAT, along with the national agricultural research and extension systems (NARES), NGOs, and farmers in the watershed conducted research to identify environmentally sound and economically viable plant protection technologies which reduce yield losses and improve the income of the farmers. Farm surveys and participatory rural appraisals identified the non-availability of IPM components such as biopesticides, *Helicoverpa* nuclear polyhedrosis virus (HNPV), pheromones, and high pest tolerant varieties. The farmers harvested six-fold increased yields through better management of pests by controlling them with neem seed extract along with pest tolerant crop varieties and there was 6–100% reduction in pesticide usage. After thorough evaluation of the existing pest management options, a comprehensive integrated pest management package for chickpea and pigeonpea has been developed and evaluated through farmer participatory approach mode. Revitalizing the effective indigenous methods like shaking off pod borers from pigeonpea plants and use of neem for pest management is done in the watersheds. These indigenous methods are effective, cheaper, and environment-friendly. Installation of pheromone traps for pest monitoring is done every year. Bird perches were also installed in the fields for birds to rest and feed on *Spodoptera* and *Helicoverpa* larvae.

The availability of good quality HNPV was considered a prime component for spread of IPM. Village-level production centers were initiated to cater to the needs of farmers. Many farmers and extension workers from villages were given training on HNPV production, storage, and usage on different crops. The project handled by ICRISAT has given high priority for training village-level scouts in identifying various pests and their natural enemies in different crops before the cropping season, and assisted them in monitoring throughout the crop period.

Impact of Consortium Model for Watershed Management on Rural Livelihoods

Improved productivities

At Kothapally, farmers evaluated improved crop management practices along with improved land management practices such as sowing on a BBF landform; flat sowing on contour; and using improved bullock-drawn tropicultor for sowing and interculture operations. Farmers obtained two-fold increase in the yields in 1999 (3.3 t ha^{-1}) and three-fold increase in 2000 (4.2 t ha^{-1}) as compared to the yields of sole maize (1.5 t ha^{-1}) in 1998.

Increased incomes

Along with the highest system productivity the benefit-cost ratio of the improved systems was more (1:2.47) compared to the farmers' traditional cotton-based systems (Table 6) (Wani et al. 2002b).

Biological nitrogen fixation using legumes in Tad Fa watershed

Most of the farmers in northeast Thailand apply chemical fertilizers to their cash crops for high yields. Chemical fertilizers are one of the costliest inputs and

Table 6. Economics of cultivation of different crops at Adarsha watershed, Kothapally during crop season 1999/2000.

Cropping system	Total productivity (kg ha^{-1})	Cost of cultivation (Rs ha^{-1})	Total income (Rs ha^{-1})	Profit (Rs ha^{-1})	Benefit-cost ratio
Improved					
Maize/pigeonpea	3300	5900	20500	14600	2.47
Sorghum/pigeonpea	1570	6000	15100	9100	1.51
Traditional					
Cotton	900	13250	20000	6750	0.50
Sorghum/pigeonpea	900	4900	10700	5800	1.18
Mung bean	600	4700	9000	4300	0.91

there is a need to identify other alternatives or supplement sources to overcome nutrient constraints. There is not much scope to use farmyard manure (FYM) as farm animals have been replaced by farm machines for draft purposes. The use of legumes in the cropping system would certainly help to reduce the amount of chemical N fertilizer. To recommend which legume should be grown in which cropping system we have to know the amount of N fixed by few legumes which are suitable to grow in this ecoregion and how much benefit these legumes give to the succeeding non-legumes. This information is crucial for recommending reduction of fertilizer N to farmers.

Rice bean, black gram, sword bean, and sunnhemp have been evaluated for quantifying N_2 fixation and the benefits of legumes using ^{15}N abundance method and ^{15}N isotope dilution method on farmers' fields at Ban Koke Mon located near Ban Tad Fa in Thailand where ICRISAT benchmark watershed is situated. The cropping systems of Ban Koke Mon are similar to those of Ban Tad Fa:

- Legume-cereal: Rice bean-maize, sunnhemp-maize, sword bean-maize, black gram-maize.
- Cereal-ceral: Maize-maize.

Growing black gram, rice bean, and sunnhemp in the system would help in reducing N requirement for the succeeding maize crop. The results showed that the actual realized benefits from legumes in terms of increased N uptake by the succeeding maize crop varied from 5.3 to 19.3 kg N ha^{-1} whereas the expected benefits from legumes through BNF and soil N sparing effect over a maize crop varied from 15 to 64 kg N ha^{-1}. These results demonstrated that it is not only the quantity of N_2 fixed that determines the benefit to the succeeding crop but also the quality of organic matter and N release pattern from the legume residue. However, in the long term for sustaining land productivity sword bean could play an important role.

Micronutrient amendments – a success at Lalatora watershed

Detailed characterization of soils in Lalatora watershed revealed that these soils are deficient in B and S and both these nutrients are critical for optimizing productivity of soybean-based systems. Farmers were made aware of the results and some farmers came forward to evaluate the response for B and S application in their fields along with the improved management options. Ten kg of borax (1 kg B) ha^{-1} and 200 kg of gypsum (30 kg S) ha^{-1} were applied by the farmers. In 2000, all the farmers reported significant differences in soybean plant growth with B, S, and B+S treatments over the best-bet control treatment. Also, soybean yields were increased by 19 to 26% over the best-bet control treatment (Table 7). The results indicated that amendments with B and S not only increased soybean yields over best-bet treatment but also benefited the subsequent wheat crop without further application of B and S. Farmers were so much impressed with their experimentation that for 2001 season they indented B and S for their use well in advance through the NGO, the BAIF Research Foundation.

The economic analysis of the on-farm trials 2000/01 showed that combined application of B and S gave maximum benefit of Rs 26,454 followed by only B (Rs 26,609) and S (Rs 25,955) application alone. All these three treatments proved to be beneficial to the farmers with 1:1.8 benefit-cost ratio as compared to control traditional practices (1:1.3) followed by the farmers.

Table 7. On-farm evaluation of soybean and wheat to boron and sulfur amendments in Lalatora sub-watershed, 2000/01.

	Grain yield (t ha^{-1})		
Treatment	Soybean	Wheat	Soybean + wheat system
Boron	1.87 (23.2)[1]	3.74 (40.6)	5.61 (34.2)
Sulfur	1.81 (19.1)	3.50 (31.9)	5.31 (27.0)
Boron + Sulfur	1.91 (25.6)	3.57 (34.2)	5.48 (31.1)
Control (Best-bet treatment)	1.52	2.66	4.18

1. Figures in parentheses indicate increase (%) over control.

Monitoring and impact of watershed management at Adarsha watershed

Monitoring

To know the impact of watershed management continuous monitoring of several parameters as described below was done:

- Changes in crops and systems in farmers' fields were monitored.
- An automatic weather station was installed to record the rainfall, maximum and minimum temperatures, and solar radiation.
- Sixty-four open wells in the watershed were geo-referenced and regular monitoring of groundwater levels was done.
- Water quality was monitored in all the wells and also from the water storage structures in the village. Sediment samples (silt) were also collected from the tanks to understand the processes of environmental degradation in the watershed.
- Nutrient budgeting studies were also undertaken.
- Runoff and soil loss were monitored by using automatic water level recorders and sediment samplers.
- Satellite monitoring was done.
- Pest monitoring was also carried out.

Impact

The management of natural resources has become effective and the livelihoods of the rural people have improved. The impact is assessed based on the following:

- Improved greenery: An increase in vegetation cover was observed; in 1996 the vegetation cover was 129 ha and in 2000 it was 200 ha at Kothapally.
- Improved groundwater levels: Groundwater level in the village significantly increased in Adarsha watershed.
- Reduced runoff and soil loss: Runoff was 12% of the rainfall in the undeveloped watershed while it was only 6% in the developed watershed where soil and water conservation measures were undertaken.
- Increased productivities: The crop productivities significantly increased with improved cropping systems and improved management practices. The yield of maize crop recorded two- to three-fold increase (3.3 to 3.8 t ha^{-1}) when compared with baseline yields (1.5 t ha^{-1}).
- Increased incomes: Farmers' incomes as well as cropping system productivities increased. Maize/ pigeonpea cropping system could give 3.5 times benefit (1:3.5) than the traditional cotton system (1:1.5).

Improved land management options

In 2000/01, at Adarsha watershed, several farmers evaluated BBF and flat landform treatments for shallow and medium-deep black soils using different crop combinations. Farmers harvested 250 kg more pigeonpea and 50 kg more maize per hectare using BBF on medium-deep soils than flat landform treatment. Furthermore, even on flat landform farmers harvested 3.6 t ha^{-1} maize and pigeonpea using improved management options as compared to 1.7 t ha^{-1} maize and pigeonpea using normal cultivation practices.

Of all the cropping systems taken up in Adarsha watershed, maize-chickpea sequential cropping (benefit-cost ratio of 1:2.85) and maize/pigeonpea intercrop (benefit-cost ratio of 1:2.81) proved to be more beneficial to farmers in terms of benefit incurred to farmers. Farmers could gain about Rs 19,590 and Rs 17,802 with these systems respectively. Sorghum, chickpea, and pigeonpea sole cropping systems also proved beneficial, whereas sorghum, maize, and chickpea traditional systems were significantly less beneficial to the farmers.

Shift in cropping patterns

A close perusal of the prevalent cropping system, its acreage and previous history before watershed intervention by ICRISAT gives a precise picture of how watershed approach benefits the final stakeholders, i.e., farmers. Before dissemination of watershed technology at Kothapally, the village was predominantly a cotton-growing area. The spread of cotton crop was 200 ha in 1998 in the village. The other crops grown were maize, chickpea, rice, pigeonpea, sorghum, and vegetable crops.

The watershed intervention by ICRISAT and consortium partners followed an integrated new technological approach which encompassed improved soil cultivation and water management techniques, and land and crop management practices (suitable varieties, intercropping, legume-cereal cropping systems, BBF system, intercultural operations, *Gliricidia* planting along bunds and incorporation of *Gliricidia* loppings, HNPV sprays, and vermicompost technology).

After three years of watershed activity in Kothapally, the acreage under cotton cultivation decreased from 200 ha to 100 ha (50% decline) with a simultaneous increase in maize and pigeonpea area (Table 8). The acreage under maize and pigeonpea increased three-fold from 60 ha to 180 ha within three years. The acreage of other crops remained almost the same. This substantial shift in the cropped area where maize and pigeonpea replaced cotton crop was mainly due to increased net profit per hectare. The cotton-based cropping system had higher cultivation costs (higher inputs) with lesser net profits compared to maize/pigeonpea, sorghum/pigeonpea, or maize/chickpea system. Adoption of legume-cereal crop combination or rotation cropping increased the net profit with less cultivation costs in the watershed area.

Land use planning for increased household incomes in Thanh Ha watershed

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 the most prudent way for higher household incomes and food security. Efforts have been made to identify appropriate crops and crop combinations in various seasons for enhanced household incomes in the backdrop of systems sustainability, soil health, and potential for large-scale adoption and adaptation. For example, maize, groundnut, and soybean combination gave higher incomes in spring while maize and groundnut and maize and soybean crop combination appear to be better in autumn-winter season. The traditional maize cultivation was not at all economical.

Crop performance differed significantly across the seasons. Spring season was more favorable in terms of grain yields and associated income gains than autumn-winter season (Fig. 5). Among the crops soybean performed better in spring and summer than in winter season. Soils in the sloping lands are highly vulnerable to erosion when cleared of vegetative cover and are subjected to various forms of land degradation. Loss of humus rich topsoil left behind the subsoil devoid of vital plant nutrients leads to rampant infertility and poor water-holding capacity. It is, therefore, important to identify crops that not only perform well on these soils but also help improve soil health over the years.

To find out the influence of land degradation on crop productivity and profitability the grain yields of soybean, groundnut, mung bean, and maize based on the location on the toposequence in the landscape watershed were delineated. In general, higher grain yields and farm incomes were obtained in the lower and middle part of the toposequence compared to that in the top due to less degradation and better soil fertility. Farmers are incurring higher expenditure due to increased fertilizer usage in top of the toposequence. Among the crops groundnut can be grown successfully in top, middle, and lower parts of

Table 8. Cropping practices at Adarsha watershed, Kothapally.

Crop	Area (ha) before watershed activity (1998)	Area (ha) after watershed activity		
		1999	2000	2001
Maize	60	80	150	180
Sorghum	30	40	55	65
Pigeonpea	50	60	120	180
Chickpea	45	50	60	75
Vegetables	40	45	60	60
Cotton	200	190	120	100
Rice	40	45	60	60

the toposequence while mung bean and soybean need high level of management in 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 systems resilience and increased household incomes.

Human Resource Development

Human resource development is an important component of integrated watershed management model to train farmers, national researchers, and development workers and to empower them by enhancing their knowledge. Farmers are exposed to new methods and knowledge for managing natural resources through training, video shows, and field visits to on-station and on-farm watersheds. Educated youth are trained in skilled activities such as HNPV production and vermicomposting. Micro-watershed within the main watershed serves as “an island” for learning for the farmers. Special emphasis is given to educate the women farmers to new management options. The technical backstopping team is always handy to the farmers for clarifying their doubts and seeking more information at their location. Farmers and landless families are trained and encouraged to undertake income generating activities in the watershed which can be of help to sustain the productivity at catchment/watershed level.

Specialized hands-on training courses/workshops were held for NARS partners. Training courses for department officials and farmers were conducted. Twenty-four apprentices from developed/developing countries were trained. Important dignitaries and policy makers were also made aware of the watershed programs. Training materials were developed: (i) Web page of the project; (ii) On-line data monitoring system for the project; and (iii) CD-ROM training module for watershed management.

Way Forward

Spectacular gains made and lessons learned in this project must be encashed for integrated rural development. Institutional, policy, and technological needs for sustaining watersheds need to be in place. Sharing and transfer of knowledge of natural resources management to NARS through empowerment as well as a study of on-site and off-site impacts on sustainability and environment quality are essential. Second generation problems in watersheds need to be addressed.

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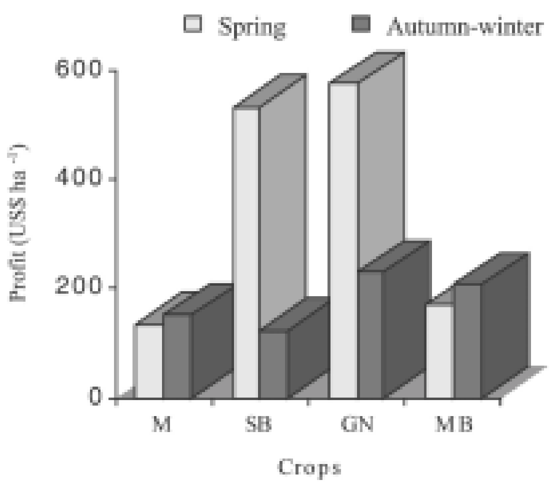

Figure 5. Performance of crops in spring and autumn-winter seasons, Thanh Ha, 2000.
(Note: M = maize, SB = soybean, GN = groundnut, and MB = mung bean.)

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