Integrated Watershed Management for Land and Water Conservation and Sustainable Agricultural Production in Asia

International Crops Research Institute for the Semi-Arid Tropics

International Water Management Institute

Asian Development Bank

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Abstract

Erratic rainfall, land degradation, soil erosion, poverty and burgeoning population characterize the dry regions in Asia. To develop sustainable natural resource management options for increasing the agricultural productivity and income of the rural poor in these regions, a new Integrated Farmer Participatory Watershed Management Model was developed by ICRISAT in partnership with the national agricultural research systems (NARS). This model was applied at selected benchmark locations in Asia by ICRISAT through the project RETA 5812 “Improving management of natural resources for sustainable rainfed agriculture in Asia”, funded by the Asian Development Bank (ADB). The challenge for catchment research is to generate technologies and management systems that is now being addressed by the Management of Soil Erosion Consortium (MSEC) project RETA 5803 “Catchment approach to managing soil erosion in Asia”. This project is funded by ADB and the International Water Management Institute (IWMI) serves as the facilitator. The workshop “Integrated Watershed Management for Land and Water Conservation and Sustainable Agricultural Production in Asia” was held to review these projects. Forty-five scientists from China, India, Indonesia, Laos, Nepal, Philippines, Thailand, and Vietnam participated in the workshop. The objectives of the workshop were to:
(1) Review the progress made at benchmark watersheds/catchments and synthesize the findings from the work of the projects RETA 5812 and RETA 5803; (2) Discuss work plans for 2002, identify emerging issues and future strategies for sustainable use of natural resources for improving rural livelihoods through new initiatives; and (3) Discuss watershed development and management technologies. During the period, a one-day workshop on Watershed Methodologies was also organized. The research papers based on the work conducted for three years at different benchmark sites in Asia are covered in this publication. The multi-country and multi-institutional research findings about watershed/catchment management reported here will serve as a valuable resource for the researchers, policymakers and students working in the area of sustainable management of natural resources.

Integrated Watershed Management for Land and Water Conservation and Sustainable Agricultural Production in Asia

Proceedings of the ADB-ICRISAT-IWMI Project Review and Planning Meeting

10–14 December 2001, Hanoi, Vietnam

Editors

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Many individuals contributed to the success of the workshop. We sincerely thank Drs T D Long, Deputy Director General, VASI, Thai Phein and T D Toan of National Institute for Soils and Fertilizers (NISF), and M/s N V Viet and D D Phai for all the logistical support for the Workshop. We are thankful to the Asian Development Bank (ADB) for providing financial support through RETA 5812 "Improving Management of Natural Resources for Sustainable Rainfed Agriculture" and RETA 5803 "Catchmeat Approach to Managing Soil Erosion in Asia" for conducting this workshop. The Organizing Committee sincerely thanks Drs C D Phat, Ministry of Agriculture and Rural Development (MARD), Vietnam, D J Bandaragoda, IWMI, and William D Dar, ICRISAT for delivering the opening and inaugural addresses and also for extending their full support. We are indebted to Drs R C Sachan, K L Sahrawat, and Piara Singh for reviewing the manuscripts. M/s K N V Satyanarayana and Y Prabhakara Rao undertook the various secretarial tasks graciously and their help is acknowledged. We are thankful to Ms Sheila Vijayakumar for invaluable assistance for editing the manuscripts and to Mr K N V Satyanarayana for incorporating corrections and page-setting the proceedings.

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Local Organizing Committee

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Foreword

Natural resources throughout the world, particularly in Asia where demographic pressures are very high, are under severe threat. The need to improve the management of natural resources for meeting the food, feed and fuel needs of the ever-increasing population, is urgent. Since 1999, the Asian Development Bank (ADB) has supported the efforts of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to address these concerns through RETA 5812, *Improving the Management of Natural Resources for Sustainable Rainfed Agriculture.*

The project has covered substantial ground over the last three years, establishing benchmark watersheds in India, Thailand and Vietnam, and bringing about substantial increases in the productivity of the rainfed systems. The project has also achieved a significant milestone through close collaboration with another ADB-supported project, *Catchment Approach to Managing Soil Erosion in Asia*, executed by the Bangkok office of the International Water Management Institute (IWMI). These two projects have brought new life to the management of watersheds by promoting participatory integrated management at the community level, and by assessing the impact of these efforts on soil erosion.

I am very pleased to note that these two projects have joined hands through a final workshop on *Integrated Watershed Management for Land and Water Conservation and Sustainable Agricultural Production in Asia*, in addition to a Watershed Methodology Workshop. Scientists from seven Asian countries and three international institutions working in Asia on the management of natural resources contributed to the proceedings of the workshop, which were published jointly by ICRISAT and IWMI. The detailed papers of both workshops, which include detailed case studies from seven Asian countries, constitute a very valuable source of information on methodologies for managing natural resources.

The ADB is to be commended for supporting this very important area of research. The Project Managers, Dr Suhas P Wani of ICRISAT and Dr Amado Maglinao of IWMI, have put a great deal of effort into coordinating these two multi-country projects. Having had the opportunity to monitor the progress of the project in India, Thailand and Vietnam, I am happy to state that the results of three years of painstaking research of both projects have been coherently assembled in this publication. I am confident that these proceedings will serve as a valuable resource for researchers, development workers, policymakers and students of natural resource management.

November 2003

William D Dar
Director General
ICRISAT

Welcome Address

T D Long[1]

On behalf of the local organizing committee, I wish to extend a very warm and hearty welcome to the scientists and experts from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Water Management Institute (IWMI), China, India, Indonesia, Laos, Nepal, Philippines, Sri Lanka, Thailand and local dignitaries from Danish Agency for Development Assistance (DANIDA), Research and Technological Exchange Group (GRET), Centre de cooperation internationale en recherché agronomique pour le développement (CIRAD), Centro Ricerche Fiat (CRF), and Bioseed who have come here to participate in the workshop on Integrated Watershed Management for Land and Water Conservation and Sustainable Agricultural Production in Asia (ADB-ICRISAT Annual Project Review and Planning Meeting and 6th MSEC Assembly).

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 many areas. As the burgeoning populations are expanding into steeper and more fragile areas in the uplands, more catchments are threatened with severe soil erosion, declining soil productivity, and environmental degradation. Degradation of natural resources in the watersheds now poses a great threat to the economies of many developing countries and more so in the developing world as the livelihoods of the ever-growing populations depend on these resources.

On-site soil loss reduces soil fertility in terms of chemical, physical, and biological depletions. These soil changes in turn are reducing crop yield, farm 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 reduced living conditions of the people.

The Integrated Participatory Watershed Development Program promoted under the Asian Development Bank (ADB) assisted project (RETA 5812) very well addressed the above constraints with emphasis on:

- Simultaneous development of land, water, and biomass resources in light of the symbiotic relationship among them.
- 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 the research was 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 has also ensured that the whole range of stakeholders, from land users to policy makers, are involved in the generation and promotion of improved land use practices. Benchmark watersheds managed by Vietnam Agricultural Science Institute (VASI) and National Institute for Soils and Fertilizers (NISF) are serving as good demonstration sites for the farmers and other stakeholders to develop sustainable farming technologies on sloping lands through participatory approach.

We would like to congratulate ICRISAT and IWMI as well as VASI and NISF project team members for their innovativeness and pioneering spirit that has provided the project with very important information on the agronomic advisability,

1. Vietnam Agricultural Science Institute (VASI), Hanoi, Vietnam.

economic feasibility, and social acceptability of what increasingly appear to be very promising technological possibilities for a large number of farmers in northern Vietnam.

But much more important, it is our opinion that the project is rapidly moving into a position of leadership in northern Vietnam. If it continues its present course of innovation for another 3–5 years, it could well become the state-of-the-art integrated watershed project in northern Vietnam, the project under which virtually all others in northern Vietnam will be placed to learn about soil and water conservation, recuperation, integrated nutrient management, sustainable cropping systems and how to apply science and technology-led development to significantly improve prospects for reducing poverty, food insecurity, and malnutrition in the sloping lands of northern Vietnam.

I wish that the deliberations in the next few days would be very stimulating and thought provoking and help develop effective research plans. I once again welcome all the participants to the beautiful country of smiling faces and wish you all a pleasant and productive stay in Hanoi, Vietnam.

Thank you.

Catchment Research: A Valuable Support for Integrated Land and Water Resources Management

D J Bandaragoda[1]

Land-Water Interactions

The linkage between land and water is well known, particularly in the context of agriculture. However, in most policy, administrative, and scientific deliberations, land and water have often been treated in two distinct sectors. In the process, some important land-water interactions have tended to be ignored, or considered in a fragmented manner. Many issues focusing on sustainable management of natural resources such as those related to desertification, erosion, nutrient depletion, floods, drought, and protection of watersheds and coastal areas tend to be analyzed and understood either solely as land issues, or as water issues. "Water, a reflection of land use", illustrates how human actions in changing the landscape and their side effects influence water flows and pathways, causing various chemicals to be introduced into water, which in turn affect land fertility and thereby cause many social problems (Source: Falkenmark et al. 1977). Water in any catchment has passed through upstream land and "carries the chemical memories from that journey", while land needs access to safe water to be productive. Thus, the catchment experiences a constant interaction between the hydrological process and their ecological effects.

Catchment research, such as the efforts undertaken by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Water Management Institute (IWMI), and their partners, is important in understanding these phenomena. This research also underscores the usefulness of considering a catchment as the appropriate context in which land and water interactions can be effectively researched in an integrated manner. An integrated approach is more likely to help in the designing of better policies and administrative structures for sustainable development and management of these two intrinsically interlinked resources.

An integrated effort in research, development, and management of land and water coincides with the valued idea of sustainability. As defined by FAO in 1990, "Sustainable development is the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for the present and future generations." Conservation and proper management of land, water, and plant and animal genetic resources for agriculture, forestry, and fisheries are the key criteria of sustainability.

Both land and water resources are often used in unsustainable ways, resulting in the degradation of most catchments. Fulfilling the short-term economic demand of the increasing rural population often outweighs the concern for a more sustainable use of these resources. Recent estimates by the International Food Policy Research Institute (IFPRI) indicate that about 40% of world's agricultural land is seriously degraded. In South and Southeast Asia, about 46% of the total land area is affected by human-induced soil degradation, and of this, about 90% has experienced some decline in agricultural productivity. This poses a challenge to develop and apply catchment management strategies that will harmonize the use of catchment resources, particularly land and water, to produce the desired goods and services without any adverse effect on the environment. Soil degradation is a biophysical process, but its primary cause can invariably be traced to socioeconomic and political forces. Therefore, the real challenge of catchment research is to attract the attention of policy makers, an aspect which is yet to be fully realized.

1. International Water Management Institute (IWMI), Southeast Asia Regional Office, Bangkok, Thailand.

Catchment as a Unit of Analysis

Shifting the focus of analysis from irrigation or other land and water use systems to the river basin, or the catchment, is helpful in many ways. For instance, we are able to capture most of the interventions by land and water users, as the catchment is the area where they interact and live. It also helps to include in the analysis the interactions among various resource uses and user groups. In the process, a catchment approach greatly helps in understanding better the environmental, social, and economic influences that impinge on the productivity of land and water management. In a basin or a catchment context, inter-related issues on quantity and quality of land and water resource use, surface and groundwater, upstream influences and downstream effects, use of other inputs such as fertilizer, and disposal of waste and surplus water, can all be more easily and more comprehensively analyzed. Participation of a larger number of stakeholders can be sought, and natural resources planning can be more effectively carried out. As can be seen in emerging results of catchment research, the broader view is able to capture dimensions which are not normally included in a system management approach, such as the causes (and not only the effect) of land degradation, water scarcity, water quality, land and water related disputes, and inequitable benefits.

Non-physical Issues Related to Catchment Research

In conducting catchment research, in addition to the physical aspects related to land and water use, there are some non-physical (institutional and policy) concerns that need to be considered. I would like to highlight some of these.

Appropriate coordination mechanisms

Land and water resources are managed and used by multiple groups. Left to themselves, each group tends to give priority to its own needs, as coordinating mechanisms do not often exist on the basis of catchments. Consideration of all users and uses within a catchment facilitates the introduction of such inter-sectoral coordination.

Strong community participation

The need for greater coordination calls for a higher level of participation in resource management from all the resource users. Issues related to local natural resources can usually be identified clearly and more easily by the local community. A long-term association with the catchment area enables the local people to gain a very intimate knowledge about the natural phenomena and the related constraints on resource use. Therefore, the pooling of their knowledge is essential.

Collective action

The stakeholders may collectively derive some synergic benefit from being able to integrate their efforts. Effective participation and collective action in resource management, however, depend on the degree of awareness of important technical considerations. Some efforts in social organization to establish manageable groups within the community helps not only in bringing about this required awareness through various capacity building measures, but also in developing capability for collective action through effective participation. Dissemination of catchment research is greatly helped by such organized user groups. Effective community participation leads to an empowerment of the people, enabling them to take their own decision in agreed framework of rules. In a genuinely participatory approach, outsiders can play only a facilitating role. Helping the local people to help themselves, through increased awareness about the physical, ecological, and socioeconomic aspects of catchment management would be the best option we researchers and extension workers have for generating some impact of our work.

Security of property rights

Similarly, another important institutional requirement for sustainable land and water management is the security of property rights. The reason is that a sustained effort in catchment management requires a longer-term and secure property rights for individuals and groups as benefits would accrue over a long period of time. Stakeholders would be encouraged to invest on various catchment management measures, such as land contouring, tree planting, constructing check-dams, and bund protection, only if property ownership and land tenure are adequately secured.

Reliable information base

For effective coordination and institutional integrity, resource management within the catchment must be essentially knowledge-driven. As the physical and social characteristics of a river basin system or a catchment are not easily discernible, an effective catchment management effort should necessarily rely on a sound database. Data on the physical, social, environmental, economic, and institutional parameters of the catchment need to be collected and maintained. The different actors and sectors using land and water resources within the catchment should be able to understand and assess the requirements of one another. The most critical consideration in establishing an information base is its location, i.e., how well it can be placed so that all the involved parties could have easy access to the information they need. Also the methods of collecting the information, which ensure appropriate levels of reliability are important.

Policy support for resources management

In a river basin or a catchment, a large number of individuals and groups are involved in using land, water, and environmental resources for different sectoral purposes. An integrated approach in land and water resources management can be achieved only within a helpful policy environment. A coordinated set of policies, rules, and regulations is essential to cover all natural resources within the catchment, and also an effective coordination among the agencies related to the management of each natural resource. For example, the land laws should be in keeping with the laws related to the use of surface and groundwater, and the laws for environmental protection.

MSEC as an Important Catchment Research Program

Soil erosion is considered a major cause of land degradation and quite a few studies have been conducted to address the problem. The challenge for catchment research is to generate technologies and management systems that are widely accepted and maintained. This is the major task that is now being addressed by the Management of Soil Erosion Consortium (MSEC) project with funding support from the Asian Development Bank (ADB).

MSEC uses a network approach to the organization and implementation of soil erosion management research. The approach provides a mechanism that engages different scientists and research institutions to work together in a coordinated and participatory mode. As mentioned above, the unit of analysis is at the level of a catchment to be able to capture both the on-site and off-site effects of erosion. Research planning and implementation is undertaken through consultation among concerned national agricultural research and extension services (NARES), international agricultural research centers (IARCs), advanced research institutions (ARIs), non-governmental organizations (NGOs), and farmers.

The NARES play the central role in the consortium, particularly in the participatory research, but with a broad responsibility for underpinning applied and strategic research as well. Typically in catchment research, partnerships play a very vital role, and the efforts so far made in the MSEC project are commendable.

The Role of IWMI

For those of you who may still be wondering why IWMI is now involved in MSEC, and in this meeting, I would like to mention that as of 1 April 2001, the International Board for Soil Research and Management (IBSRAM) ceased to exist and its work continues as part of IWMI's science program. The IBSRAM staff have become part of IWMI's new Southeast Asia Regional Office based at Kasetsart University in Bangkok, Thailand. This work includes the supervision of the MSEC, which serves as the executing agency for the ADB project RETA 5803 (Catchment Approach to Managing Soil Erosion in Asia). I must mention at this point that IWMI greatly values the network tradition inherited from IBSRAM, and the opportunity of being able to collaborate with a number of such experienced research partners. While IWMI serves as the consortium secretariat and facilitator, it also has an important responsibility to ensure a good quality research content in the MSEC activities. To strengthen this relationship, IWMI has embarked on establishing appropriate institutional linkages with partner countries, and looks forward to fulfilling its obligations, both towards the respective countries, and the donors, who essentially expect high level research quality through MSEC activities.

IWMI, being one of sixteen centers of the Consultative Group on International Agricultural Research (CGIAR), is basically a research organization. IWMI's mission is to improve water and land resources management for food, livelihoods, and nature, and in this respect, IWMI conducts a worldwide research and capacity-building program to improve water and land resources through better technologies, policies, institutions, and management.

IWMI has chosen five research themes as its key instruments to address the need for strategic priority setting in the institute and to assure thematic integration of research agendas across physical locations. The five themes are:

1. Integrated Water Resource Management for Agriculture;
2. Sustainable Smallholder Land and Water Management Systems;
3. Sustainable Groundwater Management;
4. Water Resource Institutions and Policies; and
5. Water, Health, and Environment

The MSEC activities are mainly associated with IWMI's Theme 2: Sustainable Smallholder Land and Water Management Systems. Research under this theme concentrates on identifying the promising smallholder innovations and evaluating them together with partners to understand how they work and what their impacts are. It seeks to understand the conditions under which the high potential smallholder practices are viable, and then support their uptake in developing countries and regions.

Next Step

The first phase of the ADB-supported MSEC project has been going on for three years now and with ADB's approval has been extended for another year. Under IWMI's management, MSEC will stay as a major program, particularly in Southeast Asia. As we plan for the project's continuation, we anticipate a much strengthened program with the integration of land and water management concerns in catchment research. This integration is the very essence of IWMI's proposal for a second phase of MSEC submitted to ADB for consideration of funding.

Notably, most CGIAR centers such as the Centro Internacional de Agricultura Tropical (CIAT), Center for International Forestry Research (CIFOR), International Center for Research in Agroforestry (ICRAF), ICRISAT, International Food Policy Research Institute (IFPRI), International Rice Research Institute (IRRI), and IWMI have recognized the value of carrying out research on and in catchments. For us at IWMI, we expect that the outputs of the present catchment research that we are doing will provide valuable inputs to scale up the application of research results and technology options to much larger catchments and to the bigger river basins that we are very much involved in. This research will fully capture the interactions among the on-site and off-site users of land and water resources and provide a more comprehensive basis to come up with the resolution of the competing demands of these users. These are all in support of IWMI's vision of "Improving Water and Land Resources Management for Food, Livelihoods and Nature". We hope to have a very productive collaborative program with all MSEC partners in the years to come.

This joint activity between ICRISAT and IWMI is a recognition of the value of collaboration among different CGIAR centers, working together towards a common goal. The Global Challenge Programs that the CGIAR now advocates emphasize the collaboration among centers and zero in on the value of synergy and complementarity. As IWMI prepares to participate in these inter-center programs, we look forward to see more research on the linkage between land and water management in the near future.

I hope that this week-long activity will be able to generate valuable information and further interest in this aspect.

Thank you.

Integrated Natural Resource Management: The Key to Prosperity and Peace in the Drylands

W D Dar[1]

Ladies and gentlemen!

I extend my warmest welcome to the Honorable Vice Minister of Planning, Cao Duc Fat, Dr Ngo The Dan, President, Scientific Committee, Nguyen Van Bo, Chairman, Scientific Department, Le Hung Quoc, Chairman, Extension Department, Dang Kim Son, Director, Information Center, Nguyen Dinh Huong, Deputy Chairman, International Cooperation Department, Ministry of Agriculture and Rural Development, and Mr D J Bandaragoda, Regional Director, International Water Management Institute (IWMI), who are with us in this joint project planning meeting. Let us recognize their presence by giving them a loud applause. I also welcome Dr T D Long, Deputy Director General (DDG), Vietnam Agricultural Science Institute (VASI), Dr Le Quoc Doanh, DDG, VASI, Dr Thai Phien, and the delegates who have come from different countries and the media staff from Vietnam.

For some of you, this may be the first visit to Vietnam, a beautiful and historic country with very hospitable people. While you are here, you will also have an excellent opportunity to see an example of intensive agriculture. I speak on behalf of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), a non-profit, apolitical, international organization for science-based agricultural development. Established in 1972, it is one of the 16 centers of the Consultative Group on International Agricultural Research (CGIAR). ICRISAT's new vision is "improved well-being of the poor of the semi-arid tropics (SAT) through agricultural research for impact."

Our new mission is "to help the poor of the SAT through science with a human face and partnership-based research and to increase agricultural productivity and food security, reduce poverty, and protect the environment in SAT production systems." Basically, we aim to improve and sustain agricultural productivity in some of the harshest environments that account for about two-third of the world's cultivable land.

We serve more than 800 million people in 48 countries, the poorest of the poor, who live in the dry tropics of Asia and Sub-Saharan Africa. We are supported by more than 50 governments, foundations, and development banks. Our strategy is to focus on comparative advantage, develop a competitive edge, and enhance strategic partnerships. The situation is challenging as this region is heavily populated and pressure on natural resources is very severe. Unless we protect our soil and water resources, they will be degraded and will not be able to support the rural livelihoods in the SAT. ICRISAT has a mandate to improve the livelihoods of the millions of poor living in the SAT through increased agricultural productivity through integrated genetic and natural resource management.

Water is the life line of the people living in the SAT region and unless it is managed, its continuing depletion will endanger the survival of the people living in this region. The main source of water in SAT is the monsoon rain, which generally occurs as downpours resulting into excess water during the rainy days. Downpours cause severe soil erosion and also take away nutrient rich top soil along with the runoff, which causes severe damage to the natural resources. Subsequently, dry spells follow during the crop growing season. The appropriate way to manage these problems is the adoption of watershed management. Watersheds are not only the units for managing the rainwater but also are the converging points of various rural activities of millions of the poor living in them.

The Asian Development Bank (ADB) and ICRISAT share a common vision of alleviating poverty in Asia and ADB's valuable support to ICRISAT is through our project "Improving

1. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India.

Management of Natural Resources for Sustainable Rainfed Agriculture" that has gone a long way. I have a special concern for this project since it showcases our credo of science with a human face operating in this project. Our approach of integrated participatory watershed management has attracted the attention of not only the researchers and farmers but also top policy makers in India and Vietnam.

The integrated watershed management approach involves participation of all stakeholders in the watershed program. It demands teamwork and effective cooperation. Traditionally watersheds have been viewed as hydrological units to conserve soil and water. However, this view has not benefited farmers. Instead we must adopt the integrated watershed management approach. Here, all natural resources in the watershed are nurtured properly so that livelihood sources are effectively sustained.

The world is changing and in a borderless global economy, things done locally can have global impact. Thus, farmers in the drylands not only must increase productivity of their farm but also become competitive. Working together, we must fight poverty and hunger especially in the drylands. They are the root causes of the political and social instability we frequently see today. Global disorder could be handled effectively by local efforts in the watersheds by increasing productivity and rural incomes.

A recent study conducted by ADB indicated that investments in rainfed areas are as productive as those in favorable irrigated areas. The same study also highlighted a need to develop rural infrastructure which will have direct impact on alleviating rural poverty and improving rural livelihoods. The integrated watershed management approach will help to manage the natural resources efficiently and effectively so that the rural livelihoods can be improved substantially through convergence of various activities in the watershed.

ICRISAT has a 29-year experience in watershed management. It is time we now share experiences with farmers. Hence, ADB's timely support has helped ICRISAT and the national agricultural research systems (NARS) in Asia to develop a suitable model for sustainable natural resource management of watershed. The concerned efforts of a team of scientists led by Dr S P Wani have shown excellent results in this project. Dr Ian Johnson, Chairman, CGIAR who visited Adarsha watershed in Kothapally, Andhra Pradesh, India said: "This is an excellent example of the value of partnerships, research and action in the field as well as the dedication of ICRISAT staff to small and poor farmers." Recently, a Planning Commission Member of the Government of India also visited Kothapally. He was highly impressed with the visible impact in this watershed. In fact, he asked details for discussion in the commission for possible replication in other watershed programs.

Our important partners in Kothapally watershed are the Central Research Institute for Dryland Agriculture (CRIDA) and Drought Prone Area Programme (DPAP). Dr H P Singh (CRIDA) and Ms T K Sreedevi (DPAP) are with us in this meeting. Our other partners from other benchmark sites in India, Thailand, and Vietnam are also here. We are happy that together, we have brought ICRISAT and NARS experiences in watershed management to benefit our poor farmers. Ten other villages in Andhra Pradesh are adopting this model in the Andhra Pradesh Rural Livelihoods Programme (APRLP). We are looking forward to promote this model in five districts in Andhra Pradesh to alleviate poverty by improving rural livelihoods.

Kothapally is not an isolated watershed model, but is just one of the benchmark sites operated in this project. I have personally visited benchmark sites in Vietnam and Thailand. When you visit Thanh Ha watershed in Vietnam you will see and experience the happiness of the farmers whose incomes have increased two-fold during the last three years. I met Deputy Prime Minister Mr Nguyen Cong Tab during this visit, and he was very satisfied with our work. I am happy to announce that the Thanh Ha watershed has helped in generating support from the Vietnamese government for natural resource management research. VASI and Danish Agency for Development Assistance (DANIDA) have also recognized the importance of watershed research.

Likewise, I am happy to note that ADB's support has made a big difference to the rural poor in the benchmark watersheds in India, Thailand, and Vietnam. Now the challenge is for us to translate our success into a broad-based movement of natural resource management. We can do this through the consortium approach adopted in this project. For a peaceful world and a better tomorrow, natural resource endowments must be managed and used sustainably. ICRISAT vows to convert “Grey SAT areas into green”. We are committed to achieve this through “Science with a human face”. The support of development investors such as ADB is very critical in this effort. I am sure that we, as a team, will win this fight to help attain a food secure, prosperous and peaceful world for present and future generations.

Thank you all.

Inaugural Address

C D Phat[1]

At the outset, on behalf of the Vietnamese Government I would like to convey my warmest greetings to the honorable participants of this workshop from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Water Management Institute (IWMI), China, India, Indonesia, Laos, Nepal, Philippines, Sri Lanka, Thailand, Danish Agency for Development Assistance (DANIDA), Research and Technological Exchange Group (GRET), Centre de cooperation internationale en recherché agronomique pour le développement (CIRAD), Centro Ricerche Fiat (CRF), Bioseed, and Vietnamese deputies who are present in this workshop. I also wish this seminar meets with splendid achievements.

Market oriented reforms in the economic system introduced in Vietnam in late 1980s, including a land law, placed greater emphasis on families as the basic unit of production. Recently a number of new initiatives have been taken; these demonstrate awareness and needs for the commitment to improve management of land and water resources, including those in the uplands of Vietnam, which comprise over three quarters of its total area. Upland development involving ethnic minorities and the settlement of lowland farmers in the hills has been going on for a long time. But new emphasis is being placed of late. New initiatives in this direction are:

- New legislation to strengthen the role of land potential benefits for households in land management (the Law on Land of 1993) and to some degree, also in forest land management (the Forest Resources Protection and Development Act of 1991).
- Various national action plans, including National Forestry Action Plan, the National Environmental Action Plan (Vietnam National Environment Action Plan, 1993), and the National Conservation Strategy.
- The creation of a new administrative body, the Committee for Ethnic Minorities and Mountainous Areas, to improve the coordination of existing programs and new initiatives.
- Increased government funding for the planning and implementation of activities under the Decree 327, "Master guidelines and policies to utilize unoccupied land, barren hilly areas, forests, denuded land, beaches, and waterfronts", implementation of which started in 1993.
- Requests for international assistance to increase the resources for land and improve the quality of these efforts.

However, awareness and further improvements in planning and implementation of these programs is required.

Watershed Management and Erosion Control Problems

The importance of water resources management through adequate watershed rehabilitation and conservation is increasing. Water is required to irrigate the lowlands, for hydroelectric energy, and for domestic and industrial use of the country's large population. Watershed management is required to mitigate the effects of floods and drought and to provide a livelihood for the large number of ethnic minority groups living in the mountains.

A national watershed management program does not exist yet. The new land management and land tenure policy aims at distributing both the agricultural and forestry land to local people. This has created a situation in which grass root associations and self-help groups can take a leading role in the development and management of productive land. There is, however, a lack of well-tested integrated and flexible models and methods to effectively involve

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local communities in the sustainable development and management of watershed resources.

Until a few decades ago shifting cultivation practices in the mountainous areas were not a threatening factor for the watersheds. Few local inhabitants, mostly ethnic minorities, used only those sites, which were not much affected by erosion. Due to population pressure and the resulting requirement for more land for agriculture, the picture is now rapidly changing. Besides a rapid increase in the population, people migrated from the densely populated delta areas into the mountainous regions, especially in the lower areas. They often practice land use patterns inspired by delta area agricultural techniques, but generally not suitable for these sites. This has resulted in the worst cases of erosion being encountered on the low hills adjacent to densely populated areas.

Effective People's Participation: A Must for Success

In most areas in Vietnam, watershed management and erosion problems can be mitigated through appropriate soil and water management practices. The farmers, especially the indigenous communities (ethnic minorities) in most mountainous areas, have a lot of experience and knowledge to use the land for agriculture, forest, and animal husbandry. We need to consider their knowledge in developing improved technologies for greater adoption of new innovations.

As stated earlier, the new land management and land tenure policy has created a situation in which grass root organizations can take a leading role in the development and management of land. Ways have to be found of integrating sustainable technical, social, economical, and operational measures aimed at improving the effective participation of people and guaranteeing access by small land users to sustainable land husbandry and conservation techniques and to the related services and supplies.

This could be achieved through promotion and strengthening of participatory methods and models and the progressive design and adoption by local communities of an integrated watershed management approach. Key to this strategy is not imposing an artificial reorganization of local social structures, but promoting and supporting a participatory process to be more effective for sustainable resource utilization, so as to contribute to better social, economic, and environmental living conditions.

The adoption of participatory methods and approaches in the development and conservation of rain-fed upland areas will only provide the desired results if adequate provisions are made to improve living standards through appropriate management of natural resources, integration of cropping systems, forest management, animal husbandry, and rural development.

Finally, watershed management programs do not represent a panacea, and cannot be everything to all people. In order to be more meaningful and manageable the activities included in a watershed management program should contribute to the objective of improved overall natural resource management with a clear orientation towards upstream/downstream use and conservation of water resources. However, given the general situation of resource degradation and poverty in the uplands, it is essential that a watershed program, in order to be sustainable, contributes significantly to the economic and social well-being of the upland people through improved overall natural resources management. I hope the deliberations in the next few days would consider these aspects and come out with appropriate research plans.

We are very happy that the Asian Development Bank (ADB)-funded projects implemented by ICRISAT and IWMI with collaborative research support from Vietnam Agricultural Science Institute (VASI) and National Institute for Soils and Fertilizers (NISF) are addressing these concerns very effectively. We wish that the projects continue the good work with the necessary support from the ADB for undertaking this important research.

The Ministry of Agriculture and Rural Development (MARD) is making concerted efforts to mitigate constraints in agriculture and rural development sectors and identify appropriate technologies for sustainable agriculture through close cooperation with various national and international institutions. We hope ICRISAT and IWMI make Vietnam as a partner in many more future projects in the coming years in this endeavor and work closely since we too firmly believe and acknowledge ICRISAT's motto "Science with a human face".

I hope this workshop helps foster partnership research between MARD and ICRISAT and IWMI further and identify new areas for future research collaboration. I wish all the participants a pleasant stay and hope you enjoy our warm hospitality. I once again wish that the workshop meets with splendid achievements.

Thanks for your attention.

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

S P Wani[1], H P Singh[2], T D Long[3], and Narongsak Senanarong[4]

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

1. Milli watershed, Lalatora micro-watershed (Vidisha, India)
2. Ringnodia (Indore, India)
3. Adarsha watershed (Kothapally, Ranga Reddy, India)
4. Tad Fa (Thailand)
5. Thanh Ha (Vietnam)

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).

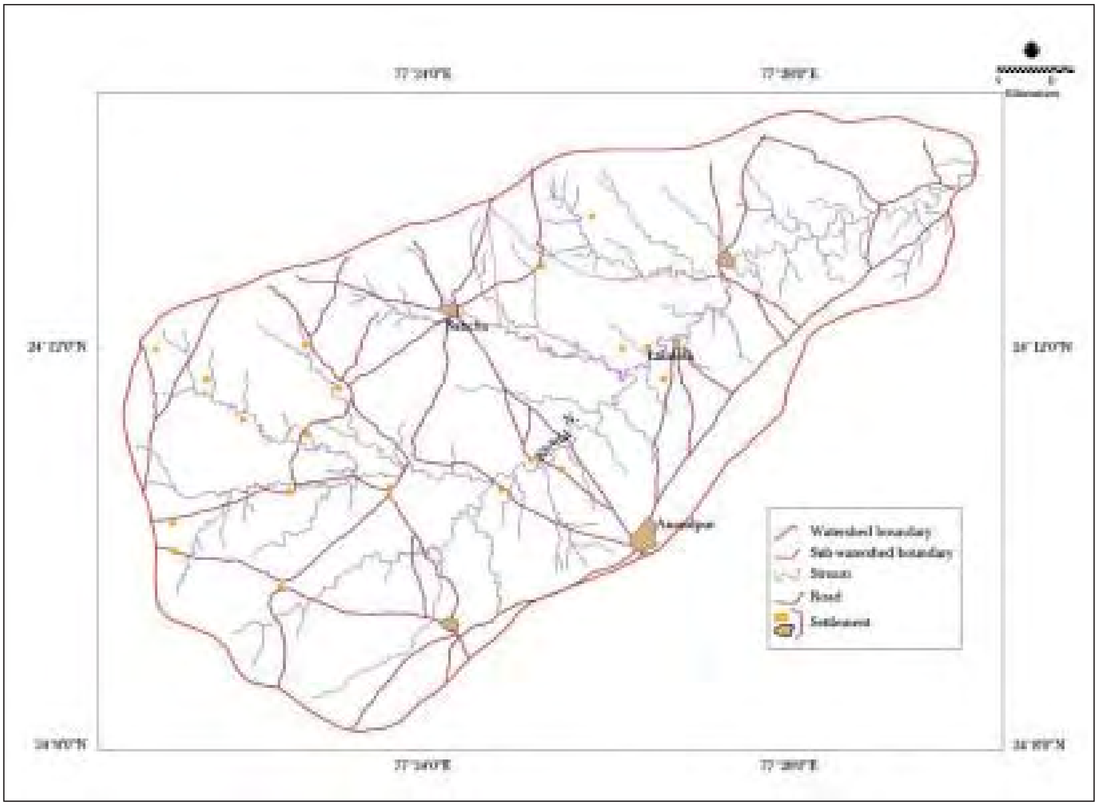

Figure 2. Map showing Milli watershed and Lalatora watershed in Madhya Pradesh, India.

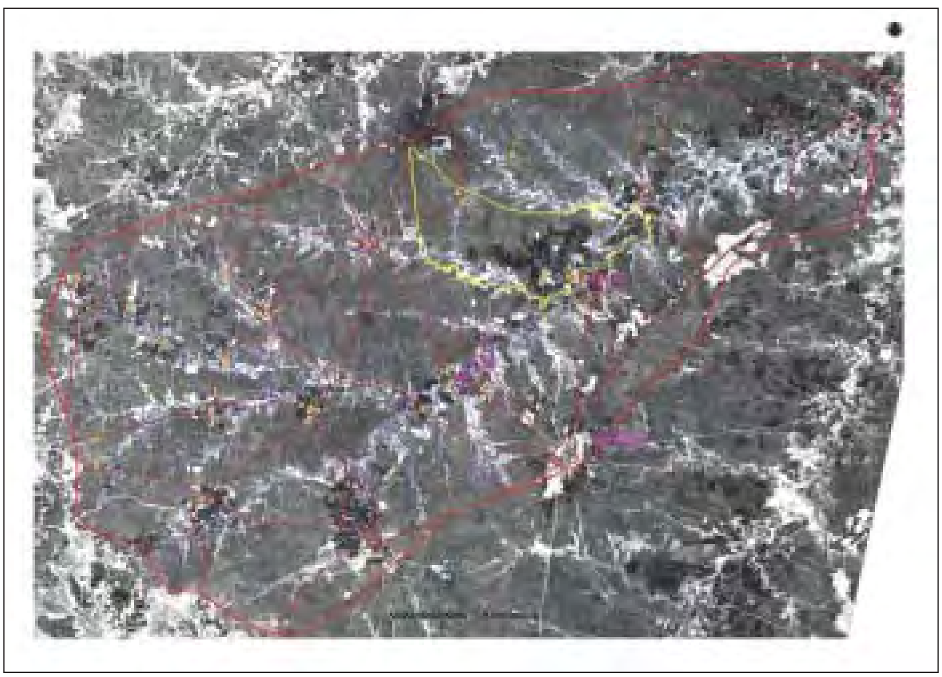

Figure 3. IRS-1C PAN image of Milli micro-watershed showing agricultural land use.

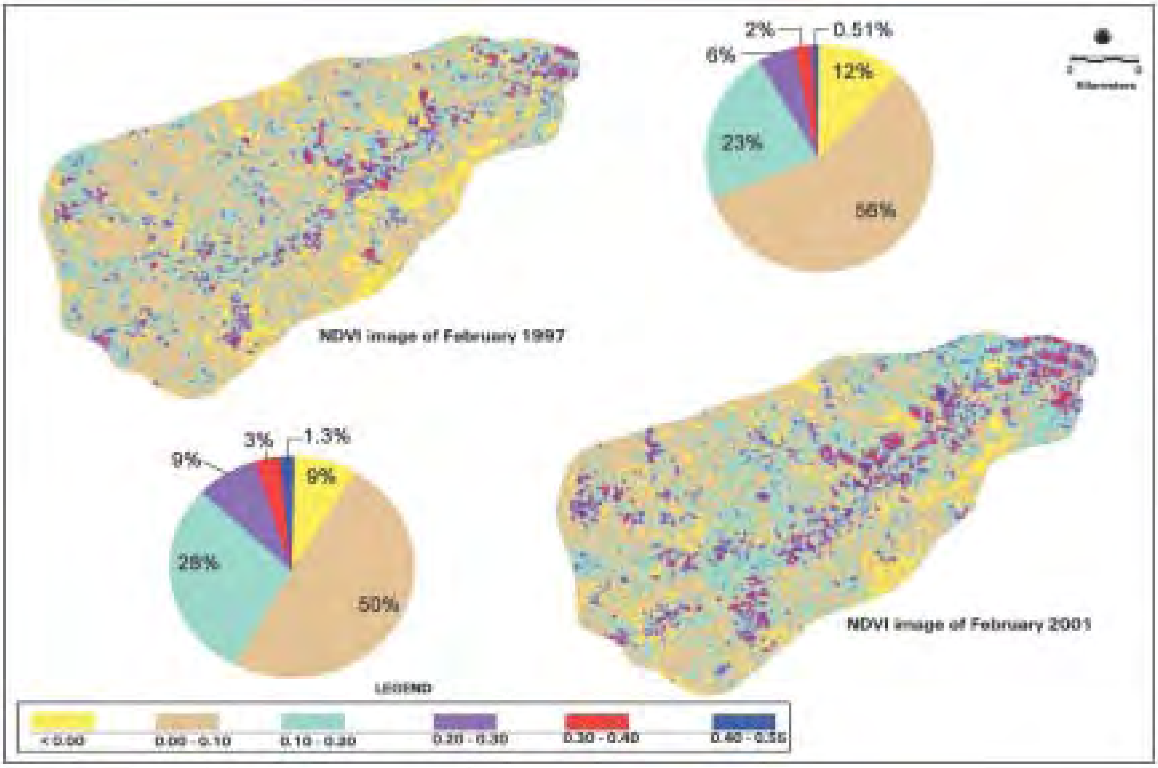

Figure 4. NDVI image of land use in Lalatora micro-watershed during postrainy season 1997 and 2001.

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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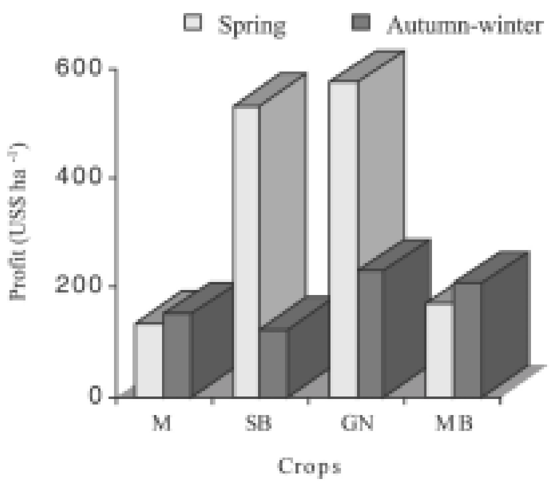

Figure 5. Performance of crops in spring and autumn-winter seasons, Thanh Ha, 2000.
(Note: M = maize, SB = soybean, GN = groundnut, and MB = mung bean.)

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The Management of Soil Erosion Consortium (MSEC): Linking Land and Water Management for Sustainable Upland Development in Asia

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Abstract

A case study of soil erosion research under the Management of Soil Erosion Consortium (MSEC), a system-wide initiative of the Consultative Group on International Agricultural Research is presented. The study aims at developing and promoting sustainable and socially acceptable community-based land management options through a participatory and interdisciplinary approach. The study has been undertaken in 6 countries namely Indonesia, Laos, Nepal, Philippines, Thailand, and Vietnam under diverse agro-ecological situations. In each country up to 6 catchments were selected, the area of each ranging from 63 ha in Laos to 139 ha in Indonesia. The paper describes the program objectives, expected outputs, approach to program implementation, and research progress and discusses the results of erosion losses in relation to land uses, catchment size, and nutrient depletion. The study links the land and water management systems which were identified, in consultation with farmers, for conservation of natural resources and improving soil fertility and lists some of the accomplishments.

Continued land degradation brought by soil erosion in the sloping lands has been a major constraint in sustaining upland agriculture and food security in most of Asia. Farming and other economic activities have become environmentally unsustainable causing deleterious on-site and off-site effects. A few studies on soil erosion and soil conservation have been undertaken, but results have not yielded sustainable land management options that can provide reasonable returns without further degrading the resource base and the environment. Greenland et al. (1994) made a reexamination of approaches to research on sustainable land management and recommended a new research paradigm providing an organizational model that engages scientists and research institutions to tackle a common goal through a participatory, interdisciplinary, and community- and catchment-based approach. This led to the establishment of the Management of Soil Erosion Consortium (MSEC) as one of the four consortia under the soil, water, and nutrient management (SWNM) system-wide initiative of the Consultative Group on International Agricultural Research (CGIAR).

In 1998, MSEC initiated a research project on soil erosion management in six countries in Asia with support from the Asian Development Bank (ADB). The project aimed to develop and promote sustainable and socially acceptable community-based land management options for sloping uplands through a participatory and interdisciplinary approach at the level of a catchment. This paper presents an overview of the progress of the project in Indonesia, Laos, Nepal, Philippines, Thailand, and Vietnam. It highlights the progress of the project in catchment research and summarizes its accomplishments in the other components of information dissemination and capacity building vis-à-vis the outputs expected. It also discusses the project's strategy in governance and management.

Program Objectives and Expected Outputs

The objectives of the program are to:

- Develop sustainable and acceptable community-based land management systems that are suitable for the entire catchment.
- Quantify and evaluate the biophysical, environmental, and socioeconomic effects of soil erosion, both on-site and off-site.

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- Generate reliable information and prepare scientifically-based guidelines for improvement of catchment management policies.
- Enhance capacity of the national agricultural research and extension systems (NARES) in research on integrated catchment management and soil erosion control.

The program focuses on three major components to address the stated objectives. These are:

- Catchment research to evaluate the effects of different land management practices on water and nutrient flows in selected representative catchments.
- Capacity building of participating NARES in research on integrated catchment management and soil erosion.
- Dissemination of research results for enhanced adoption of land management technologies and for more accessible information as concrete basis for decision making.

Outputs from the activities are expected to be generated in the first three years, but for some, a longer timeframe is needed. In fact, the consortium is envisioned for a period of at least 10 years. The expected outputs are given in the project logical framework and summarized as follows:

- Decision support tools and guidelines based on a better understanding of the on- and off-site effects of soil erosion.
- Alternative technologies and land management systems that are socially and institutionally acceptable to the communities in the catchment.
- Methodology for assessment of impacts and obtaining participation of farmers and other stakeholders in the management of catchments which includes policies that will improve the management of catchments by the local government and the communities.
- Information and communication strategies to effectively disseminate the results of the research to the farmers and other land users.
- Enhanced NARES capacity in integrated catchment management research.
- Improved program management for catchment management research.

Program Implementation

MSEC uses a new approach to the organization and implementation of soil erosion management research. The approach provides a mechanism that engages different scientists and research institutions in a coordinated and participatory mode at the catchment scale. Research planning and implementation is undertaken through consultation among concerned NARES, international agricultural research centers (IARCs), advanced research institutes (ARIs), non-governmental organizations (NGOs), and farmers. The NARES play the central role in the consortium, particularly in the participatory research, but with a broad responsibility for underpinning applied and strategic research as well (Fig. 1). The International Water Management Institute (IWMI) serves as the consortium secretariat and facilitator. Project and

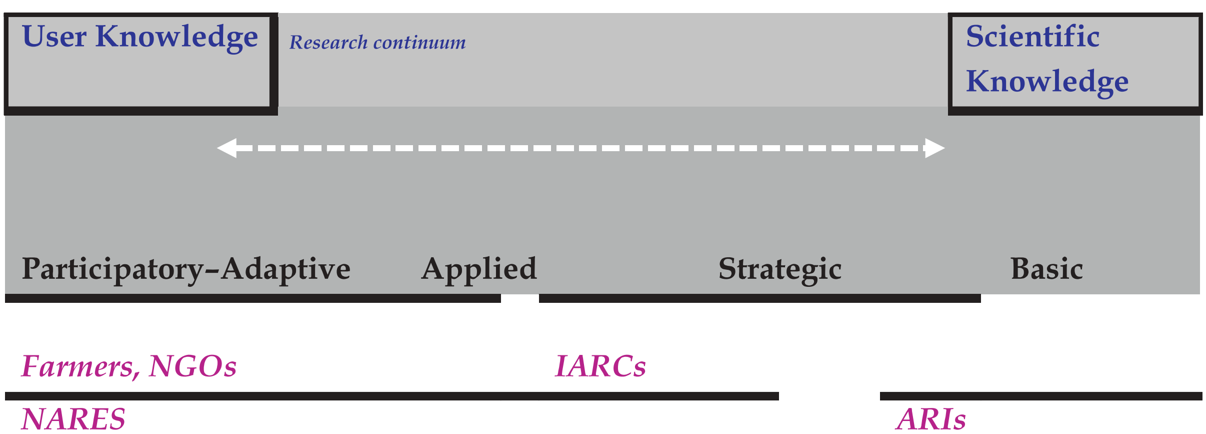

Figure 1. The research continuum showing the role of different groups in the implementation of MSEC.
(Source: Craswell and Maglinao 2001)

institutional linkages are also pursued to establish this partnership at the country level.

The study catchments were selected using carefully defined criteria and methodological guidelines developed for the purpose (IBSRAM 1997). Monitoring stations equipped with automatic water level recorders, manual staff gauges, sediment traps, automatic weather stations, automatic sediment samplers, and manual rain gauges were installed in the catchments to collect hydrological and erosion data. In addition, monitoring of the socioeconomic parameters and agricultural practices of the farmers was likewise undertaken. The detailed methodology used in carrying out the activities in the catchments is discussed in the individual country reports presented in the 5th MSEC assembly (Maglinao and Leslie 2001).

The best-bet land management options were identified in consultation with the farmers. The information gathered from the monitoring of the biophysical and socioeconomic data were explained to the farmers during the discussion. The identified options were implemented by the farmers with technical assistance from the researchers. Regular monitoring of the effect of the introduced options is underway.

Progress in Catchment Research

Catchment profiles

The experimental catchments range from 63 ha in Laos to 139 ha in Indonesia with up to four smaller micro-catchments representing different land uses delineated within (Maglinao et al. 2001). Most catchments have slopes ranging from 12 to 80%, and an average annual rainfall ranging from 1,080 to 2,500 mm (Table 1). In the Philippines and Thailand, water flows in the creeks only during the rainy season. The catchments are dominated by annual cash crops with some patches of perennials and are cultivated primarily by ethnic minorities. In general, the model catchments represent a resource management domain with common biophysical and socioeconomic characteristics common to the marginal sloping uplands (Craswell and Maglinao 2001).

In most catchments, the farmers who farm in the areas live in the village outside the catchment. It is only in the Philippines where most of the farmers settle within the catchment. Land use rights are provided to the farmers in Vietnam and Laos while those in the other sites are either shareholders or owners. A number of research and development institutions have been collaborating with the project in all areas.

The sub-catchment in the Philippines is small (0.9 ha) (Table 2). The sub-catchments in Indonesia are primarily cropped either with upland annual crops or perennials, primarily rambutan. In the Philippines, the sub-catchments represent a combination of the area cultivated to maize, vegetables, or potato and grasslands with a small settlement area in one of the sub-catchments. In Vietnam, the sub-catchments are cropped with cassava, either monocropped or intercropped, but with areas of natural grass still present. In Laos, a large part of the area of the sub-catchments is under rotating cultivation or bush fallow. Annual upland crops also predominate in the catchments in Thailand and Nepal.

Erosion and land use

The existing land management practices in Indonesia influenced the degree of soil erosion in the different sub-catchments within each of the three catchments. Except in Nepal, soil loss is higher in areas more intensively cultivated with upland crops than those with perennials or left under grass cover (Table 2). This confirms the initial observations seen from the same catchments a year before (Maglinao et al. 2001). In Indonesia, sediment yield was highest in the sub-catchment MC-1I dominated by upland annual crops, with soil loss of 6.7 t ha^{-1}. This is presumably because of minimal soil surface litter and little canopy cover of the catchment. On the other hand, the other sub-catchments, MC-2I and MC-3I, planted to perennials (primarily rambutan), lost relatively less amount of soil (only about 1 t ha^{-1}) during the same period and yielded considerable amount of sediment only during the middle part of the rainy season (January).

In the Philippines, observations recorded during April 2000 to March 2001 showed the effect of land use on soil erosion. The smallest sub-catchment MC-4P, which has a higher percentage of cultivated area, gave the highest soil loss of 53.9 t ha^{-1}. The lowest soil

Table 1. Profile description of the MSEC catchments in participating countries.

General descriprion	Babon	Huay Pano	Masrang Khola	Mapawa	Huay Yai	Dong Cao
Basic information						
Country	Indonesia	Laos	Nepal	Philippines	Thailand	Vietnam
Province	Semarang	Luang Prabang	Chitwan	Bukidnon	Phrae	Hoa Binh
Latitude	7°22'25" S	19°51'10'' N	27°49' N	8°02'50'' N	18°13'20'' N	20°57'40'' N
Longitude	110°29'02" E	102°10'45'' E	85°32'30" E	125°56'35'' E	100°23'40'' E	105°29'10'' E
Elevation (m)	390–510	400–700	650–1400	1080–1505	400–480	125–700
Catchment size (ha)	139	63	124	91	71	96
No. of equipped catchments and sub-catchments	5	9	5	5	5	5
Biophysical attributes						
Slope (%)	15–75	30–80	40–60	8–35	12–50	40–60
Geology and landform	Basaltic lava	Shale, schist	Gneiss, schist	Basalt, pyroclastics	Siltstone, sandstone	Schist
Rainfall (mm)	2,500	1,403	2,200	2,537	1,077	1,500
Soils	Inceptisol	Ultisol, Entisol	Inceptisol, Alfisol	Ultisol, Inceptisol	Alfisol, Ultisol	Ultisol
Vegetation and land use	Rice, maize, rambutan	Forest, bush fallow, rice, maize, job's tears	Forest, grasslands, rice, maize, millet, potato	Forest, open grassland, maize, potato, vegetables	Soybean, mung bean, tamarind	Cassava, rice, maize, taro, groundnut
Hydrology	Permanent flow (water flows year round)	Permanent flow (water flows year round)	Permanent flow (water flows year round)	Intermittent flow (water flows only during rainy season)	Intermittent flow (water flows only during rainy season)	Permanent flow (water flows year round)

continued

Table 1. *continued.*

General descriprion	Babon	Huay Pano	Masrang Khola	Mapawa	Huay Yai	Dong Cao
Socioeconomic attributes						
Population						
Household (HH)	405	80	54	70	50	38
Persons	1,812	427	354	155	3,655	196
Ethnic group	-	Lao Theung (92%); Lao Lum (2%)	Gurung; Gharti; Brahmin; Chhetri/Thakuri	Talaandig	Thai	Kinh (40%); Muong
Land tenure	Owners, shareholders	State owned; land use right	With certificate of ownership; leased	Private owner	Land use title	Land use right
Annual income (US$)	372	296		726	627	774
On farm	64%	70%	41%	-	-	96%
Off farm	36%	30%	59%	-	-	4%
Dominant crops	Rambutan, lowland rice, upland crops	Upland rice, job's tears	Maize, rice, millet, mustard, legumes	Vegetables, maize	Soybean, mung bean	Cassava, rice, maize, groundnut
Agricultural practices	Two crops in one year	Shifting cultivation	Two or three crops a year	Two crops in one year	Two crops in one year	Two crops in one year

Table 2. Land use and soil loss in the micro-catchments in different countries.

Micro-catchment	Area (ha)	Land use	Soil loss[1] (t ha^{-1})
Indonesia (15–75% slope)			
MC-1I	3.2	50% annual upland crops, coffee and nutmeg on the upper slopes	6.7
MC-2I	2.0	Rambutan and some bare plots	0.8
MC-3I	38.5	Rambutan	1.0
Laos (30–80% slope)			
MC-1L	1.2	69% rotating cultivated land, 31% teak	0.5
MC-2L	19.5	76% rotating cultivated land, 6% upland rice	0.6
MC-3L	13.3	80% rotating cultivated land, 12% forest	0.0
MC-4L	18.6	61% rotating cultivated land, 11% job's tears, 10% forest, 7% upland rice	2.1
MC-5L	8.8	53% rotating cultivated land, 35% forest, 8% upland rice	2.8
MC-6L	1.7	56% rotating cultivated land, 13% forest, 31% teak	2.0
Nepal (40–100% slope)			
MC-1N	72.6	Mixed (45% upland, 5% lowland, 20% shrub, 30% forest)	0.08
MC-2N	39.6	Mixed (60% upland, 10% shrub, 30% forest)	0.14
MC-3N	11.5	Mixed (23% upland, 2% lowland, 35% shrub, 40% forest)	0.09
MC-4N	1.6	Upland cultivated (100%)	Traces
Philippines (8–35% slope)			
MC-1P	24.9	20% cultivated, 80% falcata, grassland	0.1
MC-2P	17.9	40% cultivated, 60% grassland/forest	0.7
MC-3P	8.0	10% settlement, 15% cultivated, 75% natural grass	1.0
MC-4P	0.9	40% cultivated, 60% grassland	53.9
Thailand (12–50% slope)			
MC-1T	11.6	47% soybean-mung bean, 47% tamarind	0.1
MC-2T	9.8	78.2% soybean-mung bean, 13% shrub	1.6
MC-3T	3.2	94% tamarind, shrub	1.0
MC-4T	7.1	51% soybean-mung bean, 23% mango, tamarind	0.4
Vietnam (40–60% slope)			
MC-1V	4.8	67% monoculture cassava, 33% natural grass	5.2
MC-2V	9.4	24% cassava intercrop, 59% cassava monoculture, 17% natural grass	4.3
MC-3V	5.2	Cassava intercrop	3.9
MC-4V	12.4	26% cassava intercrop, 74% natural grass	2.0

1. Period of observation: Indonesia – March 2000 to February 2001; Laos – May to September 2001; Nepal – March to September 2001; Philippines – April 2000 to March 2001; Thailand – June to September 2001; Vietnam – January to August 2001.

loss was in the sub-catchment MC-1P, which has a lower percentage of cultivated area and a larger area covered with grasses. The sub-catchment MC-3P, which has the lowest percentage of cultivated area but with some settlement within, yielded a higher soil loss. The relatively higher soil loss in this sub-catchment which has 10% built-up area may be attributed to erosion from the foot trails and road network (Duque et al. 2001). Using a simulation model, Ziegler et al. (1999) showed that roads generate runoff sooner during an event, and have greater discharge values than other surfaces. Sediment transport was also greater. Footpaths emerged as important areas of accelerated runoff generation on agricultural fields that otherwise require large amount of rainfall to produce runoff.

In Vietnam, the data collected from January to October 2001 showed that among the sub-catchments, MC-1V (predominantly cassava monoculture with some natural grass) had the largest soil loss of about 5.2 t ha^{-1}. The least was from MC-4V (predominantly natural grass and cassava intercropping) at 2.0 t ha^{-1}. The larger soil loss from MC-1V (primarily cassava monoculture) when compared with MC-3V (cassava intercropping) shows the effect of cassava intercropping system as opposed to cassava monoculture. At its peak growth, cassava provides only about 47–56% soil cover and mixed cropping or intercropping can increase this protection. The effect of natural grass in the sub-catchments was also manifested. Natural grass enhances infiltration, reduces runoff and runoff velocity, and consequently reduces soil loss.

In Laos, observations made from May to October 2001 showed that the micro-catchment with the smallest proportion of rotating cultivated land and with about 8% of upland rice (MC-5L) gave the highest soil loss of 2.8 t ha^{-1} (Phommassack et al. 2001). No erosion was observed in the micro-catchment with the largest proportion of rotating cultivated land and about 12% forest (MC-3L). Contrarily, in Nepal lowest soil loss was observed in the sub-catchment which was extensively cultivated (Maskey et al. 2001).

Soil erosion and farming operation

Farming operations in the field is related to how the land is managed and obviously can also affect soil erosion. Observations in Indonesia showed that at the time of planting the upland crops (in November), rainfall of nearly 600 mm produced sediment yield as high as about 2 t ha^{-1}. At this time, the soil surface was bare and the soil aggregates were loose because of tillage. With rainfall exceeding 400 mm in January, March, and April, sediment yield was greater than 1 t ha^{-1}.

In Vietnam, at the start of the rainy season when the soil was still dry, there was not much runoff even during heavy rains. The amount of rainfall could have just been enough to saturate the soil as rainfall of more than 300 mm in May did not result in significant increase in runoff. But runoff sharply increased in June. Incidentally, the overall cover density of the area was also at its highest from June to August.

Soil erosion and catchment size

In the Philippines, the smallest sub-catchment (MC-4P) which incidentally has a large proportion of cultivated area had the highest soil loss. In Indonesia, most of the sediments measured from the trap in the smaller sub-catchments (MC-1I and MC-2I) were of the larger sized aggregates or particles (bed load) while for the larger sub-catchment (MC-1I), the finer sediment (suspended load) dominated (Fig. 2). This reflects that during the erosion process, relatively small portion of soil aggregates was dispersed, especially for the MC-2I sub-catchment with no tillage and with ideal cover. This also reflects that the source of most sediment reaching the sediment trap was relatively close to the trap and the larger the catchment, the less the bed load contribution to sediment yield. In Laos, the measured erosion from the microplots reached as high as 78 t ha^{-1} compared with approximately 1 t ha^{-1} at the micro-catchment scale. These observations reconfirm earlier reports that direct extrapolation of soil loss data from plot scale to small catchments and from small catchments to bigger catchments will lead to overestimation.

Nutrient depletion and off-site effects

Analysis of the soil eroded from the catchment in Vietnam clearly showed that a large quantity of plant nutrients is carried away with the sediments. The catchment has lost a total of 740 kg organic matter, 39 kg nitrogen (N), 31 kg P_2O_5, and 80 kg K_2O. In one of the micro-catchments in the Philippines, 3.4 t organic

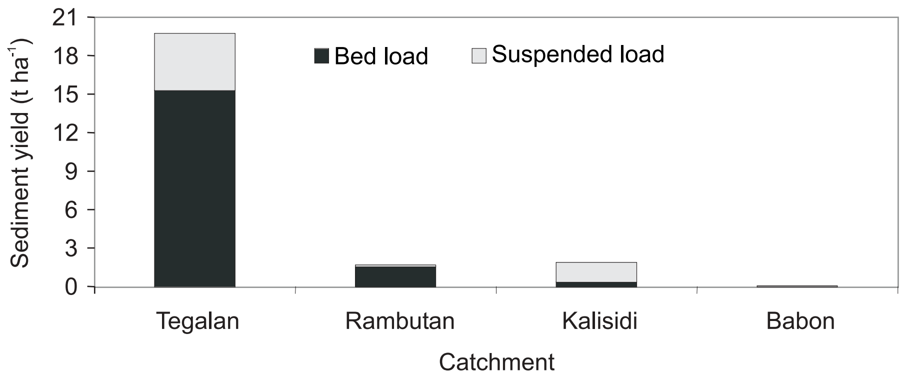

Figure 2. Sediment output from different sub-catchments in Babon catchment, Indonesia from March 2000 to February 2001.

matter, 0.1 kg extractable phosphorus (P), and 7.9 kg exchangeable potassium (K) were lost with 62 t of eroded soil measured from May 2000 to August 2001 (Duque et al. 2001). The data clearly show that farming without soil conservation results in soil and nutrient losses that could further result in lower crop yields and productivity. It is anticipated that with proper soil management and land use, soil and nutrient losses could be minimized.

One visible off-site effect of erosion is the sedimentation downstream due to the transport of soil from the uplands. An initial valuation of this effect at the site in the Philippines was done by valuing the cost of dredging the silted irrigation canals of the Manupali River Irrigation System (Carpina et al. 2001). Since 1995, a total of 81,724 m^3 of sediments was estimated to have been transported to the system costing about US$ 49,000 for dredging. Assuming that 0.5% comes from the Mapawa site, it was estimated to have contributed 409 m^3 of sediments to the irrigation system or an equivalent of US$ 245 as cost for dredging (Duque et al. 2001).

Although only some of the model catchments have nearby reservoirs where the effect of erosion on sedimentation can easily be assessed, initial attempts have identified economic activities and environmental effects that could be studied to evaluate the effect of soil erosion off-site. The effect of erosion on the quality of the water that flows downstream and on the production of crops in the lowlands could also be assessed and valued. Related to the amount of soil loss, the amount of nutrients that are carried away is a reflection of the degrading effect of soil erosion. As the top soil is removed by water erosion, considerable amounts of plant nutrients are also lost. This reduces the soil fertility resulting in reduced crop yields unless external nutrient inputs are supplied. Thus the land management systems that must be introduced should be able to restore the lost fertility and increase farmers' income.

Best-bet land management options

In most instances, the land management options identified for introduction in the catchments were variants of the contour hedgerow farming in combination with soil fertility management and animal production. In the Philippines, the use of natural vegetative strips was identified by the farmers in Mapawa catchment. Naturally-growing grasses and some agroforestry crops are used as hedgerows. Several farmers have already made use of this technique as a result of the promotion activity by the International Center for Research in Agroforestry (ICRAF) in the area. Adoption seems to be affected by the tenure system of the farmers. About 50% of the landowners (but none of the tenants) have adopted some conservation measures (Duque et al. 2001). For those who are interested but have not yet adopted, the major reason is the cost of establishment.

In Indonesia, the option identified for Babon catchment is a combination of fodder grass planted on alternate terraces of land currently used for annual upland crops and cattle fattening. The fodder grass is expected to reduce erosion and serve as feed for livestock. The identification of the option was based on lessons learned from elsewhere in Indonesia that farmers' adoption and improvement of a conservation measure is determined by the economic contribution of the measure to the household economy. Farmers are attracted to a practice only if it promises economic benefit.

Hedgerows of vetiver grass and *Tephrosia candida* in the alley cropping system with improved variety of cassava have been introduced in the Dong Cao catchment in Vietnam. The technology intervention has just been started. The farmers believe that the system will reduce runoff and soil loss; incorporation of hedgerow trimmings into the soil will increase organic matter content and thus improve soil fertility.

Other options that the farmers in the Philippines looked at are the planting of pasture legumes during fallow after growing potato, maize, or cabbage instead of grass fallow for 3–4 years and planting tiger grass and bamboo along the creek banks to serve as buffer. Tiger grass and bamboo are expected to provide additional income as tiger grass is used for soft broom and bamboo as props for the banana plantation.

Presentation and discussion of the results of monitoring in the catchments with the farmers helped in the identification of the land management options that are more appropriate in the particular area. While the farmers are aware of soil erosion and its negative effect, actual observations and the alarming figures presented increased their appreciation of looking at a longer time horizon. As they are aware of the declining productivity of their land, they were also interested in fertility management. Of course, their immediate concerns are the benefits that they will gain in the short term. These concerns should be given more emphasis in introducing any interventions in their farms.

Modeling and extrapolation

The soil erosion and hydrology model (PCARES) developed by Dr E Paningbatan of University of Philippines, Los Banos (UPLB) was tested using MSEC data from the Philippines and found to need some modifications. ICRAF agreed that MSEC also looks at a similar model that they have developed. The model was found to work using the data inputs required by the other model. The model was demonstrated during the MSEC assembly in Hanoi, Vietnam. Further analysis of secondary data, complemented with the primary data collected from the different catchments, was done to produce maps that would be needed in the application of the PCARES and ICRAF models. These were used during the follow-up training conducted in Vientiane, Laos from 22 to 26 October 2001.

Other strategic research

Rainfall simulation studies in Thailand showed that infiltration rate increased while runoff coefficient decreased with decreasing slope gradient. Runoff volume decreased with increasing slope. These results suggest that for convex landforms, the steep mid-slope zone can play the role of infiltration trap for runoff water from upper gentler zone. This may have substantial impacts on flow volume generated from small watersheds and on water quality.

The work of the University of Bayreuth in northern Thailand showed that vegetation (and land use) influences the quality and rate of organic matter input into the mineral soil and is therefore one of the main factors controlling the composition of soil organic matter (Moller et al. 2001). The conversion of forests to cabbage cultivation resulted in enhanced breakdown of soil organic matter as indicated by the lower contents of organic carbon and N in the mineral soil in the latter land use. Reforestation with *Pinus* did not lead to a significant buildup of organic matter in the mineral soil.

Accomplishments

Tools and guidelines for improved decision making and research implementation

MSEC's emphasis not only on research but also on research methodology is expected to produce tools and guidelines to support decision making and improved implementation of MSEC research activities. One such output is an earlier publication by the International Board for Soil Research and Management (IBSRAM) which provides the guidelines for model catchment selection for MSEC. The site selection was based on criteria agreed upon by the consortium partners.

The minimum data sets for biophysical and socioeconomic site characterization was prepared and employed. Protocols on the biophysical data collection, analysis, storage, and retrieval were discussed during the country visits of IWMI staff. The existing methodologies for the economic assessment of soil erosion and nutrient depletion and on-farm trials were adapted and applied in the MSEC sites. Existing soil erosion and hydrology models were reviewed to identify appropriate models applicable to the MSEC work.

Alternative technologies and land management systems

The best-bet land management options introduced in the farming systems in the catchments were identified in consultation with the farmers. These options have been elaborated earlier.

Enhanced capacity of the NARES

MSEC has so far conducted 10 training programs on topics such as program management, participatory approaches, hydrology, geographic information system (GIS) and modeling, and rainfall simulation data analysis. More than 60 partners from 16 institutions participated in these programs. Ten graduate students have been involved with the project by conducting their research in the sites. Consultants have also been tapped to provide assistance in addressing more specific research topics.

Improved program management, monitoring, and evaluation

A better management of the program is expected to yield more usable tools and guidelines, relevant technologies, effective information dissemination, and significant institution development. MSEC envisions to optimize the use of scarce research resources by strengthening linkages and collaboration with related projects and institutions. Regular visits to the MSEC sites are still a major activity to monitor progress and anticipate problems in implementation. The regular monthly meeting of the MSEC group at IBSRAM has provided better interaction and sharing of ideas within the organization. In 2001, 11 monthly meetings were held.

Summary and Conclusion

Past research and development efforts have not been able to provide sustainable solution to land degradation problems, and soil erosion has remained a major constraint in improving the living conditions of the people in the marginal and sloping uplands in Asia. MSEC with the funding support from the ADB has implemented a research project to address such problems employing a new research paradigm.

Concrete outputs in terms of capacity building have been achieved. Complete instrumentation of the experimental catchments and training of NARES participants have been useful in initiating the research work in the field. The initial results from different participating countries have shown some interesting observations on the erosion and hydrological processes occurring in the experimental catchments and the factors that may affect them.

The consortium approach and the participatory and interdisciplinary research methods could be a potential key to sustaining upland development in Asia. With stronger and continuing partnerships among stakeholders, it has added a new dimension to soil erosion management, with the potential to enhance the adoption and sustainability of introduced interventions. MSEC will continue to employ this approach and the promising outputs will further be validated at different scales of application and expanded to a much wider area for greater impact. Under IWMI's leadership, the results of the integration of land and water issues are expected to be highlighted.

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Feasible Solutions for Sustainable Land Use in Sloping Areas

L Q Doanh and L V Tiem[1]

Abstract

In Vietnam nearly 74.1% of land is sloping land and subjected to soil erosion and degradation due to human interventions of cultivation of these lands. Unless some technologies are developed to check the soil erosion, the sustainability of crop production in these lands is uncertain. Some solutions like intensive cultivation in the valley to reduce pressures on uplands, use of hybrid rice and maize instead of local cultivars, introduction of commercial perennial crops instead of food crops, and appropriate sloping land management practices have been discussed in detail.

Of 33 million ha of Vietnam's natural land, only 8.6 million ha are relatively flat; the rest are sloping lands, which cover 74% of Vietnam's total land. In addition, the average land for cultivation per person is lowest in the world. At the same time expansion of cultivated area in the flat delta region has almost exhausted. Thus, expansion of cultivation in the sloping lands in a sustainable way is essential.

Sloping lands in the tropical and humid areas like Vietnam is an unsustainable environment for cultivation. Also, when the forest vegetative cover is decreased, the threat for erosion and soil loss increases. In the past, when the population pressure was low, it was possible to maintain the natural fertility by practicing shifting cultivation with 8- to 10-year cycle of no cultivation (coefficient of <12%) and high forest cover. There was a balance between the loss of natural fertility due to cultivation and gain of regenerated fertility due to the regenerated forest in the long fallow period. As the population pressure increased, the fallow period for fertility regeneration was decreased and finally became zero, which means the cultivation coefficient was 100% and thus the threat of erosion and soil loss was the highest (Table 1). Emphasis should be laid on the selection of cropping system on the sloping lands and development of the appropriate method of cultivation that maintains soil fertility, guarantees farm income, and meets the investment level of the local people.

Constraints of the Sloping Lands

Erosion and leaching

Erosion and leaching are regular threats to the sloping lands and cause loss of surface fertile soil and nutrients, followed by acidulation of the soil. These effects are severe if the cultivated land gets exposed without any vegetative cover, or land is cultivated just before the rainy season. The degree of erosion depends on many factors such as rainfall, land erosion, length of the slope, level of the slope, plant cover, and measures for soil protection.

The inappropriate methods of cultivation followed in many regions such as burning vegetation and plowing of land just before the rainy season cause serious erosion and leaching because the newly plowed lands can easily be eroded. Erosion causes soil loss both in quality and quantity, land degradation and leaching, loss of nutrients, and acidulation of the soil, and increases aluminum toxicity.

Soil degradation

Due to the destruction of the forest and annual regime of cultivation, burning trees for cultivation of food crops leads to serious deterioration of the sloping lands in many regions. Fast deterioration of soil limits production in the sloping lands. The increase of aluminum toxicity in soil results from soil acidulation.

1. Vietnam Agricultural Science Institute (VASI), Hanoi, Vietnam.

Table 1. Change in cultivation coefficient.

Year	Land use pattern	Cultivation coefficient[1]
Before 1954	Traditional shifting cultivation (long fallow period)	<20
1965	Traditional shifting cultivation (long fallow period)	20–25
1980	Transfer from traditional to non-traditional shifting cultivation	30–40
1985	Non-traditional shifting cultivation (short fallow period)	45–50
Present	Non-traditional shifting cultivation (very short fallow period)	50–100

1. Cultivation coefficient (R%) $= \frac{\text{Number of cultivation year}}{\text{Total cultivation cycle including fallow period (years)}} \times 100$

In addition, there is decrease in the availability of minerals such as phosphorus, potassium, calcium, magnesium, and zinc.

Drought in the dry season

It is difficult for the sloping lands to conserve water. Cultivation is dependent on rainwater and in the dry season, there is always serious drought. In many regions, there is not enough water for animals and human beings. Drought and shortage of water are the main problems in the sloping lands; if it rains a month later than expected, crop failure is common. Drought in the dry season is due to the loss of forest and uncontrolled cultivation on the sloping lands.

The isolated position

Due to poor transportation and separated relief, many sloping areas become isolated resulting in low exchange of commodities. This slows down the process of the shift of cropping pattern from shifting cultivation by clearing the forest to cultivation of food crops or perennial commercial crops.

Poor infrastructure

The sloping areas usually lie in mountainous areas, far from the center of development. So infrastructure in those areas are very poor, which in turn badly affect economic development.

High rate of poverty and low level of education

The inhabitants of the sloping areas are mainly ethnic minorities and have high rate of poverty and low level of education. The construction works for erosion prevention, water conservation, and growing of crops with high commercial value demand more investment and higher level of farming technology.

Depletion of plant cover

The traditional methods of cultivation turned large areas into barren land. When the forest is destroyed for farming of food crops, majority of area becomes acidified and infested with alang grass (*Impera cyclindrica*). A few years later, the people have to leave the land and look for new farming land. The reduced forest cover affects the general ecological environment causing drought, flood in the plain, and flash flood in the mountainous area.

The Potential of Sloping Land

The potential for expansion of cultivated land

The sloping land constitutes an important component of agricultural production, covering 973 million ha (66%) out of 1500 million ha of arable land of the world. In Vietnam, out of 33.1 million ha of natural land, 24.4 million ha is still unexplored (74%). Due to the difficulty in exploration, the proportion of cultivation on sloping land, and lower population density in comparison with the plain areas, the sloping land still holds good potential for expansion of cultivated land.

The forest potential

The forest is not only a precious natural resource in economic terms but also has high environmental value in terms of water regulation and oxygen-carbon regulation. Most of the forest in Vietnam is concentrated in the sloping area.

Potential of commercial crops

Most of the flat land is reserved for the cultivation of food crops to meet food demand. Most of the crops with high commercial and/or export value such as coffee, rubber, sugarcane, coconut, palm oil, and cocoa can be planted in the sloping land.

Energy potential

The high altitude and high volume of rain provides good potential for hydropower from the sloping areas.

Livestock development potential

The sloping area is potentially good for the development of pasture to provide nutritional feed for livestock. However, the development of pasture fields depends on the customs and level of development in each region.

Change in Land Use Systems in Upland Regions

Traditional shifting cultivation transformed to non-traditional shifting cultivation

Traditional shifting cultivation has been practiced for long in history, but increase in population leads to the increased demand for land for cultivation. Adoption of farming methods from the plain area by immigrants makes the traditional shifting cultivation gradually change to non-traditional form of shifting cultivation (Fig. 1). The differences between these two forms are given below:

Traditional shifting cultivation:

1. Minimum tillage
2. Hole sowing (minimum tillage)
3. Long fallow period
4. Slow soil degradation

Non-traditional shifting cultivation:

1. Thorough land preparation
2. Sowing on flat land or ridges by dibbling
3. Short fallow period
4. Rapid soil degradation

Expansion of continuous cultivation areas

Continuous cultivation does not have a fallow period. The shift from shifting cultivation to continuous cultivation increases cultivation coefficient and helps to increase productivity and output of crops on the sloping lands but causes severe land degradation (Table 2). This process of change occurs very quickly together with the population increase because of the increasing demand for food. There are two types of continuous cultivation: monocultural continuous cultivation and rotated continuous cultivation. Apart from high economic value, continuous cultivation results in erosion and leaching and decrease in soil fertility (Table 2).

Diversification of land use forms

Together with the demand from both the local population and the market, the forms of sloping land use have become more varied. In the past, the main form of land use was forest and shifting cultivation. Now there are many new forms of land use such as continuous cultivation, house garden, and hill garden. In different regions, based on their climatic and socioeconomic conditions, specific forms are created. The diversified forms of sloping land exploration are described in Figures 2 and 3.

Some Feasible Solutions for Sustainable Use of Sloping Lands

Intensive cultivation of rice in the valley

In most sloping lands native communes practice mixed farming of "sloping land and flat fields". In

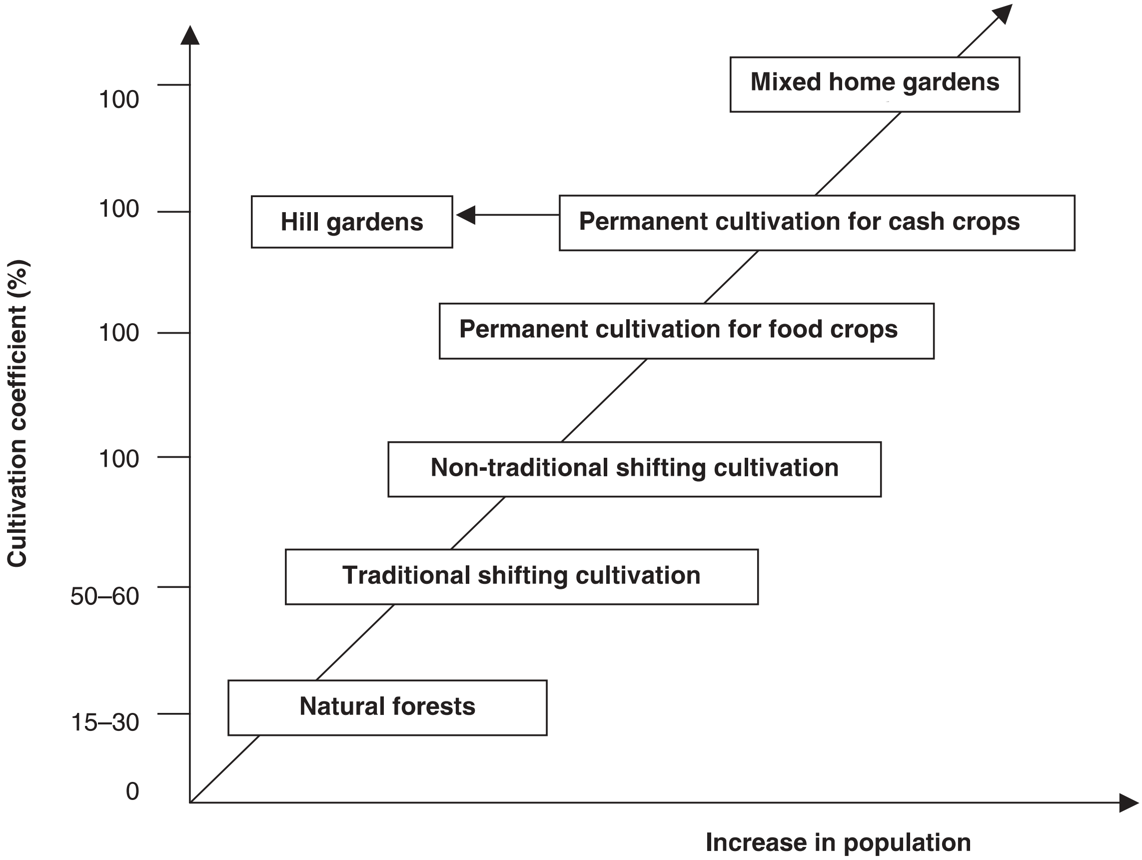

Figure 1. Change in land use systems by increase of cultivation coefficient.

Table 2. Relationship between soil fertility and farming practice in uplands.

Farming practice	R[1] (%)	Available P_2O_5 (mg $100g^{-1}$ soil)	Total K_2O (%)	Available K_2O (mg $100g^{-1}$ soil)	pH
3 years cultivation + 12 years fallow	20	8.8	1.9	8	6.4
5 years cultivation + 10 years fallow	33	4.8	1.7	17	6.0
15 years cultivation (maize-cassava-bean rotation)	100	4.8	1.7	9	5.5
5 years cultivation of annual crop +10 years banana	100	1.6	1.5	27	4.8
15 years cassava monoculture	100	1.0	1.4	8	5.0

1. R = Corelation coefficient.

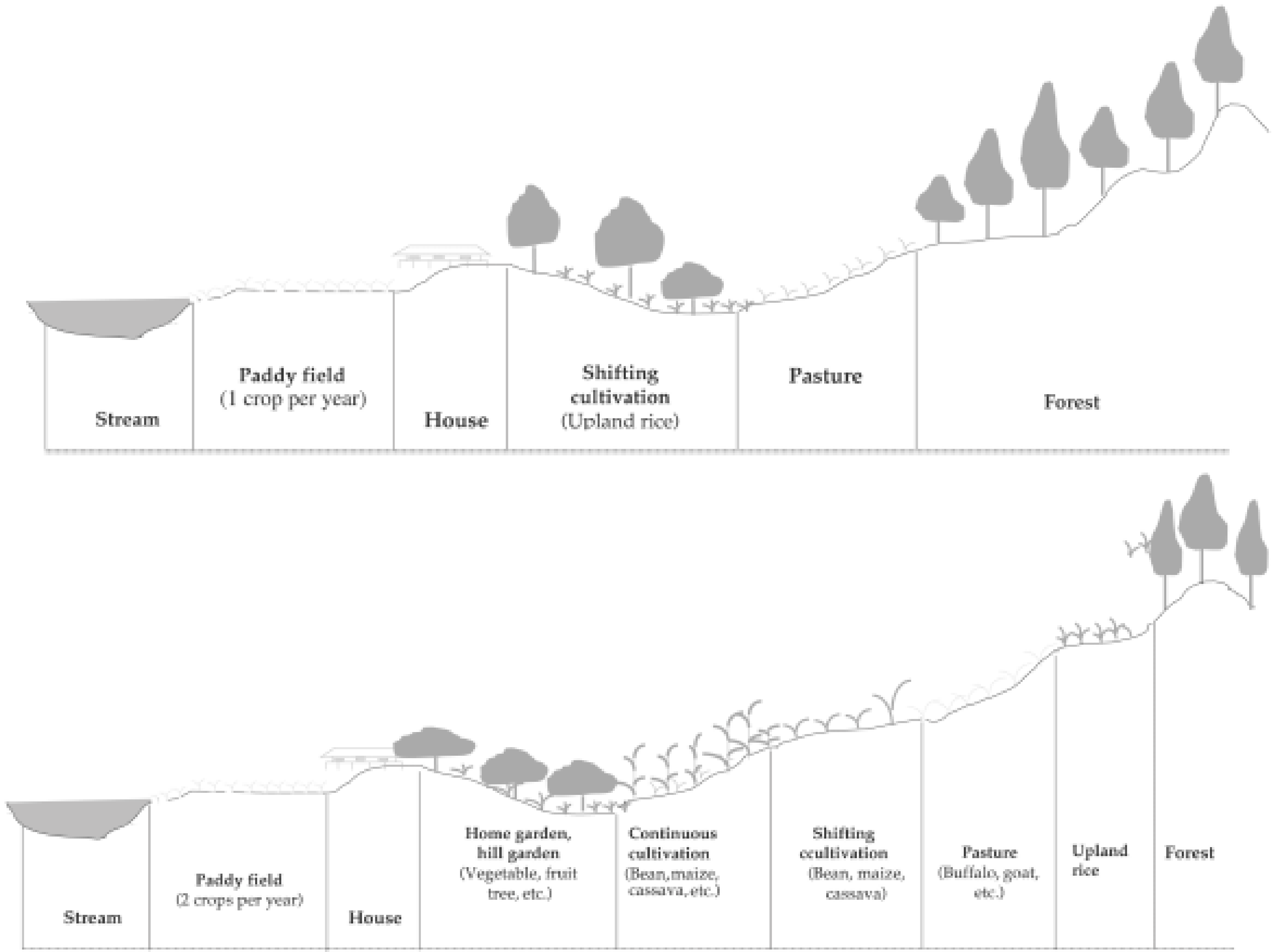

Figure 3. Transformed land use system of the present.

fact, there are a very small number of communes with only upland cultivation. The survey of some communes of the mixed farming group shows correlation between the area of rice and the area of upland fields. In the communes with larger area of irrigated rice and high yield, the upland area under cultivation for food crop is reduced; this also depends on the availability of land in each commune. For example, three communes, Chieng Phu, Phat, and Thai are in Chieng Pan village but the average upland area in each commune varies. The Thai commune has the largest upland area (almost three times that of Chieng Phu) because the rice area of this commune is the smallest. The yield of upland rice is the lowest. On the contrary, in Chieng Phu the area of irrigated rice is not large, but the yield is high; therefore, the upland area is the smallest. Intensive cultivation of rice in the valley helps reduce forest destruction and burning of forests for expansion of land for cultivation of food crops (Table 3).

The yield of rice in the mountainous communes is still low, but the opportunity for intensive cultivation exists. Many rice varieties with high yield potential can be grown in the mountainous area. Many mountainous communes successfully planted hybrid rice. In spite of the high fertility in the valleys, planting without balanced fertilization (i.e., application of urea only) resulted in low yields. With the new technological advancement, such as new varieties with high yield potential, balanced fertilization, construction of small channels for irrigation, and use of intensive cultivation of rice in the valley area can be carried out successfully.

Hybrid rice and maize varieties

The cultivated land in the mountainous area has low soil fertility and the ethnic farmers either do not use or use little fertilizer. Hence varieties that need intensive cultivation should not be introduced. However, it has been proved that the hybrid rice and maize varieties have been successfully cultivated in mountainous area. Many hybrid varieties gave high yield and have shown better resistance to pests than normal varieties.

Development of hybrid maize variety in the mountainous area

In recent years, the area under upland rice in northern mountainous areas has reduced greatly. At the same time, the area under maize has increased, especially after introduction and expansion of hybrid maize. In three North Western provinces the area under maize increased by 36% (from 67,100 ha to 91,900 ha) during 1995–99 and hybrid maize occupies 76% of total area under maize. However, in nine provinces of the Red River delta, the area increase was only 1% (from 75,100 ha to 76,100 ha).

The replacement of upland rice by hybrid maize not only brought about higher economic gains but also helped to reduce soil erosion and leaching because the cover of maize is better than rice. Maize roots penetrate deeper and thus the crop has better drought resistance. Normally, the land for upland rice can be cultivated for 3 years; then it should be left uncultivated or used to grow maniocs. Over expansion of maize area by destruction of the forest or growing maize on sloping lands (>15% slope) should not be

Table 3. Average area of irrigated and upland rice per household in Chieng Pan, Son La province, Vietnam.

Ethnic group/ village	Irrigated rice (ha)	Paddy yield (t ha^{-1} yr^{-1})	Upland rice (ha)	Upland rice/ irrigated rice	Land use system
Kinh (Chieng Phu)	0.09	10 (2 crops yr^{-1})	0.40	5:1	Monoculture continuous cultivation
Thai (Phat village)	0.25	8 (2 crops yr^{-1})	0.80	3:1	Rotated cultural continuous cultivation
Kh Mu	0.07	3 (1 crop yr^{-1})	1.10	15:1	Shifting cultivation

recommended. Intensive cultivation of hybrid maize also demands higher amounts of fertilizers. Maize being an annual crop, cultivation of annual crops on sloping lands is not sustainable.

Development of hybrid rice in the mountainous area

Due to the price subsidies by the state, the area of hybrid rice in the valley fields and in the terrace fields in the mountainous areas is increasing rapidly. The percentage of valley field rice of the mountainous villages is very low and due to the slope relief, it is very difficult to expand the area of rice. Therefore, the only way to increase food security is to increase rice productivity in these areas.

Although it is not easy to transfer improved technology of rice to the farmers in the mountainous area, the results obtained so far in the mountainous area confirmed the feasibility. In 1998 when hybrid rice was not planted in Quan Than San (Sa Ma Cai district, Lai Chau Province), the people had enough rice for food for 8 months; in the remaining months they had to depend on maize. Now hybrid rice covers 80% of their terrace fields. People have enough rice for food and do not have to eat maize. The quantity of manure used for rice is much higher than before. Expansion of hybrid rice and increased fertilizer usage in the mountainous areas increase food security and maintain soil fertility.

Securing food supply with commercial perennial plants on the sloping land

The market economy and expansion of agricultural product trading allows shift in cultural practices. Earlier farmers were forced to grow rice on the sloping land when market was not available. Growing of commercial crops was possible with markets and this has improved income generation and livelihoods. On the sloping lands, forest trees and perennial crops are the best cropping patterns that can help reduce soil erosion. There are many mountainous communes that have been successful with the cultivation of commercial perennial crops (i.e., fruit trees, industrial plants, medicinal herbs, etc.). Hill sugarcane and bamboo garden are best examples.

Intensive cultivated hill sugarcane

In comparison with upland rice and maize, sugarcane has better adaptability. Sugarcane can be planted in the upland field left uncultivated for many years after rice, maize, or on soils depleted of fertility. This is because the roots of sugarcane can penetrate deeper than rice or maize. In a survey of the hill sugarcane growing communes of Ngoc Lac District, Thanh Hoa province, it was observed that sugarcane has higher economic value than other annual crops like cassava, upland rice, and maize on the sloping lands (Table 4).

Table 4. Economic efficiency of different land use patterns.

Land use pattern	Income (US\$ ha^{-1} yr^{-1})	Benefit (US\$ ha^{-1} yr^{-1})
Extensive cassava	200	27
Intensive cassava	373	73
Upland maize	573	373
Intensive sugarcane	1067	533
Bamboo	1000	853

Intensive cultivated hill sugarcane is different from the local sugarcane. In addition to the ditches dug as parallel lines, balanced application of nutrients must be ensured. Because sugarcane requires more nutrients than other crops, it is necessary to apply required quantities of nutrients. After sugarcane is harvested, the ratoon crop is covered to preserve soil moisture and return part of the nutrients back to the soil. Sugarcane is a semi-perennial crop, and needs to be planted every three years. Therefore, the amount of soil lost through erosion is much less in comparison to other annual crops like upland rice, maniocs, beans, maize, etc. (Table 5). Even if there is no major change in consumption of sugarcane, intensive cultivated hill sugarcane is relatively sustainable and ensures both increased incomes and maintenance/restoration of soil fertility.

Bamboo garden

Bamboo is a forest crop having high adaptability. It can be planted on degraded land where other crops like maize, upland rice, or sugarcane cannot grow. It

Table 5. Soil erosion from different land use patterns.

Land use pattern	Slope (°)	Soil loss ($t\ ha^{-1}\ yr^{-1}$)	OM loss[1] ($t\ ha^{-1}\ yr^{-1}$)
Bare hill	18	40.28	-
Annual cassava	17	75.16	1.650
Broods	16	17.40	0.504
Sugarcane (2 years old)	17	14.46	0.376
Bamboo (9 years old)	18	9.12	0.200

1. OM = Organic matter.

can also be planted on sloping lands with >25% slope. The survey carried out in some bamboo planting areas in the western districts of Thanh Hoa province showed that economic value of bamboo is approximately equal to maize and sugarcane. The bamboo garden can control erosion better and the soil loss is much less in comparison to annual crops (e.g., maize) and semi-perennial crops (e.g., sugarcane). Bamboo can retain water better on the bamboo hill, when the plants are high enough to provide full cover; the groundwater level also increased significantly. The humus content also increased after many years of planting bamboo though soil fertility improvement was not as high as in broad-leaved crops.

Appropriate methods for sloping land cultivation

As mentioned earlier, due to the shortage of cultivated area, it is impossible to stop cultivation of food crops on the sloping lands when the population is continuously increasing. In the last few years, in the framework of the cooperation between the Vietnam Agricultural Science Institute (VASI) and the Centre de cooperation internationale en recherché agronomique pour le développement (CIRAD), France, a study on agricultural system of the mountainous area was initiated to identify promising techniques that meet the above mentioned requirements. Many promising technologies were identified; e.g., mini-terraces, planting parallel hedges, and hedgerow cropping.

Strengthening the capacity of local people and officials

The technological innovations need to be widely adopted in mountainous areas. Besides investment in infrastructure, it is necessary to increase training activities, information dissemination, and networking activities to create conditions for both local people and officials to improve their capabilities for proper understanding and application of technologies envisaged for the sloping lands.

Conclusions

The most difficult question that needs to be addressed immediately is how to undertake production activities on the sloping lands, which are easily subjected to erosion and leaching and have low soil fertility. The following solutions help address some of the concerns effectively:

- Intensive cultivation in the valley to reduce the pressure of upland exploration.
- Use of hybrid rice and maize cultivars for high yields.
- Securing food supply with commercial perennial crops.
- Developing appropriate methods for sloping land cultivation.

All technologies should be feasible solutions that secure food supply and improve household incomes in the mountainous areas and help to preserve soil fertility.

Productivity and Resource Use Management of Soybean-based Systems in a Vertic Inceptisol Watershed

Piara Singh, S P Wani, P Pathak, R Sudi, and M S Kumar[1]

Abstract

Erratic rainfall and land degradation are the major constraints affecting productivity of soybean-based systems in central India. Operational scale watershed experiments were conducted for six seasons on a Vertic Inceptisol at ICRISAT, Patancheru, India to study the effects of improved management on land degradation, rainfall use efficiency, and the productivity of the soybean-chickpea sequential and soybean/pigeonpea intercropping systems. Improved management comprised of integrated nutrient management (additions of crop residues and Gliricidia *loppings) and sowing on broadbed-and-furrow (BBF) system. The traditional management consisted of sowing on flat landform and no addition of external sources of nutrients, except P application. These treatments were imposed on medium-deep and shallow phases of the soil type. The BBF system decreased surface runoff (16% of rainfall) compared to the flat system (21% of rainfall) with concomitant increase in deep drainage. Mean rainfall use efficiency was 70 to 73% across cropping systems and soil depths. Integrated nutrient management resulted in balanced soil N budget, whereas the traditional system showed a deficit of about 50 kg ha^{-1}. Denitrification and leaching losses were negligible. Landform treatments did not increase the crop yields significantly. Total productivity of the soybean-chickpea system ranged from 2.3 to 2.7 t ha^{-1} of seed yield and that of soybean/pigeonpea intercropping system ranged from 2.1 to 2.3 t ha^{-1} over the years, still showing a yield gap of about 1 t ha^{-1} for the Patancheru site. Simulated yield gap analysis for other nine sites in central India showed a mean yield gap of 1.2 to 1.9 t ha^{-1} under rainfed conditions, which could be even more in good rainfall years. This study has shown the potential of the improved technology for higher productivity and efficient use of natural resources on a Vertic Inceptisol, which has potential applications in the target region of central India.*

Soybean is grown on about 6 million ha in India mainly in the states of Madhya Pradesh, Maharashtra, and Rajasthan (FAO 2002). It is also grown in the states of Uttar Pradesh, Andhra Pradesh, Karnataka, and Tamil Nadu (Fig. 1). Despite the increase in production and area under soybean in the country, its productivity has stagnated at less than 1.0 t ha^{-1} (Fig. 2). Major increase in the area under soybean has occurred in Madhya Pradesh, where the annual rainfall spatially ranges from 800 to 1200 mm. The soils are Vertisols and associated Vertic Inceptisols. Major constraints to the production of soybean-based systems in Madhya Pradesh are physical, chemical, and biological forms of land degradation. Soil erosion is particularly high in central India because Vertisols and associated soils which predominate the landscape are prone to sheet and gully erosion under tropical monsoon climate. Therefore, to sustain crop yields of soybean-based systems, it is essential that land degradation is minimized, natural resources are efficiently used, and efficient cropping systems are introduced that will optimally use the natural resources. Considering these issues, a small watershed was developed on Vertic Inceptisol at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India with the following objectives:

- Evaluate the productivity of the selected soybean-based cropping systems with improved and traditional management on a Vertic Inceptisol.

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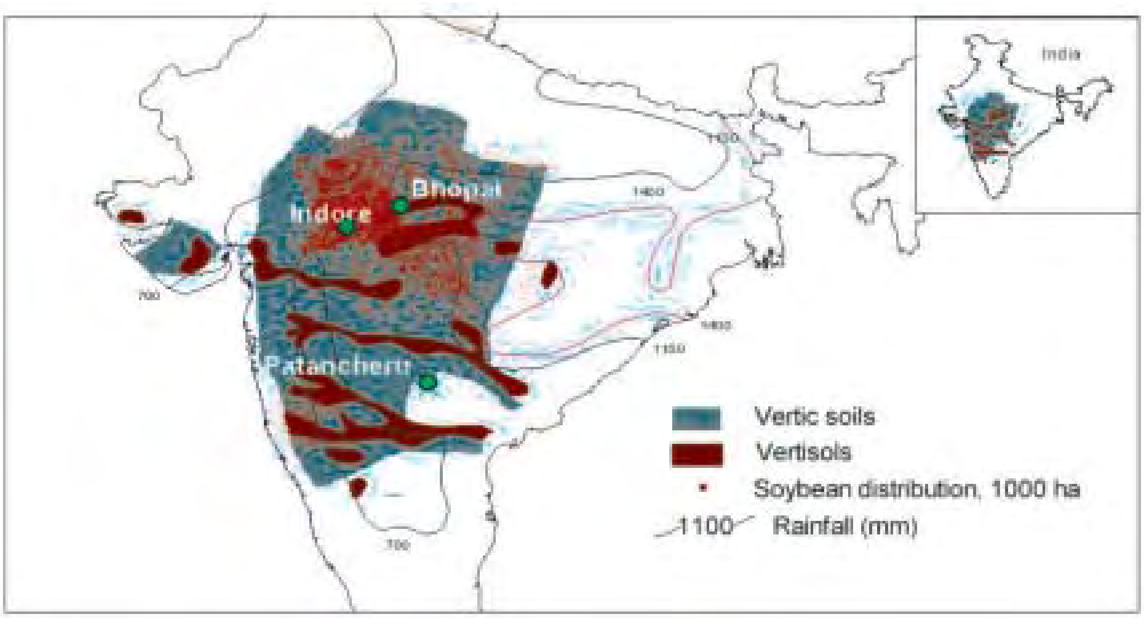

Figure 1. Soybean distribution and its agroecology in India.

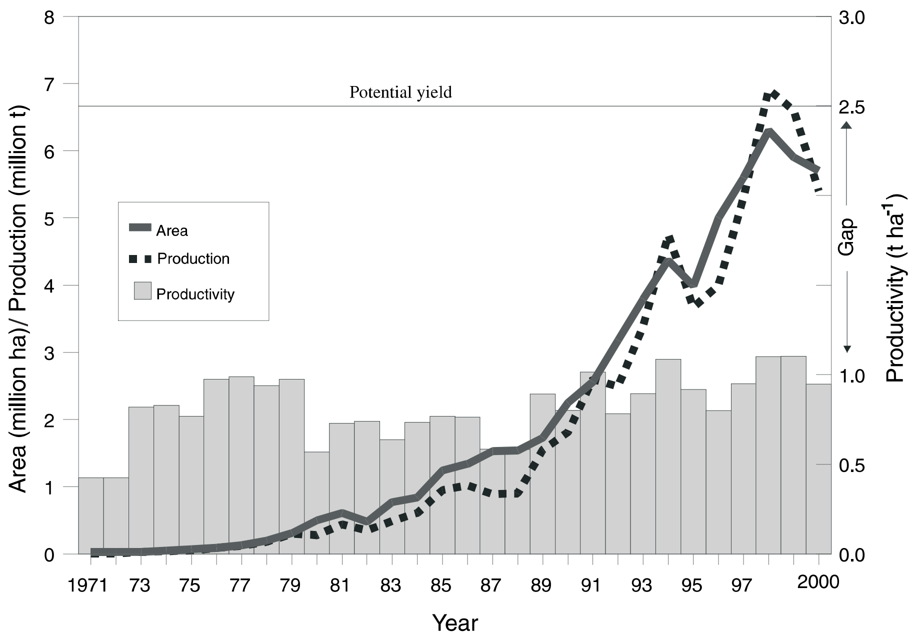

Figure 2. Area, production, and productivity of soybean in India.

- Evaluate the extent to which land degradation (soil erosion and nutrient depletion) can be minimized, productivity can be increased, and the other natural resources can be efficiently used with improved management.

Agroecology of the Patancheru Site and the Target Region

The annual rainfall (average of 30 years) of Patancheru is 800 mm. In the past 20 years, the rainfall was below normal in 8 out of 20 years. On an average 3 years out of 5 are average rainfall years (<25% variation of normal rainfall), 1 out of 5 years is above average (>25% of normal rainfall), and 1 out of 5 years are below average (<75% of normal rainfall). Since the average potential evapotranspiration required by any rainy season crop in Patancheru area is 600 mm, the below average years can be broadly termed as drought years. The coefficient of variability of the annual rainfall is 27% based on rainfall observed during the past 30 years.

The daily rainfall during the past seven years (1995–2001) clearly shows that at Patancheru the rainfall is unevenly spread during the rainy season (Fig. 3). It is not uncommon to receive 50% of the total seasonal rainfall in a few high volume, high intensity rainstorms. This amount of rainfall exceeds the water intake rate of most soils at Patancheru when the surface is fully wet. Rainfall then flows as surface runoff and causes extensive soil erosion and loss of nutrients. Effective rainfall is thus a fraction of the total rainfall received. This leads to reduced rainfall use efficiency caused by rainfall variability during the rainy season.

Madhya Pradesh receives annual rainfall varying from 800 to 1600 mm. Eighty percent of this is received from mid-June to mid-October. The rainfall increases from 800 mm in the western parts of Madhya Pradesh to 1500 mm in the eastern parts (Fig. 1). Madhya Pradesh has six soil types ranging from alluvial soils to deep black soils distributed over 12 agroclimatic zones. Medium to deep black soils receive 800 mm to 1200 mm annual rainfall. Because of poor manageability of black soils the cropping intensity is low (117%). Soybean-based cropping systems are mainly practiced. Various constraints of these soils are low infiltration rate, low organic matter content, poor structural stability, and vulnerability of soil to erosion. Harvesting and recycling of water on a watershed basis is required for sustaining production on these soils. Water balance of the two sites (Indore and Bhopal) in Madhya Pradesh is compared with that of Patancheru site (Fig. 4). The data shows that although the length of water availability period is longer at Patancheru compared to Indore and Bhopal, there are 3 months of rainfall exceeding potential evapotranspiration. Total rainfall in July and August received at Indore and Bhopal is greater than that received at Patancheru. This indicates that the opportunities for water harvesting are greater at these two sites in Madhya Pradesh compared to the Patancheru site. The problem of land degradation because of soil erosion is also greater at Indore and Bhopal. Therefore, it is expected that technological concepts developed at Patancheru site would have potential application at these two sites in Madhya Pradesh.

Current and Potential Land Use Systems in the Target Region

Various cropping systems are being followed in the target region of Madhya Pradesh where soybean crop has even greater potential in the region. Cropping systems practiced are cotton-wheat, maize-chickpea, pearl millet-wheat/mustard, pigeonpea-chickpea, rice-chickpea/mustard/wheat, sorghum-wheat, and soybean-wheat/chickpea. Madhya Pradesh accounts for more than 75% of total area and production of soybean in India. Soybean-wheat is a popular rotation in partially irrigated areas, while soybean-chickpea/safflower/lentil/linseed /mustard cropping systems are practiced in the rainfed areas. Soybean is also grown as an intercrop with medium-duration pigeonpea.

With improved management of black soils (Vertisols and Vertic Inceptisols), soybean is further expected to replace high input requiring crops such as cotton, maize, pearl millet, and sorghum grown during the rainy season. Soybean being a legume crop, the replacement of other crops by soybean is expected to result in saving of chemicals such as mineral fertilizers and biocides, thus contributing to the alleviation of environmental pollution.

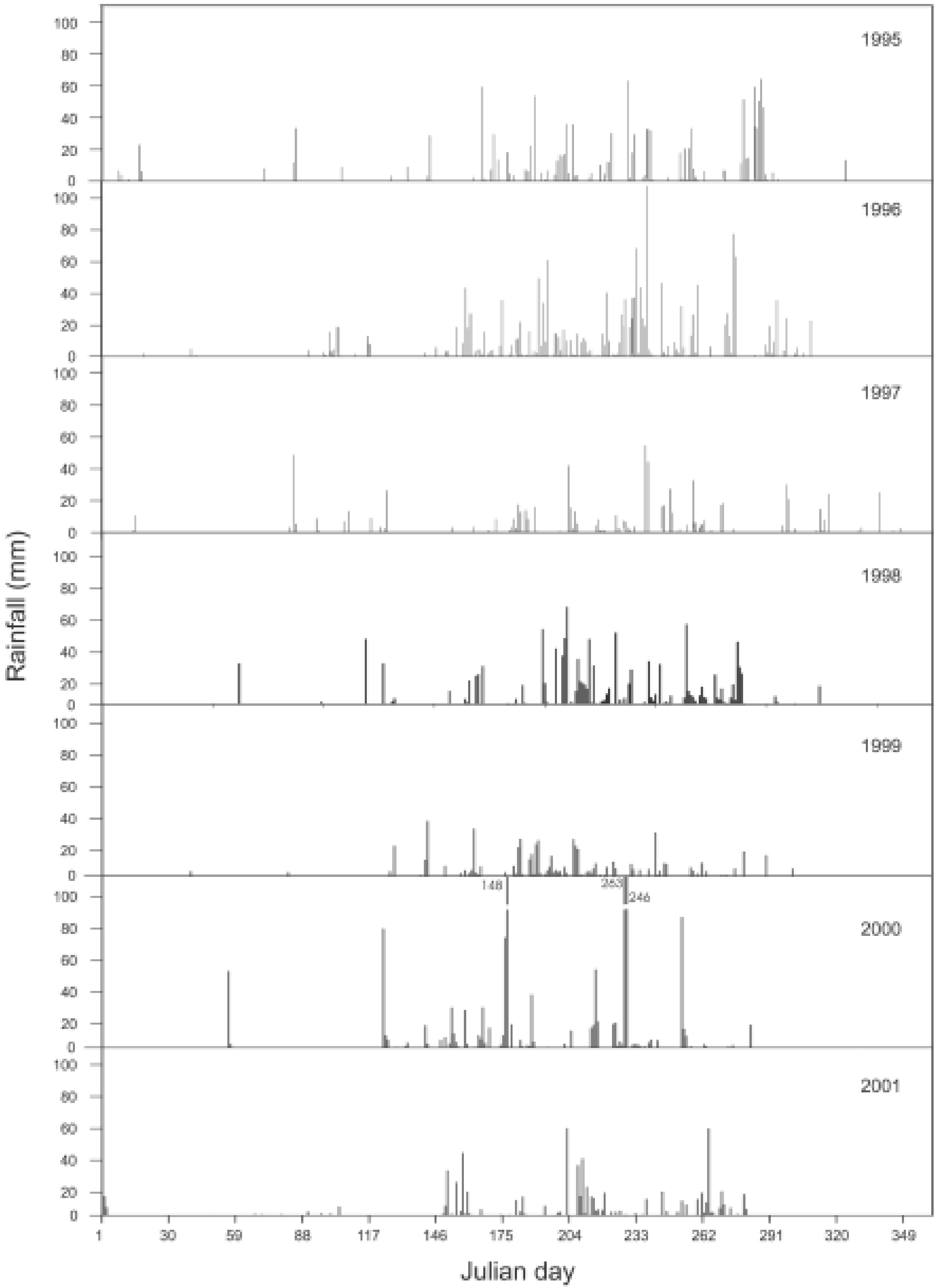

Figure 3. Daily rainfall at ICRISAT, Patancheru, India during 1995 to 2001.

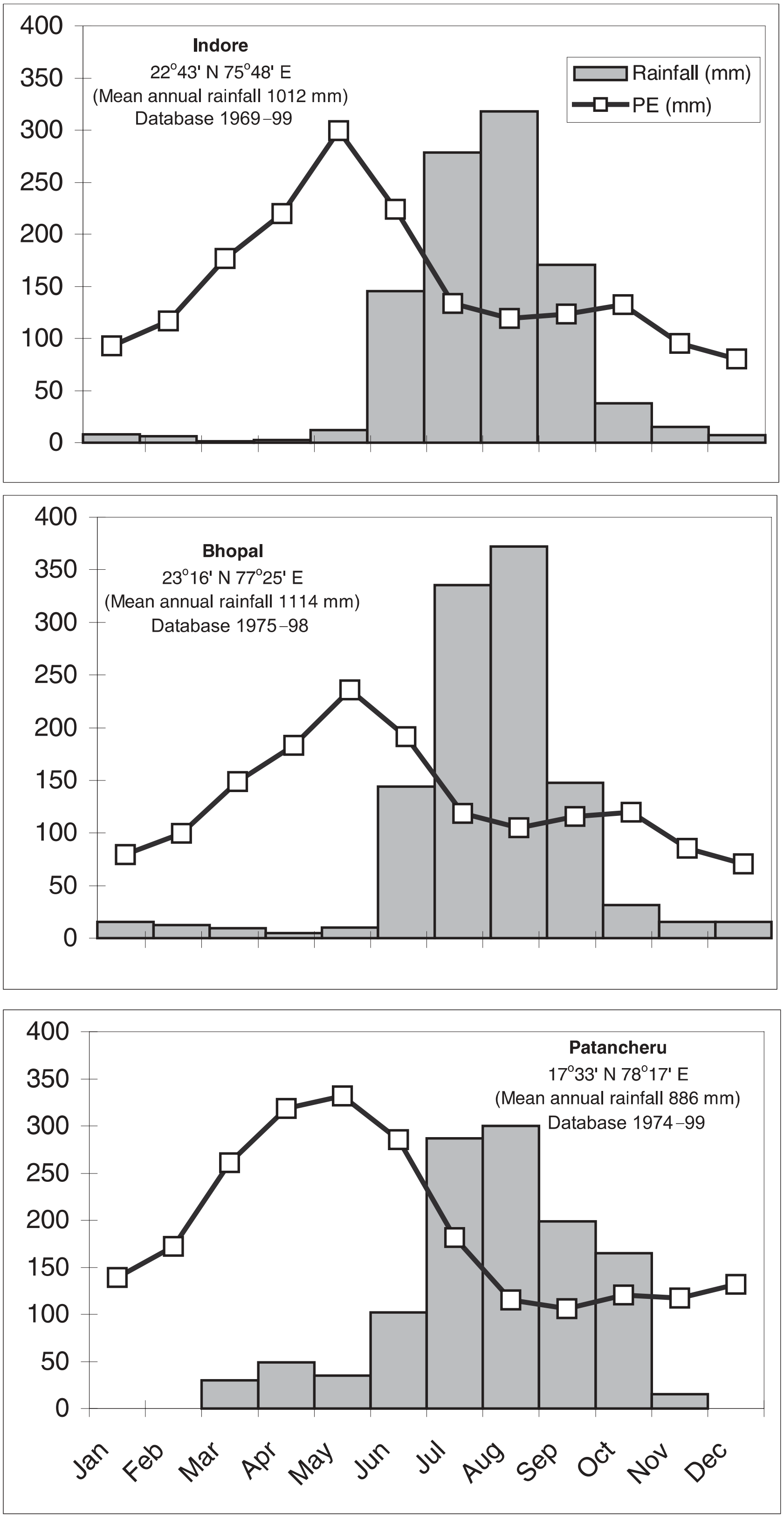

Figure 4. Water balance of Indore, Bhopal, and Patancheru sites.

Watershed Research at ICRISAT

The Patancheru site (BW7) serves as a reference site on a Vertic Inceptisol for strategic research on the soybean-based farming system (Fig. 5). Because the Vertic Inceptisols are relatively shallow in depth, the focus of the technology for these soils was to recharge the groundwater through land management and harvesting of excess rainfall in percolation tanks. Integrated nutrient management practices (legumes in the system, biofertilizers, and chemical fertilizers) was followed to meet the nutrient needs of the crops and to minimize the pollution of groundwater. Based on the toposequential soil depth the 15-ha watershed was divided into two hydrological units: medium-deep (50–90 cm) and shallow (<50 cm). These two hydrological units were further divided into two units on which two landform treatments were imposed: (1) broad-bed and furrow (BBF) with *Gliricidia sepium* on graded bands; and (2) flat landform with sowing on grade. Thus the watershed was divided into four hydrological units and on each unit two cropping systems were evaluated: (1) soybean/pigeonpea intercropping system; and (2) soybean-chickpea sequential cropping system except in the first year when only soybean-chickpea system was evaluated. This experiment has been conducted for six years from 1995/96 to 2000/01 and data have been collected on crop yields, runoff and soil erosion, water and nitrogen (N) balance, and groundwater recharging.

Surface runoff and soil erosion

Significant amount of runoff occurred in four out of six years of study (Table 1). Surface runoff, though variable over the years, averaged about 25% of the rainfall. Surface runoff was relatively more from the medium-deep soil than from the shallow soil. Because of greater time of concentration, total seasonal runoff and peak runoff rates were lower on the BBF landform compared to those on the flat landform on both the soil depths. On the medium-deep soil, BBF landform on an average reduced surface runoff by 22% compared to the flat landform, whereas on the shallow soil such reduction in runoff by the BBF system was about 18%. Whenever surface runoff occurred, the peak runoff rates were lower on the BBF landform than on the flat landform and did not differ significantly between the two soil depths (Table 1). Soil erosion observed between the landform treatments over the seasons was proportional to the amount of runoff observed and the peak runoff rates. Total soil loss averaged over the years was 2.4 to 2.5 t ha^{-1} on the BBF and 4.0 to 4.5 t ha^{-1} on the flat landform. Maximum soil loss was recorded during 2000/01 season, which was 6.5 to 6.7 t ha^{-1} on BBF and 11.1 to 12.0 t ha^{-1} on flat landform on two soil depths.

Simulated water balance of the soybean-chickpea sequential system

Water balance of the soybean-chickpea sequential system was simulated using Decision Support System for Agrotechnology Transfer (DSSAT) model (Tsuji et al. 1994). Model parameters for soil water balance were calibrated using the observed surface runoff and soil water dynamics data. Though the simulated runoff varied across seasons and soil depths, it averaged 160 mm for BBF medium-deep, 157 mm for BBF shallow, 213 mm for flat medium-deep, and 196 mm for BBF shallow (Table 2). On an average surface runoff constituted 16% of seasonal rainfall for the BBF landform and 20% of seasonal rainfall for the flat landform. This resulted in concomitant increase in deep drainage in both the soil types. For the medium-deep soil, average deep drainage for the cropping period was 135 mm for BBF (14% of rainfall) and 93 mm for the flat landform (11% of rainfall) (Table 2). For the shallow soil, average deep drainage was 183 mm for the BBF landform (21% of rainfall) and 139 mm for the flat landform (16% of rainfall). Total water use by the soybean-chickpea sequential system averaged over the seasons ranged from 481 to 515 mm across soil types and landforms (70 to 73% of rainfall) (Table 2).

Simulated water balance of the soybean/pigeonpea intercropping system

Water balance of the soybean/pigeonpea intercropping system was simulated using the Agricultural Production Systems Simulator (APSIM) (McCown et al. 1996) following the same approach as for the soybean-chickpea sequential system. As the intercropping system is of longer duration than the sequential system the values of various water balance

Year	Rainfall (mm)	Surface runoff (mm)		Peak runoff rate ($m^3 s^{-1} ha^{-1}$)		Soil loss ($t ha^{-1}$)	
		BBF[1]	Flat	BBF	Flat	BBF	Flat
Medium-deep							
1995/96	657	168	196	0.068	0.098	NR[2]	NR
1996/97	961	232	263	0.120	0.137	3.2	4.9
1997/98	546	1	3	0.003	0.003	0	0
1998/99	1043	200	290	0.135	0.145	2.7	5.5
1999/2000	401	0	0	0	0	0	0
2000/01	1062	477	641	0.270	0.385	6.5	12.0
Mean	778	180	232	0.099	0.128	2.5	4.5
Shallow							
1996/97	961	130	194	0.109	0.235	1.8	3.7
1997/98	546	2	2	0.003	0.004	0	0
1998/99	1043	251	283	0.130	0.168	3.4	5.3
1999/2000	401	0	0	0	0	0	0
2000/01	1062	489	588	0.270	0.320	6.7	11.1
Mean	803	174	213	0.102	0.145	2.4	4.0

Table 1. Seasonal runoff, peak runoff rates, and soil loss in BW7 watershed at ICRISAT, Patancheru, India.

1. BBF = Broad-bed and furrow.
2. NR = Not recorded.

Figure 5. BW7 watershed at ICRISAT, Patancheru, India.

Table 2. Simulated water balance components of soybean-chickpea sequential system in various treatments on a Vertic Inceptisol, ICRISAT, Patancheru, India.

Year	Rainfall[1] (mm)	Surface runoff (mm)		Deep drainage (mm)		Crop water use (mm)	
		BBF[2]	Flat	BBF	Flat	BBF	Flat
Medium-deep soil							
1995/96	653	81 (12)[3]	92 (14)	133 (20)	137 (21)	517 (79)	512 (78)
1996/97	973	231 (24)	272 (28)	165 (17)	172 (18)	559 (57)	563 (58)
1997/98	532	1 (0)	3 (1)	0 (0)	1 (0)	563 (100)	565 (100)
1998/99	876	171 (20)	259 (30)	215 (25)	126 (14)	518 (59)	510 (58)
1999/2000	401	8 (2)	18 (5)	0 (0)	0 (0)	395 (98)	406 (100)
2000/01	1251	466 (37)	630 (50)	295 (24)	121 (10)	541 (43)	499 (40)
Mean	781	160 (16)	213 (21)	135 (14)	93 (11)	515 (73)	509 (73)
Shallow soil							
1995/96	653	77 (12)	85 (13)	234 (36)	215 (33)	487 (75)	481 (74)
1996/97	973	142 (15)	207 (21)	327 (34)	271 (28)	496 (51)	503 (52)
1997/98	532	2 (0)	4 (1)	38 (7)	19 (4)	565 (100)	558 (100)
1998/99	876	228 (26)	269 (31)	206 (24)	152 (17)	487 (56)	487 (56)
1999/2000	401	16 (4)	40 (10)	0 (0)	0 (0)	400 (100)	388 (97)
2000/01	1251	479 (38)	574 (46)	296 (24)	177 (14)	459 (37)	472 (38)
Mean	781	157 (16)	196 (20)	183 (21)	139 (16)	482 (70)	481 (70)

1. During the cropping season.
2. BBF = Broad-bed and furrow.
3. Values expressed as percentages of rainfall are given in parentheses.

components (runoff, deep drainage, and water use) were generally larger than those for the sequential system (Table 3). However, when these water balance components were expressed as percentage of seasonal rainfall, their values were similar to those simulated for the soybean-chickpea sequential system.

Groundwater recharge

Overall improvement in land management in BW7 watershed resulted in increased groundwater recharge. Surface runoff and deep drainage water was captured in surface tanks and dug wells in the watershed. During 1996, 1998, and 2000 there was significant rise in water level (5 to 6 m) in the wells situated at the lower part of the watershed (Fig. 6). Because of low rainfall during 1999 the rise in water level in the wells was small. This additional water availability in the wells helped provide supplemental irrigation to the horticultural crops in the lower part of the watershed. Thus the overall rainfall use efficiency on watershed basis was greater than 50% in most years.

Measured nitrogen balance

Integrated nutrient management followed in the improved system (sowing on BBF + *Gliricidia* on bunds + addition of compost) resulted in balanced N budget for the soybean-chickpea sequential and soybean/pigeonpea intercropping systems (Table 4). In spite of N contributions through rainfall, biological nitrogen fixation (BNF), leaf fall, and roots, there was a net loss of about 50 kg N ha^{-1} for both the cropping systems in the conventional system (flat landform treatment) during the first four years. In the improved system, the application of *Gliricidia* loppings and compost provided about 45 kg N ha^{-1} without affecting the yield of crops in the nearby rows, thus balancing the N budget. Pigeonpea derived up to 89%, soybean up to 75%, and chickpea up to 42% of their N requirement through BNF.

Simulated nitrogen balance

Simulated N uptake and N fixation by the soybean/pigeonpea intercropping system was variable across

Table 3. Simulated water balance components of soybean/pigeonpea intercropping system in various treatments on a Vertic Inceptisol, ICRISAT, Patancheru, India.

Year	Rainfall[1] (mm)	Surface runoff (mm)		Deep drainage (mm)		Crop water use (mm)	
		BBF[2]	Flat	BBF	Flat	BBF	Flat
Medium-deep soil							
1996/97	966	234 (24)[3]	268 (28)	184 (19)	198 (20)	545 (56)	534 (55)
1997/98	531	1 (0)	0 (0)	0 (0)	0 (0)	544 (100)	538 (100)
1998/99	1035	229 (22)	304 (29)	262 (25)	223 (21)	577 (56)	568 (55)
1999/2000	436	1 (0)	1 (0)	0 (0)	0 (0)	460 (100)	465 (100)
2000/01	1248	473 (38)	622 (50)	251 (20)	97 (8)	579 (46)	567 (45)
Mean	843	187 (17)	239 (21)	139 (13)	104 (10)	541 (72)	534 (71)
Shallow soil							
1996/97	966	137 (14)	207 (21)	360 (37)	299 (31)	521 (54)	514 (53)
1997/98	531	0 (0)	0 (0)	23 (4)	16 (3)	543 (100)	536 (100)
1998/99	1035	291 (28)	291 (28)	267 (26)	257 (25)	574 (55)	565 (55)
1999/2000	436	0 (0)	0 (0)	0 (0)	0 (0)	468 (100)	460 (100)
2000/01	1248	478 (38)	583 (47)	269 (21)	162 (13)	545 (44)	537 (43)
Mean	843	181 (16)	216 (19)	184 (18)	147 (14)	530 (71)	522 (70)

1. During the cropping season.
2. BBF = Broad-bed and furrow.
3. Values expressed as percentages of rainfall are given in parentheses.

seasons depending upon weather and amount of total dry matter produced by the system (Table 5). The N uptake by the intercropping system approximately ranged from 240 to 270 kg ha^{-1}, whereas N fixation approximately ranged from 170 to 250 kg ha^{-1}. There was no significant difference between the two landforms and the two soil depths for plant N uptake and N fixation by the soybean/pigeonpea intercropping system. Although denitrification and leaching of N were greater in the BBF treatment in both the soil depths because of higher rainfall infiltration and deep drainage, these constituted insignificant amounts of N losses from the soil to be of any environmental concern (Table 5).

Table 4. Nitrogen (N) contributions and balance (kg ha^{-1}) of soybean-based cropping systems in a Vertic Inceptisol watershed, ICRISAT, Patancheru, India, 1995–98[1].

Description	Soybean-chickpea		Soybean/pigeonpea	
	BBF	Flat	BBF	Flat
Total N uptake	197	198	220	214
Total N loss (runoff + deep drainage)	13	17	14	17
N additions (rainfall, fallen leaves, roots, and BNF)	165	168	200	183
N additions (compost, *Gliricidia* loppings)	45	0	44	0
N balance	0	–47	+10	–49

1. BBF = Broad-bed and furrow; BNF = Biological nitrogen fixation.

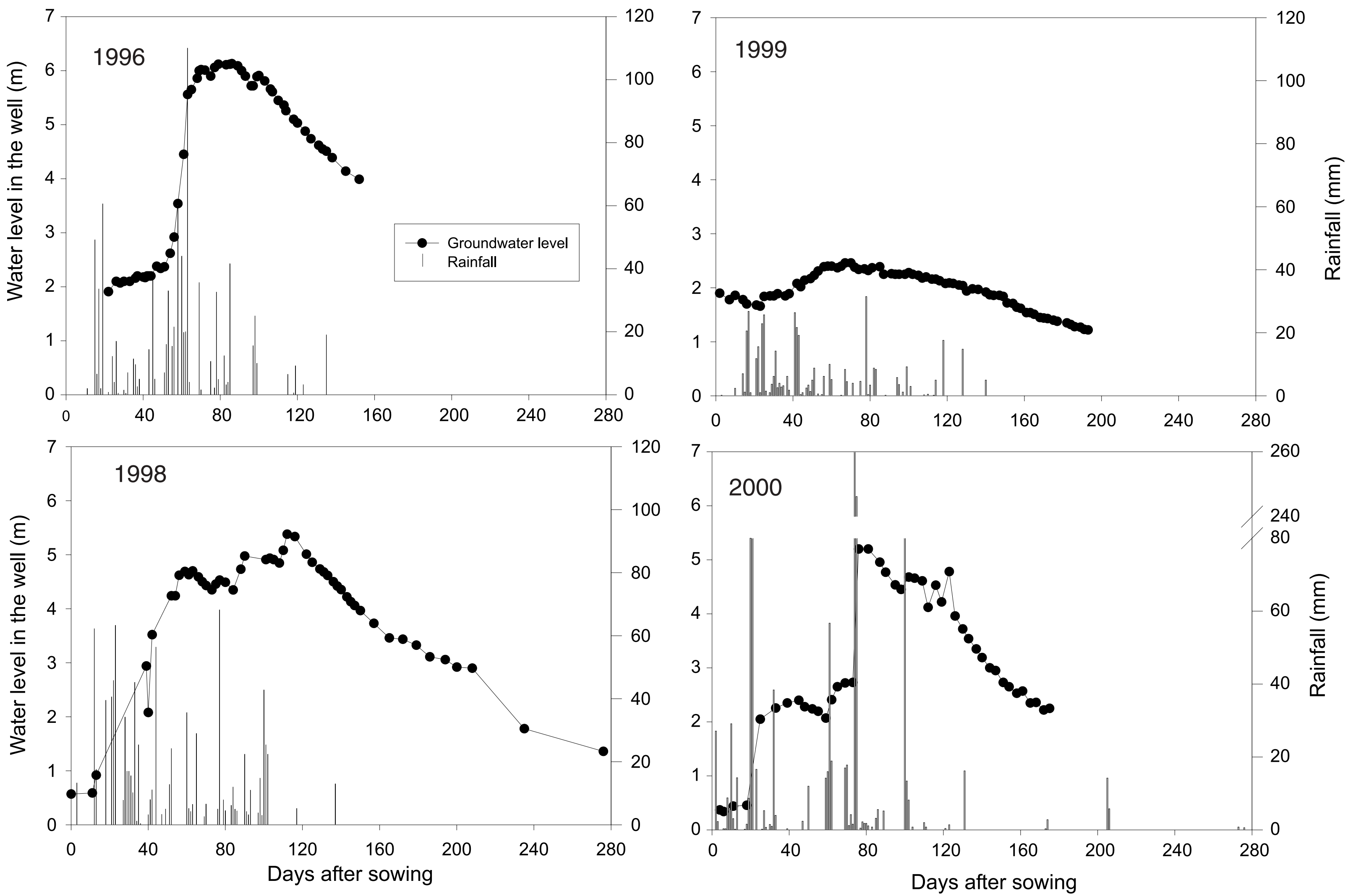

Figure 6. Rainfall distribution and groundwater level in the well in BW7 watershed.

Table 5. Simulated nitrogen (N) balance (kg ha^{-1}) of soybean/pigeonpea intercropping system on a Vertic Inceptisol, ICRISAT, Patancheru, India.

	Plant N uptake		N fixation		Denitrification		Leaching	
Year	BBF[1]	Flat	BBF	Flat	BBF	Flat	BBF	Flat
Medium deep soil								
1996/97	259	263	189	200	0.95	0.56	3.03	0.014
1997/98	242	239	169	168	0.60	0.72	0	0
1998/99	270	269	218	228	0.33	0.20	0.001	0
1999/2000	263	259	201	209	0.62	0.47	0	0
2000/01	271	269	253	251	0.024	0.023	0	0
Mean	261	260	206	211	0.50	0.39	0.61	0.002
Shallow soil								
1996/97	259	262	200	212	0.3	0.08	2.1	0.02
1997/98	242	239	174	175	0.14	0.10	0.001	0
1998/99	270	268	218	230	0.047	0.015	0.006	0.002
1999/2000	271	269	222	220	0.072	0.077	0	0
2000/01	265	262	231	244	0.03	0.002	0.005	0
Mean	261	260	209	216	0.12	0.05	0.42	0.004

1. BBF = Broad-bed and furrow.

Crop yields

The landform treatments did not significantly affect the yields of the component crops of the two cropping systems (Tables 6 and **7**). Soil depth did not influence the yield of rainy season crops in most years, except in low rainfall years the yields were higher on medium-deep soil. Major effect of soil depth was on the productivity of chickpea crop, which established and grew on the receding soil moisture. Chickpea yields were generally higher on medium-deep soil than on shallow soil. Pigeonpea yields were not significantly affected by soil depth. Across years and landforms, sole soybean yields ranged from 0.9 to 2.4 t ha^{-1} on medium-deep soil and 1.0 to 2.3 t ha^{-1} on shallow soil (Table 8). Chickpea yields ranged from 0.5 to 1.5 t ha^{-1} on medium-deep soil and 0.4 to 1.0 t ha^{-1} on shallow soil. Total productivity of the soybean-chickpea sequential system ranged from 1.9 to 3.7 t ha^{-1} on medium-deep soil and 1.5 to 3.3 t ha^{-1} on shallow soil. Average productivity of the soybean-chickpea system on medium-deep soil was 2.7 t ha^{-1} and on shallow soil it was 2.3 t ha^{-1}.

As expected, soybean yield in the intercropping system was less than that observed in the sole system. Across seasons, soil types, and landforms the intercropped soybean yield ranged from 0.7 to 2.0 t ha^{-1} and was slightly higher on medium-deep soil than on shallow soil (Table 7). Pigeonpea yield across seasons, soil types, and landforms ranged from 0.5 to 1.4 t ha^{-1}, giving an average yield of 0.9 t ha^{-1} irrespective of the soil type and landform. Total productivity of the soybean/pigeonpea intercropping system ranged from 1.2 to 2.9 t ha^{-1} across soil types and seasons, giving an average productivity of about 2.1 to 2.3 t ha^{-1} on shallow and medium-deep soils, respectively (Table 7). In the drought year of 1999/2000 the total productivity of the soybean/pigeonpea system was greater than that of the soybean-chickpea system when only about 400 mm of seasonal rainfall was received.

Long-term simulation of water balance and crop yields

Long-term analysis using simulation models and crop weather data of 26 years (1974–2000) have shown that in 70% of years total seasonal runoff ranged from 35 to 269 mm for shallow soil and 70 to 320 mm for medium-deep soil (Table 8). Deep drainage beyond the rooting zone ranged from 60 to 390 mm for shallow soil and 10 to 280 mm for medium-deep soil.

Table 6. Seed yield (t ha^{-1}) of soybean-chickpea sequential system in various treatments on a Vertic Inceptisol, ICRISAT, Patancheru, India.

	Soybean			Chickpea			Soybean and chickpea		
Year	BBF[1]	Flat	SE[2]	BBF	Flat	SE	BBF	Flat	SE
Medium-deep soil									
1995/96	1.7	1.9	0.06	0.5	0.6	0.02	2.2	2.5	0.05
1996/97	2.1	2.4	0.07	1.5	1.4	0.13	3.6	3.7	0.17
1997/98	1.0	0.9	0.06	1.5	1.1	0.12	2.5	2.0	0.11
1998/99	1.6	1.6	0.10	1.5	1.3	0.12	3.1	2.9	0.20
1999/2000	1.8	1.7	0.06	0.1	0.2	0.04	2.0	1.9	0.11
2000/01	2.4	2.1	0.12	0.9	0.7	0.08	3.3	2.8	0.18
Mean	1.8	1.8	-	1.0	0.9	-	2.8	2.6	-
Shallow soil									
1995/96	1.6	1.5	0.06	0.4	0.4	0.05	2.0	1.9	0.12
1996/97	2.3	2.3	0.07	1.0	1.0	0.13	3.3	3.3	0.17
1997/98	1.1	1.0	0.06	1.0	1.0	0.12	2.1	2.0	0.11
1998/99	1.5	1.7	0.10	1.0	0.8	0.12	2.5	2.6	0.20
1999/2000	1.7	1.5	0.06	0.1	0.1	0.04	1.8	1.5	0.11
2000/01	1.7	1.8	0.12	0.5	0.4	0.08	2.1	2.2	0.18
Mean	1.7	1.6	-	0.7	0.6	-	2.3	2.3	-

1. BBF = Broad-bed and furrow.
2. SE = Standard error (±).

Table 7. Seed yield (t ha^{-1}) of soybean/pigeonpea intercropping system in various treatments on a Vertic Inceptisol, ICRISAT, Patancheru, India.

	Soybean			Chickpea			Soybean and chickpea		
Year	BBF[1]	Flat	SE[2]	BBF	Flat	SE	BBF	Flat	SE
Medium-deep soil									
1996/97	1.5	1.8	0.07	0.9	1.1	0.16	2.4	2.9	0.17
1997/98	0.7	0.7	0.06	0.5	0.6	0.06	1.2	1.3	0.11
1998/99	1.1	1.1	0.10	1.4	1.2	0.12	2.4	2.4	0.20
1999/2000	1.4	1.5	0.06	0.8	0.8	0.08	2.2	2.3	0.11
2000/01	2.0	1.8	0.12	0.9	0.8	0.05	2.9	2.6	0.18
Mean	1.34	1.38	-	0.90	0.9	-	2.22	2.30	-
Shallow soil									
1996/97	1.5	1.7	0.07	0.9	1.0	0.16	2.4	2.7	0.17
1997/98	0.8	0.7	0.06	0.7	0.6	0.06	1.5	1.3	0.11
1998/99	1.0	0.9	0.10	1.4	1.1	0.12	2.4	2.1	0.20
1999/2000	1.5	1.3	0.06	0.7	0.6	0.08	2.2	1.9	0.11
2000/01	1.6	1.6	0.12	0.9	0.7	0.05	2.5	2.4	0.18
Mean	1.28	1.24	-	0.92	0.8	-	2.20	2.08	-

1. BBF = Broad-bed and furrow.
2. SE = Standard error (±).

Table 8. Simulated surface runoff and deep drainage, using weather data of 26 years (1974 to 2000) for shallow and medium-deep Vertic Inceptisols at ICRISAT, Patancheru, India.

Landform	Shallow soil	Medium-deep soil
Runoff in 70% of years (mm)		
Flat	60–269	80–320
Broad-bed and furrow (BBF)	35–190	70–280
Deep drainage in 70% of years (mm)		
Flat	60–330	10–245
Broad-bed and furrow (BBF)	80–390	25–280

Total productivity of the soybean-chickpea sequential system was 3 to 4.1 t ha^{-1} on shallow soil and 3.5 to 4.7 t ha^{-1} on medium-deep soil in 70% of years (Table 9). Total productivity of the soybean/pigeonpea intercropping system was 2.9 to 4.2 t ha^{-1} on shallow soil and 3.1 to 4.3 t ha^{-1} on medium-deep soil. These results show the potential of the environment and technology for achieving higher yields provided the natural resources are managed properly. Comparing the potential yields with observed yields of the two cropping systems obtained in the BW7 watershed, it becomes evident that in spite of high yields obtained in the watershed a yield gap of at least 1.0 t ha^{-1} still exists.

Potential productivity and yield gap of soybean growing locations

To assess the scope for increasing productivity of soybean in the major soybean-growing region of India, potential productivity and yield gaps were assessed using the CROPGRO-soybean simulation model. Based on the yield gaps the locations or the regions could be targeted to bridge the yield gap. This analysis was performed for 10 locations in India for which the soils and historical weather records were available. These locations are Raisen, Betul, Guna, Bhopal, Indore, Kota, Wardha, Jabalpur, Amaravati, and Belgaum (Table 10). The potential yields (water limited) varied from year to year because of weather variability. There were large differences in maximum and minimum obtainable yields for a location. Mean yield obtained for a location was compared with the mean observed yield of the last five years to calculate the yield gap. Simulated mean yield for Raisen and Wardha was greater than 2500 kg ha^{-1}, while for Betul, Jabalpur, Bhopal, and Indore it ranged from 2000 to 2500 kg ha^{-1}. For other locations the simulated mean yield ranged from 1200 to 2000 kg ha^{-1}. The yield gap for various locations ranged from 235 to 1955 kg ha^{-1}. The yield gap was minimal for Kota where sufficient area is under irrigation. For Raisen, Betul, Bhopal,

Table 9. Simulated yield potential (t ha^{-1}) of soybean-chickpea sequential and soybean/pigeonpea intercropping systems for shallow and medium-deep Vertic Inceptisols at ICRISAT, Patancheru, India[1].

Crop	Shallow soil	Medium-deep soil
Soybean-chickpea system		
Soybean	2.2–3.0	2.2–3.0
Chickpea	0.5–1.5	0.8–1.9
Soybean and chickpea	3.0–4.1	3.5–4.7
Soybean/pigeonpea system		
Soybean	1.8–2.1	1.9–2.1
Pigeonpea	1.0–2.3	1.2–2.3
Soybean and pigeonpea	2.9–4.2	3.1–4.3

1. In 70% of years using weather data of 26 years (1974 to 2000).

Table 10. Simulated soybean yields and yield gap for the selected locations in India.

Location	Mean sowing date	Mean harvest date	Simulated yields (kg ha^{-1})				Mean observed yield[2] (kg ha^{-1})	Yield gap (kg ha^{-1})
			Minimum	Maximum	Mean	SD[1]		
Raisen	22 Jun	11 Oct	393	4670	2882	1269	-	-
Betul	19 Jun	8 Oct	924	3296	2141	603	858	1283
Guna	30 Jun	14 Oct	342	2916	1633	907	840	793
Bhopal	16 Jun	8 Oct	805	3064	2310	615	1000	1310
Indore	22 Jun	10 Oct	760	4588	2273	939	1122	1151
Kota	3 Jul	16 Oct	0	3188	1165	936	1014	151
Wardha	17 Jun	6 Oct	1824	3955	3040	640	1042	1998
Jabalpur	23 Jun	11 Oct	1132	2477	2079	382	896	1183
Amaravati	18 Jun	8 Oct	440	2624	1552	713	942	610
Belgaum	17 Jun	30 Sep	858	2943	1844	629	570	1274

1. SD = Standard deviation.
2. Mean of reported yields of five years (1996/97 to 2000/01).

Indore, and Wardha, the mean yield gap ranged from 1183 to 1955 kg ha^{-1}. However, in some years greater yield gap is expected as indicated by the maximum obtainable yields. Based on the maximum obtainable yield, the yield gap ranged from 1812 to 2930 kg ha^{-1} for various locations. These results show that there is a considerable potential to bridge the yield gap between the actual and potential yield through adoption of improved resource management technologies.

Extension of BW7 Watershed Work

In BW7 watershed we have successfully shown that integrated watershed management technology has resulted in crop intensification of the soybean-based system as well as increased use of excess rainfall stored in surface ponds and dug wells. The BBF system decreases surface runoff and soil erosion thus reducing soil degradation. The target region of Madhya Pradesh has similar agroecology as the Patancheru watershed area, except that rainfall intensity and amounts in July and August are greater than those observed at Patancheru. This is expected to cause severe soil erosion and waterlogging at Bhopal and Indore watershed sites. Therefore, the BBF system of land surface management is expected to perform better in controlling runoff and soil erosion, and to alleviate waterlogging of heavy clay soils. Groundwater recharging at these two sites could be improved by constructing percolation tanks or gully plugging.

Future Work Plan

There is a need to continuously monitor the long-term soil, water, and nutrient management on sustainability and soil quality changes in the watershed, particularly sequestration of carbon. There is also a need to quantify the economic losses due to land degradation and examine how these losses can be minimized. As water availability in the watershed has been increased due to surface ponds and wells, there is a need to quantify the overall use efficiency including water use by the horticultural system. The digital terrain model developed at the Michigan State University, USA will be evaluated for this watershed. The work done at BW7 watershed will be scaled-up for extending the benefits of watershed management to rural communities. The national agricultural research system (NARS) scientists working in other watersheds will be trained in the instrumentation for data recording. This watershed shall continue to serve as a training ground for government officials working in the area of watershed management and the farmers in the region.

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Nutrient and Water Management Studies for Increasing Productivity of Soybean-based Systems in Operational Scale Watersheds

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Abstract

Madhya Pradesh is well endowed with high moisture holding Vertisols and assured rainfall (800–1600 mm yr^{-1}) and is the heartland of dryland agriculture in India. The current productivity of soybean in India is 1 t ha^{-1} whereas the yield potential of soybean is 3 to 3.5 t ha^{-1}. At the Indian Institute of Soil Science (IISS), Bhopal, Madhya Pradesh, an operational scale watershed was developed to study nutrient and water management options for increasing productivity of soybean-based systems. Waterlogging during rainy season significantly reduced soybean yields. The excess runoff water 300–400 mm could be harnessed and used as life saving irrigation for increasing productivity of soybean-wheat system. During normal rainfall years broad-bed and furrow (BBF) landform treatment alleviated waterlogging and increased productivity of soybean. The BBF landform stored more moisture in soil than the flat on grade (FOG) treatment; BBF also had low cone penetration resistance of soil than the FOG treatment. The BBF treatment also recorded reduced runoff (10.6%) as against the runoff from FOG (18.6%). Application of green manure through alley cropping of Gliricidia *increased productivity of soybean-based systems through increased water use and improved soil fertility and reduced mineral N needs.*

Madhya Pradesh is the heartland of dryland agriculture in India which produces 4.4 million t of soybean on 4.4 million ha. The soils are Vertisols and associated soils with a good water-holding capacity, with annual rainfall varying from 800 to 1600 mm and a potential for double cropping on stored soil moisture or with supplemental irrigation. Most of the rainfall (85 to 90%) is received during the monsoon (rainy) season with a rainfall peak in June to August resulting in waterlogging and sheet erosion in the region. In spite of spectacular growth in soybean area since 1970s soybean productivity is only about 1 t ha^{-1}.

Large areas are kept fallow during the rainy season. The main constraints for low soybean yields in the region are inappropriate soil, water, and nutrient management (SWNM) practices followed by the farmers, availability of quality seeds of soybean varieties with suitable maturity duration, lack of credit facilities, and large landholdings. To address the issues related to increasing productivity of soybean-based systems, strategic research on SWNM for sustaining productivity of soybean-based systems was undertaken at the on-station watershed of the Indian Institute of Soil Science (IISS) in partnership with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) through the Asian Development Bank (ADB) supported project (RETA 5812) during 1999–2002. IISS, Nabibagh, Bhopal is located in the heartland of soybean production area (23°18'–23°20' N, 77°24'–77°25' E, and altitude 490 m) of Madhya Pradesh. A 12-ha watershed was developed on Vertisol in the campus in 1999.

Weather and Soil Characteristics

Analysis of historical weather data (1980–99) revealed that the average annual rainfall is 1130 mm and ranged from 694 mm in 1992 to 1521 mm in 1982. The rainfall is mainly received (89%) during June through October (Fig. 1). The annual evapotranspiration (ET) of Bhopal area is about 1500 mm, of which ET for the period from June through October is 650 mm. The actual ET

1. Indian Institute of Soil Science (IISS), Nabi Bagh, Berasia Road, Bhopal 462 038, Madhya Pradesh, India.

for rainy season crop is about 550 mm. Thus, on an average 300–400 mm rainwater is lost as surface runoff and deep drainage indicating good potential to harvest rainwater for securing and extending the growing season by providing supplemental irrigation and recharging the groundwater.

A reservoir of 2.5 ha-m capacity with 2 m depth was developed in the watershed to capture the runoff from the experimental watershed. A part of watershed area (1.5 t ha^{-1}) was developed as broad-bed and furrow (BBF) and flat on grade (FOG) land treatments. These plots are equipped with H flumes and automatic runoff recorders and sediment samplers for monitoring runoff and sediment. *Gliricidia* leaf manure farm was developed for providing *Gliricidia* leaves to experimental treatments. *Gliricidia* plants are planted on the field bunds. General soil and climatic characteristics are given in Table 1. The soil profile is uniform with respect to soil moisture constants (Fig. 2) except that at 60 cm depth, saturation and 0.1 bar moisture percentages are high. The pH increases slightly with soil depth and varies in a narrow range from 7.8 to 8.2 (slightly alkaline). Electrical conductivity (EC) is higher at 0–30 cm than deeper soil depths (40–90 cm) beyond which the values increase to 0.15 dS m^{-1}.

Weather data are collected using an automatic weather station. The wind speed is relatively high in summer and rainy months and gradually declines to a minimum (1.0 m s^{-1}) in November. In winter from December to January, the northerly wind blows at low average speed ranging from 1.0 to 2.0 m s^{-1}. When northerly wind is replaced by southwesterly wind in June, the speed increases steadily to a maximum of about 4 m s^{-1}. The region being characterized as semi-arid tropics receives heavy showers in rainy season (Fig. 1). The winter months are generally calm and dry except for rare light showers. The spring season starts with a sharp rise in temperature from February onwards to a maximum air temperature (about 40.5°C) in May. The soil surface temperature reaches a high range of 33–35°C and shrinkage cracks develop on the

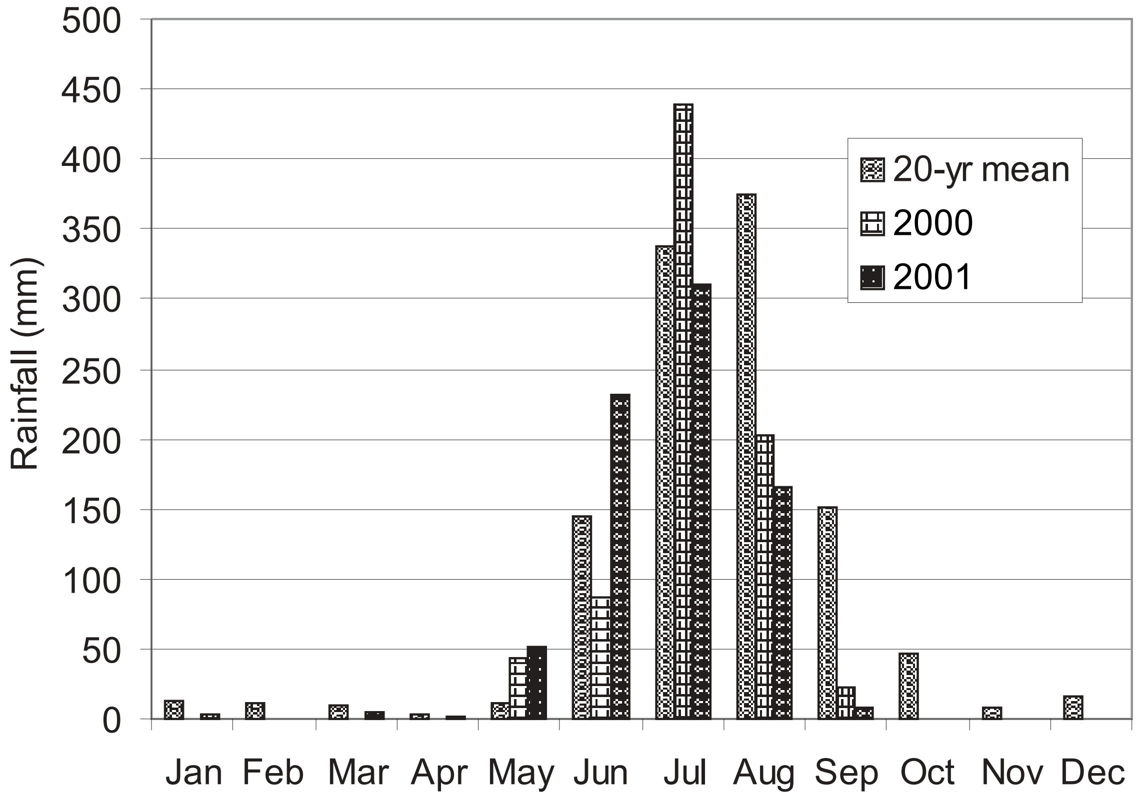

Figure 1. Mean monthly rainfall at Nabibagh, Bhopal in Madhya Pradesh, India.

Table 1. Details of weather and soil characteristics at IISS, Bhopal.

Particulars	Value
Air temperature	
Average maximum daily	40.7°C (May)
Average minimum daily	10.4°C (Jan)
Relative humidity	
Mean maximum monthly	83% (Aug)
Mean minimum monthly	25% (Apr)
Wind speed	
Mean maximum monthly	13.2 km h^{-1} (Jul)
Mean minimum monthly	4.3 km h^{-1} (Nov)
Pan evaporation	
Average maximum daily	16.7 mm day^{-1}
Average minimum daily	3.5 mm day^{-1}
Soil texture	
Sand	15.4%
Silt	26.6%
Clay	58.0%
Soil moisture	
Liquid limit	48.62%
Plastic limit	23.94%
Saturation	62.23%
0.3 bar	28.40%
15 bar	19.34%
Hydraulic conductivity	0.06 m day^{-1}
Infiltration rate	0.24 m day^{-1}
Chemical properties	
pH	7.74
Electrical conductivity	0.11 dS m^{-1}
Organic carbon	0.45%
Calcium carbonate	2.83%
Cation exchange capacity	49 Cmol kg^{-1}

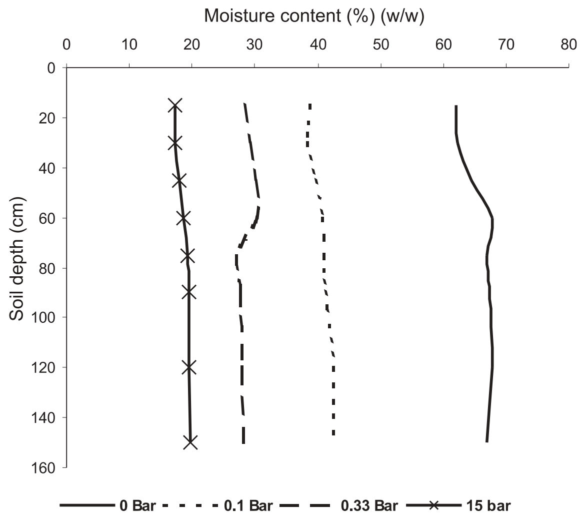

Figure 2. Variation of soil moisture constraints in soil profile.

soil surface in summer months. The air temperature data of 2000 and 2001 show that the variation in maximum temperature is bimodal as characterized by two peaks, one in May and the other in October. The soil temperature rises from an average of 20°C in January to a maximum of 33.9°C in April or May at 5 cm soil depth. The difference in soil temperature at 5, 10, and 20 cm depth is generally less than 1°C except in April and May. The variation in soil temperature follows bimodal trend and conform to variation in air temperature.

The semi-arid tropics of Madhya Pradesh is endowed with plenty of solar radiation round the year with net radiation ranging from 5.9 MJ m^{-2} in January to 11.5 MJ m^{-2} during May–June. The solar radiation increases from January and attains a peak level sometimes during late April and May. After May, the solar radiation starts declining and reaches a minimum in rainy season that is characterized by heavy clouds. After withdrawal of monsoon, the sky clears and both solar and net radiation rise slowly. Soil being black in color absorbs considerable quantity of solar radiation.

The analysis of natural resource endowments in the region demonstrated that this ecoregion bears potentially productive environment for soybean-based cropping systems, nevertheless yields of crops are poor. Safe drainage of excess rainwater from crop field and its storage in water harvesting pond and use of integrated SWNM approaches hold the key for enhancing and sustaining the soybean-based cropping system. With these in view, comprehensive field experiments were planned to address specific issues related to:

- Intensification of soybean-based systems through supplemental irrigation using harvested rainwater;
- Integrated nutrient and water management options for soybean-based systems; and
- Assessment of effects of waterlogging on soybean plant growth and soil processes.

Nutrient and Supplemental Irrigation Management in Soybean-Wheat System

Alleviation of waterlogging through safe drainage of excess rainwater from field and its storage in water harvesting pond along with integrated SWNM approach could enhance and sustain the productivity of soybean-wheat system. To validate this hypothesis, field experiments were conducted during rainy season 2000 and winter season 2000/01 with the following treatments:

- Landform
  - BBF
  - FOG
- Supplemental irrigation treatment
  - Soybean: Rainfed
  - Wheat :
    (1) Pre-sowing irrigation plus one irrigation at crown root initiation (CRI) and one at flowering stage (three supplemental irrigations): I_1
    (2) Pre-sowing irrigation, one irrigation at CRI, maximum tillering, and flowering stage (four supplemental irrigations): I_2
- Nutrient treatment in soybean (see treatments in tabular form). Wheat is grown with 120 N:60 P_2O_5:40 K_2O (kg ha^{-1}).

Treatment	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})
N_0P	0	60
NP_0	30	0
NP	30	60
$N_{50f+50i}P$	15 kg ha^{-1} through farmyard manure (FYM) and 15 kg ha^{-1} through inorganic fertilizer	60
$N_{50g+50i}P$	15 kg ha^{-1} through *Gliricidia* and 15 kg ha^{-1} through inorganic fertilizer	60
$N_{50f+50g}P$	15 kg ha^{-1} through FYM and 15 kg ha^{-1} through *Gliricidia*	60

Soybean (rainy season 2000)

During the rainy season in 2000, 798 mm (30% below normal) rainfall was received. Soybean yield was higher in BBF than in FOG landform (Table 2). Higher yield in BBF landform could be due to better soil conditions (aeration) and less cone penetration resistance (CPR) in upper layers of the soil in BBF than in FOG (Fig. 3). The less CPR in BBF was because of the loose soil and higher moisture in upper

Table 2. Seed yield, biological yield, and harvest index of soybean in different nutrient and land treatments[1].

	Seed yield (kg ha^{-1})		Biological yield (kg ha^{-1})		Harvest index	
Treatment	BBF	FOG	BBF	FOG	BBF	FOG
N_0P	1505	1440	4160	4185	0.3618	0.3438
NP_0	1570	1470	4260	4250	0.3686	0.3447
NP	1590	1480	4380	4315	0.3625	0.3455
$N_{50f+50i}P$	1590	1500	4390	4360	0.3636	0.3441
$N_{50g+50i}P$	1600	1510	4430	4370	0.3621	0.3481
$N_{50f+50g}P$	1620	1510	4460	4370	0.3641	0.3456
Mean	1580	1485	4340	4310	0.3618	0.3438
	NS	NS	NS	NS	NS	NS

1. See text for treatment details; NS = Not significant.

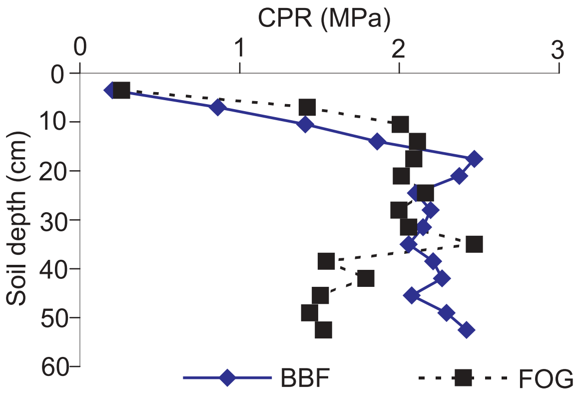

Figure 3. Variation of cone penetration resistance (CPR) in broad-bed and furrow (BBF) and flat on grade (FOG) land treatments on 20 September 2000 in Bhopal.

soil layers. Application of nitrogen (N) and phosphorus (P) had no effect on soybean yields, which could be due to moisture stress during pod-filling stage. Runoff was 13% of the seasonal rainfall (798 mm) and soil loss was 3.3 t ha^{-1} in BBF system.

Nodulation status

Number of nodules formed due to various integrated nutrient treatments was not markedly different except in NP_0 of BBF system and N_0P and NP_0 of FOG landform. The development of nodules was significantly affected by the lack of sufficient amount of available P in the soil. The dry biomass of nodules was 23% higher in BBF (109 mg $plant^{-1}$) than in FOG (88 mg $plant^{-1}$). The integrated nutrient treatments significantly influenced the synthesis of dry biomass of nodules. Overall, the dry biomass of nodules was greater in the treatments with the application of (FYM and/or *Gliricidia*) as a component of fertilization. Nodule dry biomass was maximum in $N_{50f+50g}P$ treatment; 174 mg $plant^{-1}$ was observed in BBF and 155 mg $plant^{-1}$ in FOG. The replacement of inorganic N either fully or 50% by organic material (FYM and/ or *Gliricidia*) increased nodule dry biomass over that of NP treatment from 35 to 131% under different land treatments.

Nitrogenase activity

The influence of integrated nutrient (inorganic and organic) treatments on nitrogenase activity of nodules was significant. Nitrogenase activity was lowest in NP_0 (495 and 213 µmoles C_2H_4 h^{-1} $plant^{-1}$ in BBF and FOG, respectively). Replacement of inorganic N, either fully or 50% with organic material significantly improved the nitrogenase activity over the NP treatment. The highest nitrogenase activity of 2081 µmoles C_2H_4 h^{-1} $plant^{-1}$ in $N_{50f+50g}P$ in BBF system and 1857 µmoles C_2H_4 h^{-1} $plant^{-1}$ in $N_{50g+50i}P$ in FOG system was registered.

Microbial biomass C and N

Microbial biomass carbon (C) and N in soybean was significantly influenced by integrated nutrient treatments in BBF and FOG landforms. In BBF system the microbial biomass C and N was greater by approximately 33% than in FOG system. The lowest microbial biomass C and N was registered in NP_0 treatment where fertilizer P was not applied. Nitrogen supply through organic material (FYM and/or *Gliricidia*) improved the synthesis of microbial biomass C and N. This is because applied organic material acted as substrate for microbes and resulted in intense microbial activity and accumulation of nutrients.

Wheat (winter season 2000/01)

The data on yield, biological yield, and harvest index of wheat are summarized in Table 3. The influence of nutrient and supplemental irrigation treatments on yield was not significant because irrigation in the watershed was not available after pre-sowing irrigation. The biological yield and harvest index also were not affected significantly. However, the grain yield, biological yield, and harvest index in general in BBF system were higher than in FOG landform because of the better moisture status in BBF than in FOG landform.

The moisture content at 0–15 and 15–30 cm depths was high up to 80 days after sowing (DAS) beyond which the difference in moisture decreased, whereas the moisture content at 45–60 cm was higher in BBF up to 100 DAS (Fig. 4). The 30–45 cm soil layer showed no pattern. The moisture content at 60–75 cm and 75–90 cm soil layers was higher in BBF than FOG after 80 DAS (Fig. 4) and the moisture content kept decreasing in FOG. The soil profile moisture storage change (moisture use) was also higher, in general, in BBF than FOG (Fig. 5).

Table 3. Grain yield, biomass yield, and harvest index of wheat in different landform, irrigation (I), and nutrient management (NM) treatments in 2000/01[1].

	BBF			FOG		
Treatment	I_1	I_2	Mean	I_1	I_2	Mean
Grain yield (GY) (kg ha^{-1})						
N_0P	1643	1628	1636	992	972	982
NP_0	1663	1642	1652	1021	985	1003
NP	1879	1671	1775	1116	1096	1106
$N_{50f+50i}P$	1691	1768	1730	1052	1219	1135
$N_{50g+50i}P$	1609	1842	1726	1050	1011	1031
$N_{50f+50g}P$	1846	1830	1838	1040	1146	1093
Mean	1722	1786	1045	1071		
Biomass yield (BY) (kg ha^{-1})						
N_0P	4285	4148	4217	2884	2530	2707
NP_0	4000	3704	3852	2716	2637	2677
NP	4237	4074	4156	2749	2801	2775
$N_{50f+50i}P$	4089	4741	4415	2746	3241	2993
$N_{50g+50i}P$	3704	4370	4037	2831	2874	2852
$N_{50f+50g}P$	4181	4148	4165	2680	2944	2812
Mean	4083	4198		2768	2838	
Harvest index (HI)						
N_0P	0.38	0.40	0.39	0.34	0.38	0.36
NP_0	0.42	0.43	0.42	0.38	0.38	0.38
NP	0.44	0.40	0.42	0.41	0.39	0.40
$N_{50f+50i}P$	0.42	0.37	0.39	0.39	0.38	0.38
$N_{50g+50i}P$	0.44	0.42	0.43	0.37	0.36	0.36
$N_{50f+50g}P$	0.44	0.43	0.43	0.39	0.38	0.39
Mean	0.42	0.41		0.38	0.38	
CD (5%)	I	NM	I × NM	I	NM	I × NM
GY	NS[2]	NS	NS	NS	NS	NS
BY	NS	NS	NS	NS	NS	NS
HI	NS	NS	NS	NS	NS	NS

1. See text for treatment details. Post-sowing irrigation was not possible due to non-availability of irrigation water in watershed pond.
2. NS = Not significant.

P uptake by soybean and wheat

All the nutrient input treatments supplying P alone or together with N through inorganic and/or organic sources caused a significant increase in P uptake by soybean and wheat over the treatment without P, i.e., NP_0 in both BBF and FOG landforms (Table 4). The P uptake differences among the P supplying treatments were, however, not significant. The mean values of P uptake (across nutrient treatments) by soybean as well as wheat were relatively higher in BBF than in FOG landforms.

Phosphorus availability in soil at the end of one cycle of soybean-wheat rotation

The nutrient input treatments supplying P alone or together with N applied through inorganic and/or organic sources improved significantly the P availability in soil over the treatment without P (NP_0) in BBF as well as FOG systems. Relatively greater P availability in the soil was recorded in the plots treated with inorganic plus organic (FYM, *Gliricidia*) sources of nutrients. The P availability was highest in the plots

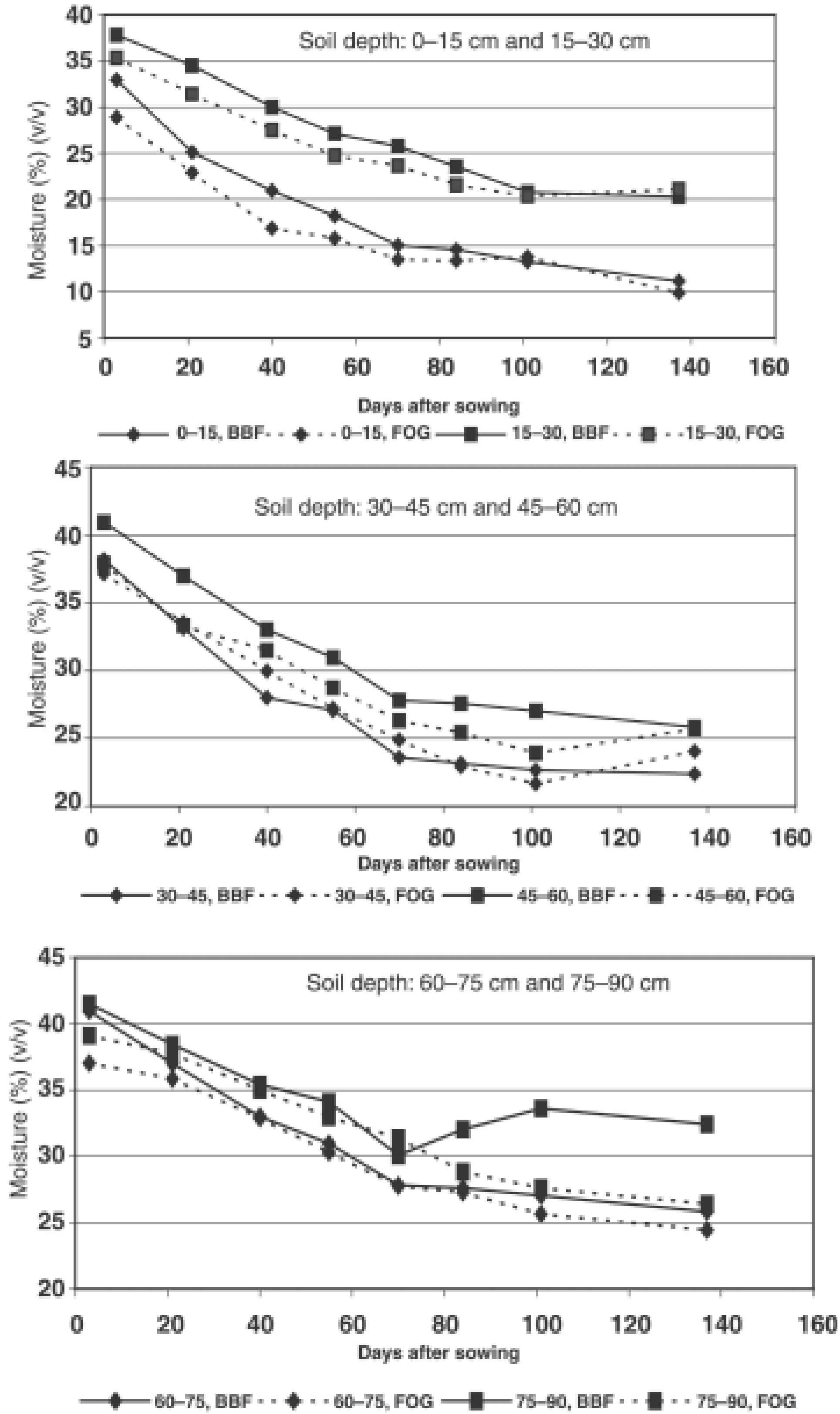

Figure 4. Seasonal variation of moisture content at various soil depths in two landforms.

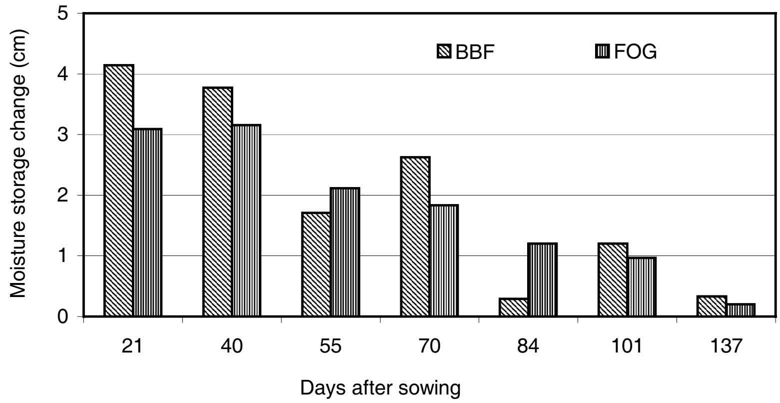

Figure 5. Seasonal variation in soil profile moisture storage change (0–90 cm depth).

Table 4. Phosphorus uptake (kg P ha^{-1}) by soybean and wheat in different land and nutrient treatments in 2000/01[1].

	Soybean		Wheat	
Treatment	BBF	FOG	BBF	FOG
N_0P	15.5	15.3	8.4	5.2
NP_0	13.3	12.7	6.8	4.2
NP	15.2	15.1	8.4	5.1
$N_{50i+50f}P$	16.2	15.4	7.7	5.0
$N_{50i+50g}P$	16.2	15.5	7.2	5.0
$N_{50f+50g}P$	15.5	15.8	8.1	5.0
Mean	15.4	15.0	7.8	4.9
CD (5%)	1.41	1.21	1.14	0.73

1. See text for treatment details.

receiving $N_{50i+50f}P$ in BBF (19.7 mg kg^{-1}) as well as in FOG (17.1 mg kg^{-1}) systems. Irrespective of the nutrient treatment, BBF maintained relatively greater P availability than FOG system, with the average soil test P values being 16.1 and 13.8 mg kg^{-1} soil, respectively.

N uptake by soybean, soil organic carbon, and available N in soil

The BBF treatment recorded relatively higher N uptake compared to FOG treatment (Table 5). However, the available N in the soil after harvest of soybean was not significantly different in FOG and BBF. Further, the contents of organic C in BBF and FOG treatments were similar. Overall, it was found that both the nutrient management and land treatments did not show any significant effect on soil organic C and available N status.

The BBF treatment increased the total N uptake by wheat crop compared to FOG. On the other hand, a reverse trend was observed in the case of available N in the soil after harvest of wheat. However, the organic content was not affected by either the land treatment or nutrient management practice. As in soybean, the differences in the N uptake and available N content were not significant in wheat.

Microbial biomass C and N

Under FOG, microbial biomass C and N in wheat rhizosphere in $N_{50f+50i}P$, $N_{50g+50i}P$, and $N_{50f+50g}P$ treatments did not differ significantly from that of NP treatment. However, under BBF microbial biomass C was significantly greater in $N_{50f+50i}P$ and $N_{50f+50g}P$ as compared to NP treatment. Microbial biomass C and N was higher by 15% in BBF than FOG. This may be due to the better soil aeration and tilth which provided congenial soil conditions for development and growth of microorganisms.

Soybean (rainy season 2001)

Runoff and soil loss

The total amount of runoff water from the FOG plot (131.6 mm) during the rainy season was higher than that of BBF plot (74.8 mm). Of the total rainfall of 708 mm, 10.6% and 18.6% were lost through runoff from the BBF and FOG plots respectively. Seasonal soil loss from the FOG plot was 698 kg ha^{-1}.

Table 5. Total N uptake by soybean, soil organic carbon, and available N in soil in different nutrient management and land treatments[1].

	N uptake (kg ha^{-1})		Soil organic C after soybean (%)		Available N after soybean (kg ha^{-1})	
Treatment	BBF	FOG	BBF	FOG	BBF	FOG
N_0P	128.3	125.4	0.43	0.44	211.8	217.3
NP_0	139.3	133.5	0.44	0.44	217.3	221.7
NP	143.5	136.3	0.46	0.47	234.7	236.7
$N_{50f+50f}P$	142.8	139.1	0.45	0.45	221.3	224.4
$N_{50g+50g}P$	143.8	139.3	0.47	0.48	219.7	221.7
$N_{50f+50g}P$	145.7	139.8	0.46	0.43	231.3	225.7
Mean	140.6	135.6	0.45	0.45	222.7	224.6
CD (5%)	NS	NS	NS	NS	NS	NS

1. See text for treatment details.

Bulk density

Bulk density of the surface soil (0–7.5 cm) was less in BBF as compared to the FOG treatment. This difference in bulk density was not tangible in the 7.5–15 cm layer. Likewise average bulk density (0–7.5 cm) of the treatments with organic amendments like FYM or *Gliricidia* was lower than inorganically fertilized plots.

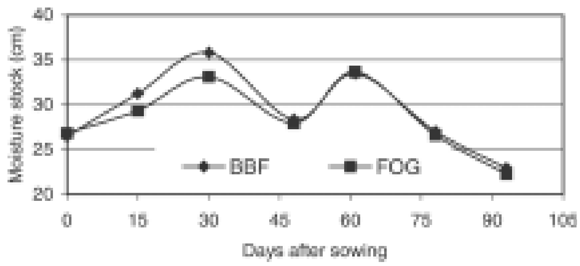

Figure 6. Temporal variation of soil profile moisture stock (0–90 cm) as affected by land treatment during kharif 2001.

Soil moisture stock

Soil profile moisture stock for both BBF and FOG land treatments increased (Fig. 6) up to 30 days after sowing of soybean because of heavy monsoon rainfall (246 mm) in that period (Fig. 7). After that moisture stock decreased up to 45 DAS. Another profile recharge period was observed between 45 and 60 DAS. After 60 DAS moisture content of the profile decreased continuously due to absence of any significant rainfall event in that period (Fig. 7). The crop suffered from moisture stress due to early withdrawal of monsoon during the pod-filling stage. BBF plots retained more moisture than the FOG plots up to 48 DAS and in the latter period this difference was not clear (Fig. 6). More moisture content in the BBF plots may be due to less loss of rainfall through runoff from BBF plots (10.6%) than from FOG plots (18.6%).

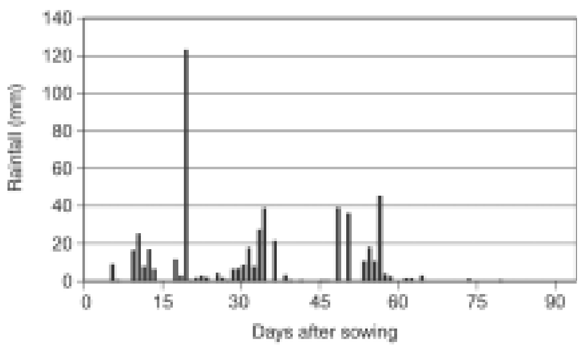

Figure 7. Rainfall during crop growth period in kharif 2001.

Nodulation status

Landform had a marked effect on nodulation status. In BBF, number of nodules and its dry biomass was greater by 42% and 56% respectively, as compared to FOG. Nodule formation in the presence of organics did not vary significantly, except in $N_{50f+50i}P$ in FOG. However, integrated nutrient management treatments, viz., $N_{50g+50i}P$ and $N_{50f+50g}P$ of FOG and $N_{50f+50g}P$ of BBF significantly improved the synthesis of dry biomass in nodules over the NP treatment of respective landforms. The synthesis of dry biomass in nodules was significantly reduced in the absence of P.

Seed yield

The variation in seed yield, total biomass, and number of pods per plant of soybean due to nutrient management was not significant in the 2001 rainy season (Table 6). In both land treatments, the crop grew well because of good distribution of rainfall up to 60 DAS. The low yield in general was due to withdrawal of rain during and beyond pod-filling stage. Though the biomass production was adequate, the number of pods per plant remained low and varied between 29 and 38 in both land treatments. Yield was less in BBF than FOG. This may be attributed to the fact that expected advantage in BBF in terms of high moisture storage and avoidance of water congestion could not be realized because of well distribution of rain up to 60 DAS. Less plant population in BBF compared to FOG could not compensate in terms of seed yield per unit area as expected in BBF because the crop experienced long period of water deficit condition during and beyond pod formation stage.

Table 6. Seed yield, total biomass yield, and podding of soybean as influenced by landform and nutrient management in 2001[1].

Treatment	BBF	FOG
Seed yield (kg ha^{-1})		
N_0P	1088	1538
NP_0	1019	1582
NP	1058	1644
$N_{50f}+N_{50i}P$	1092	1524
$N_{50g}+N_{50i}P$	1160	1525
$N_{50f}+N_{50g}P$	1047	1644
CD (P = 0.05)	NS[2]	NS
Total biomass yield (kg ha^{-1})		
N_0P	3298	4702
NP_0	3291	4424
NP	3397	4814
$N_{50f}+N_{50i}P$	3132	4985
$N_{50g}+N_{50i}P$	3509	4524
$N_{50f}+N_{50g}P$	3478	4472
CD (P = 0.05)	NS	NS
Number of pods plant^{-1}		
N_0P	31.1	32.2
NP_0	28.6	28.3
NP	31.3	29.1
$N_{50f}+N_{50i}P$	32.7	34.2
$N_{50g}+N_{50i}P$	37.6	28.8
$N_{50f}+N_{50g}P$	37.2	37.7
CD (P = 0.05)	NS	NS

1. See text for treatment details.
2. NS = Not significant.

Irrigation and Nutrient Management in Soybean-based Cropping Systems

Field experiments consisting of the following treatments with three replications were conducted during the winter season 1999/2000 and rainy season 2000:

- Production system:
  - Soybean-chickpea
  - Soybean-linseed
  - Soybean-wheat
  - Soybean + *Gliricidia*-wheat + *Gliricidia*
- Irrigation:
  - Soybean: Rainfed
  - Winter season crops: (i) Pre-sowing; (ii) Pre-sowing + one irrigation at the most critical stage of crop
- Nutrient management:
  - Soybean: FYM at 4 t ha^{-1} + recommended dose of NPK
  - Winter season crops: (i) No fertilizer; (ii) 50% of recommended NPK; (iii) 100% of recommended dose of NPK:

Soybean (JS 335)	30 N:60 P_2O_5:30 K_2O kg ha^{-1}
Wheat (Sujata)	120 N:60 P_2O_5:40 K_2O kg ha^{-1}
Chickpea (Ujjain-21)	20 N:40 P_2O_5:20 K_2O kg ha^{-1}
Linseed (RS 52)	60 N:30 P_2O_5:30 K_2O kg ha^{-1}

Soybean (rainy season 2000)

The residual effect of fertilizer treatments imposed in the previous season crops (winter season 1999/2000) on the following soybean crop (rainy season 2000) was studied. The seed yield, biological yield, and harvest index show that the crop performance was not significantly different due to the previous treatment imposed in winter season crops because soybean was grown under optimum nutrient conditions (Table 7).

The main effect of nutrients and interaction effect of cropping systems and nutrients on nodule number of soybean were not significant. However, the crop grown during the previous season significantly influenced the nodule number. Nodule number and dry biomass in soybean grown after linseed were significantly less when compared to other cropping systems. Highest number of nodules (140 $plant^{-1}$) and dry biomass (272 mg $plant^{-1}$) were registered in soybean-wheat (*Gliricidia* alley) system receiving 50% NPK during previous season. Also, nitrogenase activity was highest (893 µmoles C_2H_4 h^{-1} $plant^{-1}$) in this treatment. Nitrogenase activity was reduced in soybean plants grown after linseed as well as chickpea as compared to wheat and wheat-*Gliricidia* alley.

Cropping systems (winter season 2000/01)

Yield data showed increasing trends in all systems with increasing nutrient doses and irrigation levels (Table 8). As the crop yields of different crops cannot be compared, the yields were transformed to wheat equivalent yield (WEY). The interaction between cropping system and irrigation was significant. The maximum WEY was in soybean-chickpea system with two irrigation levels followed by one irrigation. The data also indicated that even with one irrigation the WEY of soybean-chickpea system was significantly higher than other systems.

The interaction between cropping system and NPK was also significant. The maximum WEY was in soybean-chickpea system (4181 kg ha^{-1}) at 100% NPK which was significantly higher than WEY (3658 kg ha^{-1}) at 50% NPK. The WEY in soybean-chickpea

Table 7. Residual effect of fertilizer treatments in previous cropping systems on performance of soybean, rainy season 2000[1].

Treatment in winter season	Soybean-wheat	Soybean-linseed	Soybean-chickpea	Soybean-wheat (*Gliricidia* alley)
Seed yield (kg ha^{-1})				
0% NPK	1510	1463	1428	1493
50% NPK	1487	1468	1501	1473
100% NPK	1514	1474	1515	1519
Mean	1504	1468	1481	1495
CD (5%)	CS	NM	CS × NM	
	NS	NS	NS	
Biomass yield (kg ha^{-1})				
0% NPK	4465	4350	4423	4475
50% NPK	4431	4385	4397	4454
100% NPK	4389	4395	4444	4452
Mean	4428	4377	4421	4460
CD (5%)	CS	NM	CS × NM	
	NS	NS	NS	
Harvest index				
0% NPK	0.338	0.336	0.323	0.334
50% NPK	0.336	0.335	0.342	0.331
100% NPK	0.346	0.336	0.341	0.342
Mean	0.340	0.336	0.335	0.336
CD (5%)	CS	NM	CS × NM	
	NS	NS	NS	

1. CS = Cropping system; NM = Nutrient management; NS = Not significant.

Table 8. Seed yield (kg ha^{-1}) of rabi crops as influenced by cropping systems, irrigation (I), and nutrients during 2000/01[1].

Rabi crop (cropping system)	I_1 0% NPK	I_1 50% NPK	I_1 100% NPK	I_1 Mean	I_2 0% NPK	I_2 50% NPK	I_2 100% NPK	I_2 Mean
Wheat (Soybean-wheat + *Gliricidia* alley)	1104	1409	2106	1540	1975	2533	3363	2624
Wheat (Soybean-wheat)	1172	1369	2172	1571	2069	2633	3325	2676
Chickpea (Soybean-chickpea)	1338	1829	2012	1726	1538	2223	2619	2126
Linseed (Soybean-linseed)	725	926	1031	894	923	1083	1136	1047

1. I_1 = one pre-sowing irrigation; $I_2 = I_1$ + one post-sowing irrigation at maximum tillering of wheat, and flowering of chickpea and linseed.

system even at 50% NPK was significantly higher than soybean-wheat and soybean-wheat (*Gliricidia* alley) system.

Higher irrigation and nutrient levels favored higher biomass C and N in all systems. Microbial biomass C and N was maximum in soybean-wheat (*Gliricidia* alley) and soybean-wheat systems followed by soybean-linseed and soybean-chickpea. Microbial biomass C and N in soybean-linseed was noticeably high at two irrigation levels.

The P uptake by wheat, chickpea, linseed, and wheat (*Gliricidia* alley) was relatively higher with two irrigations than with single irrigation. The irrigation effect on P uptake was, however, significant only in wheat. In contrast, the fertilizer rate showed a significant effect on P uptake in all the crops. With application of 100% recommended fertilizer dose, the mean P uptake increased by 5.53 kg ha^{-1} in wheat, 8.51 kg ha^{-1} in chickpea, 2.35 kg ha^{-1} in linseed, and 5.84 kg ha^{-1} over the P uptake in the respective control (no fertilizer). The relative magnitude of P uptake in different crops was in the order: chickpea > wheat = wheat (*Gliricidia* alley) > linseed.

In all the soybean-based cropping systems, the effect of irrigation (to rabi crops) levels on available P status of soil was not significant. Nevertheless, the available P in soil under different cropping systems was slightly lower with two irrigations than with single irrigation, possibly due to relatively greater P removal by the crops irrigated twice. The available P in soil increased significantly with an increase in the rate of fertilizer application in all the cropping systems. Irrespective of the fertilizer rate, the P availability was relatively greater in soybean-chickpea and soybean/*Gliricidia*-wheat/*Gliricidia* systems than in soybean-wheat and soybean-linseed systems. The greater P availability in soil in soybean-chickpea system may perhaps be due to higher mobilization of native soil P as the root exudates of chickpea are known to solubilize the Ca-P, a predominant P fraction in Vertisols. In soybean/*Gliricidia*-wheat/*Gliricidia* system, decomposition of large amount of *Gliricidia* leaf fall and loppings may have helped in mobilization of native soil P, thus resulting in increased P availability. Nitrogen uptake increased significantly with increase in the level of N and irrigation. In wheat, plot with two irrigations recorded almost two-fold N uptake compared to that with one irrigation. On the other hand, irrigation did not show any positive effect on N uptake by linseed.

With the increase in the level of N both the available N and the organic C content in the soil increased after harvest of all the four crops. However, there was no significant effect of irrigation on organic C and available N in the soil.

Soybean (rainy season 2001)

The residual effects of various treatments imposed during the previous season on performance of soybean grown with recommended dose of fertilizer were studied. In soybean-*Gliricidia* alley system, loppings of *Gliricidia* were added at the time of soybean flowering to these treatments.

Nodule formation and dry biomass in soybean grown after linseed and chickpea were significantly reduced. In soybean-wheat (*Gliricidia* alley) cropping system, the nodule dry biomass in soybean (0.28 g $plant^{-1}$) reduced significantly in comparison to sole soybean (0.38 g $plant^{-1}$) after wheat. Residual effect of the previous crop did not significantly influence biomass, pod, and seed yields. The low yield in general was due to withdrawal of rain during and beyond pod-filling stage.

Impact of Waterlogging on Growth and Yield of Soybean

Temporary waterlogging is a common feature of Vertisols during the rainy season. Annual rainfall on these soils ranges from 750 to 1500 mm in Madhya Pradesh. About 80% of the rainfall received during four months (June–September). Rainfall during these months exceed potential evapotranspiration (PET), causing excess water situation leading to temporary waterlogging and anaerobic conditions in these soils. Soybean is grown in diverse environments from tropical to cool temperature zones, and in both rainfed and irrigated conditions. In Madhya Pradesh, soybean is grown as a major kharif (rainfed) crop on Vertisols. Approximately 75% of the total production of soybean in India is from Madhya Pradesh. Temporary waterlogging because of poor drainage is known to reduce soybean plant growth and N uptake and yield. To quantify the effects of waterlogging on soil, plant processes, and yield of soybean during different crop growth stages, a field experiment was conducted during rainy season in 2000 including treatments with different days of waterlogging at vegetative and reproductive stages of soybean crop.

Nodulation (number of nodules and dry biomass) was not affected significantly by waterlogging treatments. Shoot and root dry biomass production decreased significantly due to waterlogging for various periods. The impact was severe in cyclic waterlogging treatment, which produced lowest shoot and root dry biomass. Six days of continuous waterlogging during vegetative stage significantly reduced the shoot/root ratio and indicated enhanced root growth as compared to shoot growth.

Two days of waterlogging during vegetative stage and 4 days of waterlogging both during vegetative and reproductive stages increased the seed yield significantly over control. The waterlogging treatments, namely, 3 cycles of waterlogging during the vegetative/reproductive stage, and 6 days of waterlogging both during the vegetative and reproductive stages, reduced seed yield, although the decrease was not significant.

Based on the results of rainy season 2000, the treatments were modified and a field experiment was conducted during the rainy season of 2001. Ten treatments were laid out in a randomized block design with three replications (Table 9). Observations were recorded next day after withdrawal of waterlogging during different stages of crop growth.

Table 9. Details of waterlogging treatments during rainy season 2001.

Period of waterlogging (days) during growing season of soybean JS 335		
7 days after emergence (V_1)	Vegetative stage (V_2)	Reproductive stage (R)
$4V_1$	$4V_2$	4R
$8V_1$	$8V_2$	8R
$12V_1$	$12V_2$	12R
Control[1]		

1. No waterlogging during crop growing season.

Soybean yield was significantly influenced by waterlogging (Table 10). The number of pods ranged between 27 and 45 $plant^{-1}$ and in $4V_2$ treatment, the decrease in number of pods over control was significant. Highest number of pods was recorded in 4R treatment. Straw yield was significantly reduced in most treatments as compared to control. Seed yield was significantly reduced in all treatments except in $8V_1$ and 4R treatments.

Table 10. Effect of waterlogging on soybean yield during rainy season 2001[1].

Treatment	Number of pods $plant^{-1}$	Seed yield ($g\ m^{-2}$)	Straw yield ($g\ m^{-2}$)	100-seed mass (g)
$4V_1$	39	117.1	382	6.93
$8V_1$	31	169.7	397	7.57
$12V_1$	28	155.8	437	6.37
$4V_2$	27	127.5	342	7.48
$8V_2$	35	90.9	297	6.22
$12V_2$	32	75.1	219	6.29
4R	45	196.1	379	6.92
8R	39	156.5	287	7.29
12R	38	88.9	212	6.39
Control	37	184.5	401	7.74
CD (5%)	9	15.4	33	NS[2]

1. See text for treatment details.
2. NS = Not significant.

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Minimizing Land Degradation and Sustaining Productivity by Integrated Watershed Management: Adarsha Watershed, Kothapally, India

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Abstract

Land degradation is a major threat for sustainable crop production in large areas of the semi-arid tropics (SAT). The Asian Development Bank gave financial assistance to evaluate the on-station watershed work of ICRISAT in on-farm situations. Adarsha watershed at Kothapally in Andhra Pradesh (AP), India is one of the benchmark sites where the evaluation was carried out. Instead of traditional structure driven approach, a new idea of integrated watershed approach was followed wherein various components of improved crop production were evaluated on a few selected individual farmers' fields in addition to community-based soil and water conservation activities. A new implementation arrangement called consortium approach wherein all the stakeholders, ICRISAT, DWMA, CRIDA, NGO, and farmers, planned and implemented various activities in a participatory manner was tried. This work has attracted not only the attention of AP Government but also many development agencies like DFID throughout the world. The AP Government is scaling-up this work in five districts through APRLP. It is one of the successful modules of watershed development. A grant by Sir Dorabji Tata Trust has been approved to replicate this work in Central and Northwest India. The success story of this work with details of various activities and the outputs is given in this paper.

Land degradation is a serious problem throughout the world, threatening economic and physical survival of mankind. Key issues on land degradation include escalating soil erosion, declining soil fertility, salinization, soil compaction, agrochemical pollution, and desertification. The result is a decline in the productive capacity of land. Existing estimates of the current global severity of the problem (Scherr and Yadav 1996) indicate that except for forest and woodland, the proportion of the land that is degraded is estimated to be more extensive in Africa and Asia. Oldeman (1994) assessed that globally, about 15% of the land is severely degraded. Water erosion was estimated at 56%, wind erosion at 28%, chemical degradation at 12%, and physical degradation at 4%. Asia's degradation is specifically attributed to deforestation with overgrazing and agricultural activities contributing as major factors. There is about 17% cumulative productivity loss between 1945 and 1990 as a result of land degradation (Crosson 1994). Lal (1995) estimated that the average yield reduction due to soil erosion is about 6%, ranging from 2 to 40%. The International Water Management Institute (IWMI) estimates show that 25% of the world's population and 33% of the developing country population live in regions that will experience severe water scarcity by 2025. One billion of the world's poorest people living in the semi-arid tropics (SAT) (Ryan and Spencer 2001) will be affected by water scarcity (Seckler et al. 1998). The poverty of Asia's poor is both a cause and a consequence of accelerating soil degradation and declining agricultural productivity. Poverty reduction is thus the major challenge for those responsible for policy and decision making on the protection and sustainable use of land resources in Asia.

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Poverty and Land Degradation

Whenever adverse changes occur in the world, it is usually the poor who suffer most. This situation arises from the very definition of the poor – those who lack adequate access to the basic necessities of life and the resources needed to obtain them. Because of land shortage, accentuated by degradation, the options for poor will be limited. Production will begin to fall and there will be an immediate attempt by the farmers in increasing the inputs to the crop and this non-sustainable management will lead to further degradation. So, it is poverty along with increased population that plays the greatest part in the casual nexus of land degradation and food insecurity in the developing world.

Erosion: On-site and Off-site Impacts

Erosion is the most important factor that degrades soils globally. It is a process where wind and water facilitate the movement of topsoil from one place to another. Soil erosion has been occurring for some 450 million years, but the problem has been accelerated more recently. As discussed above, this is a result of mankind's actions, such as over-grazing or unsuitable cultivation practices which make the land vulnerable during times of erosive rainfall or windstorms. Soil erosion occurs both incrementally, as a result of many small rainfall events, and more dramatically as a result of large but relatively rare storms. The most serious on-site impact due to erosion is decreased agricultural productivity as seen in several developing countries in Asia.

For sustainable management of natural resources such as water, soil, vegetation, and biota, watershed is a logical unit. Integrated watershed management approach covers wide-ranging aspects like health of the land (such as farming systems), agroforestry, infrastructure development, soil and water conservation, and community participation. Integrated watershed management is defined as an integration of technologies within the natural boundaries of a drainage area for optimum development of land, water, and plant resources to meet the basic needs of the people in a sustainable manner. Watershed management solutions must address the problem of rural poverty, protect the natural resources, and rehabilitate degraded areas, particularly those that pose hazards to human life and welfare. The approach improves the overall condition of land resources and also the living conditions of the people involved.

New Integrated Watershed Management Consortium Model

A new consortium model for efficient management of natural resources in the SAT has emerged from the lessons learned from long-term watershed-based research of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and national agricultural research system (NARS) partners (Wani et al. 2001). The important components of the new 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.
- Minimize free supply of inputs for undertaking technology evaluation by the farmers.
- Low-cost soil and water conservation measures and structures.
- Amalgamation of traditional knowledge and new knowledge for efficient management of natural resources.
- Individual farmer-based conservation measures for increasing productivity of individual farms along with community-based soil and water conservation measures.
- Continuous monitoring and evaluation by the stakeholders.
- Empowerment of community individuals and strengthening of village institutions for managing natural watersheds.

About the Project

The project "Improving Management of Natural Resources for Sustainable Rainfed Agriculture" is funded by the Asian Development Bank (ADB) and was established in 1999 in an effort to improve the natural resource base and to have sustained increase in food production by SAT farmers. The present project involves watershed research in three countries (India, Thailand, and Vietnam), both on-station and on-farm. The Adarsha watershed at Kothapally in Ranga Reddy district of Andhra Pradesh is one of the three on-farm benchmark watersheds in India. The details of the project activities and results of the Adarsha watershed are described.

Process of Selection

ICRISAT and the District Water Management Aagency (DWMA) [earlier Drought Prone Area Programme (DPAP)], Government of Andhra Pradesh as well as M Venkatarangaiya Foundation (MVF), a non-governmental organization (NGO), together surveyed three watersheds in Andhra Pradesh and selected Adarsha watershed as one of the on-farm benchmark sites for the ADB-assisted project. In this watershed the total irrigable area was less and there was more dryland (80%). Not a single water harvesting structure for human and animal use existed at the time of survey in 1998, i.e., at the start of this project. A large area is under rainfed farming in the village. As there were no interventions made to conserve soil and water, this watershed was selected to encompass the concept of convergence in the watershed through consortium approach of managing and developing watersheds (Wani et al. 2001). Adarsha watershed was selected after a meeting of villagers in "Gram Sabha", where the villagers came forward to participate in the proposed watershed activities. The objective was to improve rainfed agricultural production through integrated watershed development and reduce poverty of the farmers through increased systems productivity on sustainable basis while minimizing land degradation.

Consortium Partners

- ICRISAT
- Central Research Institute for Dryland Agriculture (CRIDA)
- DWMA, Government of Andhra Pradesh
- MVF
- National Remote Sensing Agency (NRSA)
- Farmers (Watershed Association, Watershed Committee, and self-help groups)

Developmental Actors

Different committees and groups were formed in the village and leaders were selected by the villagers themselves. The leaders were involved in the planning of watershed development activities from the initial stage (e.g., selection of the water harvesting sites), implementation of the activities, execution and assessment of all the developmental activities within the watershed. The various committees formed in the watershed are:

- Watershed Committee: The committee consists of a president, secretary, and 8 members representing different sections of the community.
- Watershed Association: The working committee consists of a chairman, a secretary, 8 committee members, and 270 members; i.e., farmers in the village.
- Women self-help groups – Vermicomposting: Ten groups were formed with 15 members each. These groups took up vermicomposting as an enterprise in the village.
- User groups: For water harvesting structures.
- Self-help groups: To undertake watershed development activities.

Approach

- Convergence of various activities in the watershed.
- No private contractors were involved in the watershed development activities.
- Inputs for technology evaluation were not free but were supplied at a minimum subsidy.
- Farmers conducted on-farm trials with technical support from ICRISAT and other research institutes in the consortium.
- Empowerment of farmers was through training and workshops.
- Availability of inputs and necessary machinery was ensured.
- The NGO's strength for social mobilization was harnessed.

- Monetary disbursements were by watershed committees and not through the NGO/project implementing agency.
- Social auditing was done by the villagers.

The Initial Situation – Baseline Survey

At the outset of the project, a baseline data survey was carried out, which provided the necessary information on the existing resource-base and conditions of the village for monitoring and evaluation later.

Location

Adarsha watershed is located at longitude 78°5' to 78°8' E and latitude 17°21' to 17°24' N falling in Survey of India toposheet No. 56 K13 in the village of Kothapally, Shankarpally Mandal in Ranga Reddy district of Andhra Pradesh (Fig. 1). The total area of the watershed is 465 ha of which 430 ha is cultivated land.

Physiography

Vegetation

Main rainy season crops grown are sorghum, maize, cotton, sunflower, mung bean, and pigeonpea. In the postrainy season sorghum, sunflower, vegetables, and chickpea are grown. Wheat and rice are also cultivated.

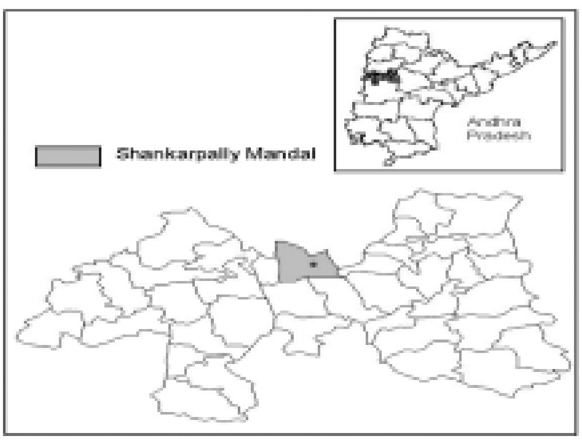

Figure 1. Location of Kothapally village in Shankarpally Mandal, Ranga Reddy district, Andhra Pradesh, India.

Climate

The annual rainfall in Kothapally is about 800 mm received mainly during June to October (85%). About 25–30% of the rainfall is lost as runoff carrying away the fertile topsoil.

Soils

The landscape of the watershed is made up of Vertisols and associated Vertic soils (90% of the area); Alfisols (10% of the area) are also present. Soil depth as perceived by the farmers and verified by the scientists through random samplings in the watershed is about 30–90 cm.

Social structure

The village consists of 274 households with the mean family size being seven. The total population is 1492, of which 54% belongs to backward communities, 15% to minorities, 20% to scheduled castes, and 9% to other castes. Beteille (1974) states that literacy and education may be unevenly distributed in an agrarian society and the data in Kothapally supports this statement with regard to inequalities between sexes and between castes. In Adarsha watershed, 40% of the land belongs to small holding farmers (0.01 to 1.00 ha), 40% to medium holding farmers (1.00 to 2.00 ha), and about 20% of the area to large holding farmers (>2.00 ha).

Groundwater table

The average depth of the 56 wells surveyed was 7.35 m (range 2–18.65 m). The variation in the groundwater table level and the amount of water harvested is based on the cropping patterns and other factors such as soil type, crops grown, topography, runoff, and geological factors of the area.

Crop productivities

The productivity of rice ranged between 0.27 and 2.4 t ha^{-1} for small landholders while for large landholders it was much less and varied from 0.19 to 0.9 t ha^{-1}. The average productivity in small, medium, and large landholdings was 1.1, 1.2, and 0.6 t ha^{-1} respectively. The same trend was observed for pulses also. The crop

Table 1. Crop productivities (t ha^{-1}) in Adarsha watershed, Kothapally in 1998.

Land-holders	Rice	Turmeric	Sorghum	Pigeonpea	Black gram	Cotton	Beans	Tomato	Other crops
Small	2.83	2.10	1.47	0.19	0.83	0.21	0.79	–	0.33
Medium	3.09	2.75	1.19	0.15	0.57	1.43	1.37	0.81	0.74
Large	1.66	1.23	0.54	0.13	0.25	0.67	0.19	0.75	1.33

productivities of cotton were 0.9, 0.6, and 0.3 t ha^{-1} for small, medium, and large landholders (Table 1).

Landholding size and use of inputs

Diammonium phosphate and urea

The majority of farmers use fertilizers. The amount of diammonium phosphate (DAP) and urea used declines sharply as land size increases.

Potash and super phosphate

These fertilizers are only applied to paddy by farmers in Kothapally. The amount of potash and super phosphate applied declines with increasing land size. In Kothapally watershed in general there is a rapid decline in usage of fertilizer with increase in landholdings of around 1–2 ha. As land size increases in Adarsha watershed the amount of fertilizer applied decreases.

Farmyard manure and compost

In the Adarsha watershed, the amount of farmyard manure (FYM) applied per hectare differs among the small landholdings. The most significant anomaly is that for a plot of 5 ha, nearly 6 t ha^{-1} of FYM is applied, and for a plot of about 4 ha approximately 1.5 t ha^{-1} of FYM is applied.

Weedicide and insecticide

Weedicide and insecticide are applied in various doses. The micro-watershed shows a sharp decline in weedicide and pesticide usage by farmers owning up to 0.4 ha, and a gradual decline with increasing land size.

Constraints

After the baseline survey, it was concluded that Kothapally village is characterized by various constraints such as:

- Low level of literacy
- Less proportion of irrigated area (20%) and higher dryland area (80%)
- Inverse relationship between land size and productivity
- Diversity in cropping systems between rainy and postrainy seasons
- Scarcity of labor
- Low crop productivity
- No water harvesting/storage structures
- Less use of fertilizers
- Low adoption of pest management practices
- Income generating activities are not taken up by women/villagers

Detailed characterization of soil samples

Soils of Kothapally watershed are of 4 series with varying depths of 0–40, 0–70, 0–90, and 0–120 cm. The soil series of 0–40 and 0–70 cm depth are developed on basaltic parent material having 1–3% gentle slope. These soils are shallow, well drained with moderate erosion. These soils have very dark grayish brown surface; subsurface horizons are clayey throughout the profile. These soils are suitable for growing sorghum, soybean, and black gram. Soil series of 0–90 and 0–120 cm depth are deep, moderately well drained, flat lands with gentle slope (0–1%). These soils have very dark brown surface horizon and very dark grayish brown to dark yellowish brown subsurface horizons which are clayey throughout the profile. The soils are developed from alluvium parent material suitable for long-duration crops like cotton, pigeonpea, turmeric, etc.

Soil samples from the watershed to a depth of 1 m are characterized in terms of their physical, chemical, and biological parameters. Surface soil pH in both medium and shallow soils was around 8.3. Soil pH increased with soil depth. The organic carbon (C) and total nitrogen (N) were more in medium-deep soils than in shallow soils. The organic C content of soils decreased from 5.7 g kg^{-1} to 1.0 g kg^{-1} in shallow soils and from 6.3 g kg^{-1} to 3.4 g kg^{-1} in medium deep soils in top 15 cm layer compared to 60–90 cm soil depth (Table 2). Similar trends were also observed for total N content. Available phosphorus (P) as estimated by Olsen's method was very low (1.4 to 2.2 mg kg^{-1} soil) in top 15 cm layer and decreased with increasing soil depth. The micronutrients like zinc (Zn), boron (B), and sulfur (S) were found to be lower than their critical limits. Fine sand and coarse sand were more in shallow soils while silt and clay were more in medium-deep soils (Table 3). Soil moisture content at wilting point varied from 21 to 27%.

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 for shallow and medium-deep soils in the watershed. Like organic C and total N contents from microbial biomass C and N soil respiration and other biological

Table 2. Analysis of pre-sowing soil samples collected from Adarsha watershed, Kothapally, May 1999.

Properties	Land depth	0–15[1]	15–30	30–60	60–90	Mean	SE±
pH	Shallow	8.34	8.46	8.76	8.86	8.61	
	Medium	8.27	8.30	8.34	8.40	8.33	
	SE ±			0.04			0.034
	Mean	8.30	8.38	8.55	8.63		
	SE ±			0.02			
EC	Shallow	0.20	0.17	0.23	0.40	0.25	
(m mhos cm^{-1})	Medium	0.19	0.17	0.17	0.16	0.17	
	SE ±			0.011			0.008
	Mean	0.19	0.17	0.20	0.28		
	SE ±			0.007			
Olsen-P	Shallow	1.44	0.67	0.53	0.10	0.68	
(mg kg^{-1} soil)	Medium	2.20	1.05	0.43	0.31	1.00	
	SE ±			0.245			0.182
	Mean	1.82	0.86	0.48	0.20		
	SE ±			1.34			
Organic	Shallow	5.7	3.7	1.0	1.0	2.9	
C (g kg^{-1} soil)	Medium	6.3	6.1	4.9	3.4	5.2	
	SE ±			0.60			0.52
	Mean	6.0	4.9	2.9	2.2		
	SE ±			0.24			
Total N	Shallow	639	445	193	172	362	
(mg kg^{-1} soil)	Medium	647	606	483	315	513	
	SE±			49.1			43.5
	Mean	643	526	338	244		
	SE±			18.6			

1. Soil depth (cm).

Table 3. Texture analysis of pre-sowing soil samples collected from Adarsha watershed, Kothapally, May 1999.							
Properties	Land depth	0–15[1]	15–30	30–60	60–90	Mean	SE±
Coarse sand (%)	Shallow	13.9	22.9	41.1	43.7	30.4	
	Medium	7.6	7.8	10.4	25.9	12.9	
	SE ±			3.98			2.75
	Mean	10.7	15.3	25.7	34.8		
	SE ±			2.35			
Fine sand (%)	Shallow	9.4	13.3	15.6	16.2	13.6	
	Medium	5.7	5.8	6.9	11.4	7.4	
	SE ±			2.05			1.37
	Mean	7.6	9.6	11.2	13.8		
	SE ±			1.24			
Silt (%)	Shallow	21.5	17.3	18.1	19.2	19.0	
	Medium	25.0	22.3	20.4	16.7	21.1	
	SE ±			1.50			1.03
	Mean	23.3	19.8	19.2	17.9		
	SE ±			0.89			
Clay (%)	Shallow	55.2	41.3	31.6	24.7	40.7	
	Medium	61.7	64.4	62.3	48.2	59.2	
	SE ±			5.46			3.74
	Mean	58.4	52.9	46.9	41.5		
	SE ±			3.25			

1. Soil depth (cm).

parameters decreased with increasing soil depth in the profile (Table 4).

On-farm Trials and Farmers' Participation

Several farmers in the watershed are coming forward to take up on-farm trials in their fields with technical backstopping from ICRISAT. The number of farmers participating in these trials increased since start of the project. Overall, 137 and 138 farmer participatory trials were conducted in 2000 and 2001 respectively to evaluate improved management options. The area under on-farm trials in 2001 season was substantially increased to 108 ha as compared to that of 2000 (81.9 ha) and 1999 (36.8 ha) seasons.

Soil and Water Conservation Activities

An urgent need to conserve water and soil in the watershed is felt after a thorough analysis of the transect walk conducted. To control erosion and restore productivity of degraded soils in this area, several soil and water conservation activities were taken up to conserve the harvested water 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 controlling desertification 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 such as vegetative barriers, grassed waterways, etc. In Adarsha watershed in Kothapally, several soil and water conservation activities along with biological control measures were taken up both at farm and at community levels.

Ex-situ conservation

Excess water is drained away from the fields safely through grassed waterways. A total of 21 potential

Table 4. Soil biological properties of pre-sowing soil samples collected from Adarsha watershed, Kothapally, May 1999.

Properties	Land depth	0–15[1]	15–30	30–60	60–90	Mean	SE±
Soil respiration ($mg\ C\ kg^{-1}$ soil $10d^{-1}$)	Shallow	126	107	52	44	82	
	Medium	157	112	96	75	110	
	SE ±			6.0			4.4
	Mean	142	110	74	59		
	SE ±			3.3			
Mineral N (NH_4+NO_3) ($mg\ N\ kg^{-1}$ soil)	Shallow	10.3	7.1	5.8	4.2	6.8	
	Medium	11.7	10.1	5.7	4.9	8.1	
	SE ±			1.35			1.04
	Mean	11.0	8.6	5.8	4.5		
	SE±			0.71			
Net 'N' mineralization ($mg\ N\ kg^{-1}$ soil $10d^{-1}$)	Shallow	1.14	0.97	0.28	0.15	0.63	
	Medium	2.05	1.12	1.08	0.57	1.21	
	SE ±			0.77			0.43
	Mean	1.59	1.04	0.68	0.36		
	SE ±			0.52			
Microbial biomass carbon ($mg\ C\ kg^{-1}$ soil)	Shallow	288	214	123	62	172	
	Medium	267	191	160	109	182	
	SE ±			16.9			11.2
	Mean	278	203	141	85		
	SE ±			10.3			
Microbial biomass nitrogen ($mg\ N\ kg^{-1}$ soil)	Shallow	45.5	33.9	19.5	9.8	27.2	
	Medium	42.3	30.2	25.2	17.2	28.8	
	SE ±			2.67			1.77
	Mean	43.9	32.0	22.4	13.5		
	SE ±			1.63			

1. Soil depth (cm).

sites for water storage structures were identified by the village committees and scientists' team and 10 structures were completed; 270 sites for gully control structures were identified and 70 structures were completed. Also, 40 ha for field bunding was proposed and completed and 10 gabion structures were proposed and one structure was completed.

In situ conservation

Shaping of the land reduces runoff. The land is made rough by broad-bed and furrow (BBF) landform treatment. The beds are prepared at 0.4 to 0.6% gradient. The BBF method helps to reduce runoff and conserves more water in the soil profile and also drains excess water safely away from the crops. This method is being adopted by the farmers in Adarsha watershed with technical backstopping from ICRISAT. Contour planting on flat (flat on grade) landform is also adopted by some farmers. Bullock-drawn tropicultor, developed by ICRISAT, is used by the farmers for planting, sowing, fertilizer application, and intercultivation. Planting of *Gliricidia* is done by farmers. About 30000 and 16000 *Gliricidia* plants were planted in 1999/2000 and 2000/01 respectively, on field bunds by the farmers for stabilizing the bunds to conserve the rainwater and soil. In addition these plants generate N-rich organic matter for field application for augmenting N supply for crop growth. This would reduce the dependence on mineral fertilizer N.

Wasteland development

Common wasteland treatment has been initiated in 1 ha land and contour trenches (10 m width and 0.3 m height) were laid out. Custard apple plantation was undertaken through local people on wastelands on the trenches during 2000 and 2001. In all 300 custard apple plants were planted. This will give additional income to the villagers as they can market the fruits in the adjacent cities. The wasteland boundaries were planted with *Gliricidia* plants at 0.5 m spacing to serve as live fence and also as a source of N-rich organic matter through loppings.

Avenue plantations

Avenue plantation was also taken up in the village as a part of the afforestation program in the village. Tree plantation along the roads, field bunds, and *nalas* was undertaken. Teak plantation (2500 trees) in private fields was also undertaken.

Integrated Nutrient Management

Vegetative bunds

In addition to grass planting, *Gliricidia* was planted on field bunds and used to conserve moisture and supply N to the crop through biologically fixed N by incorporation of loppings into the soil. This reduces the usage of fertilizers. During 1999–2001 farmers planted *Gliricidia* plants on their field bunds.

Nutrient budgeting and balanced fertilization trials

In the watershed, 15 farmers are following the improved soil, water, and nutrient (SWNM) management options along with conventional practices. Balanced nutrient doses were used for sustaining productivity in these watersheds. *Rhizobium* inoculation of pigeonpea and soybean seeds was done to increase biological nitrogen fixation (BNF). Crop responses were positive to specific nutrient amendments. Based on soil analysis, B and S applications were done at Kothapally and increased yields were observed. Higher grain yields were obtained with improved practices and this indicates a considerable scope for savings on N fertilizer. Quantification of BNF using N-difference method is being done using non-fixing crop (maize and sesame) varieties of matching duration with groundnut and soybean in farmers' fields.

The nutrient uptake by maize/pigeonpea intercrop system was more in the improved systems as compared to that of flat landform treatment. The N-difference and ^{15}N isotope dilution methods were used to quantify BNF contributions of legumes using non-fixing control plants. Similarly, for the sole maize crop uptake of nutrients was more in BBF system than the flat landform. The nutrient balances based on the available data sets showed that in this watershed all the systems are depleting potassium (K) from soils and more P is applied than removed by the crops. Nutrient removal was also more in BBF than in the flat landform treatment. Higher negative N balance in maize/pigeonpea in BBF system (–55 kg N ha^{-1}) shows that the crop extracted more N from the soil when grown on BBF system than on flat system (–48 kg N ha^{-1}) (Table 5).

In situ generation of organic matter for green manuring

Leguminous green manures such as *Gliricidia* are important in maintaining soil and crop productivity. Decomposition and nutrient release of *Gliricidia* loppings 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. Decomposing leaf prunings of *Gliricidia* are better and rapid source of nutrients. Forty-six thousand *Gliricidia* plants were planted during 1999–2001 by farmers on their field bunds at Kothapally.

Vermicomposting Boosts Incomes

Earthworms are used in vermicomposting as they are voracious eaters 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 along with plant nutrients. Vermicomposting is a cost-effective pollution abatement technology. At Kothapally, 52 women farmers were identified for vermicomposting units. Of

Table 5. Nutrient budgeting in farmers' fields in Adarsha watershed at Kothapally, 1999–2000.

Cropping system/ Landform	Total inputs			Total outputs			Balance		
	N	P	K	N	P	K	N	P	K
Maize/pigeonpea									
BBF	28.3	16.4	17.1	84.5	10.6	57.6	–55	+6	–40
Flat	32.2	13.8	21.2	80.2	8.8	49.7	–48	+5	–29
Sole maize									
BBF	20.5	10.0	0.0	74.8	14.1	70.6	–55	–4	–70
Flat	9.0	10.0	0.0	32.7	7.3	35.9	–24	+3	–35
Sole sorghum									
Flat	18.3	9.9	11.0	41.8	9.7	64.3	–24	+0.2	–53

the ten existing women groups, five groups were formed and trained in vermicomposting techniques. The groups started the units with the available organic wastes, cow dung, etc. These women self-help groups have taken up vermicomposting as a micro-enterprise to generate income.

Method of vermicomposting

Agricultural residues like sorghum straw, paddy straw, dry leaves, pigeonpea stalk, groundnut husk, wheat husk, weeds like *Parthenium,* and agricultural wastes (e.g., animal manures); dairy and poultry wastes; food industry wastes; municipal solid wastes; biogas-sludge; and bagasse from sugarcane industry can be used as raw material for vermicomposting. The composting is done in cement rings or 1.5 m^3 tanks. Dry organic wastes, dung slurry, rock phosphate, earthworms, and water are mixed (10:3:0.4:100–150:1). The bottom of the tank is filled up with dry material like coconut husk or a polythene sheet is spread and on this 15–20 cm of organic wastes is filled as a first layer, rock phosphate as the second layer, and dung slurry as third layer. More layers are filled one above the other in the tank. The top layer is plastered with mud slurry to prevent moisture loss. This is left to decompose for 15 days to dissipate the heat generated during initial decomposition. Earthworms are released into the compost through the cracks after 15 days. To maintain adequate moisture, water should be sprinkled on the vermicompost tank intermittently. The compost will be ready within 6–8 weeks. The vermicompost is heaped in a cone shape. The earthworms move to the bottom out of the compost heap and these can be collected and used again.

Response of tomato to vermicompost application

In 2001, a demonstration plot was initiated in the village with a plot size of 300 m^2. Vermicompost was applied to the standing crop of tomato at 3–5 t ha^{-1}. The productivity (5.8 and 4.8 t ha^{-1}) of tomatoes was significantly higher in plots with 3 and 5 t ha^{-1} vermicompost when compared with plots with conventional compost (3.5 t ha^{-1} yield). The worm castings in the vermicompost have nutrients that are 97% utilizable to the plants.

Integrated Pest Management

Integrated pest management (IPM) is the coordinated use of pest and environmental information to design and implement pest control measures that are economically, environmentally, and socially sound. It promotes prevention over remediation and advocates integration of at least two or more strategies to achieve long-term solutions. IPM uses methods such as crop or site scoring, pest trapping, pest tolerance crop varieties, weather monitoring, cultural controls, biological controls, and precise timing and application of pesticide treatments, only when needed. Complete dependency on chemical control for the past three decades led to unsatisfactory pest management along with environmental degradation. ICRISAT along with national agricultural research and extension systems

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

Crop surveys

Crop surveys were carried out to know the plant protection practices followed by farmers in Kothapally. All the farmers interviewed indicated use of chemical pesticides against insect pests. They indicated *Helicoverpa* as the key pest on several crops. Endosulfan, cypermethrin, fenvalerate, monocrotophos, and quinalpos were the commonly used chemicals across the farming community. Precautions were not taken while spraying. This preliminary survey clearly brought about several inappropriate ways of chemical usage, which need to be addressed in the coming years.

Pest control

Cotton

Cotton crop was sown in the first fortnight of June with the onset of monsoon. Initially farmers could protect their crop by 3–4 chemical sprays against sucking pests like jassids, aphids, and whiteflies. *Helicoverpa* population was controlled by *Helicoverpa* NPV (HNPV), which kept the population below the economic injury level.

Pigeonpea

Pigeonpea crop was sown as both sole and intercrop with maize or sorghum. *Helicoverpa* was the key constraint to pigeonpea production. The adult population of *Helicoverpa* was monitored using pheromone traps. The farmers applied neem sprays and HNPV sprays followed by manual shaking. No chemical sprays were used. These farms had lower pod borer damage and higher yields when compared with fields where IPM practices were not followed.

Chickpea

Observations of egg and larval populations indicated the onset of pest infestation, particularly *Helicoverpa* and farmers applied HNPV in their fields. The farmers obtained three-fold more yield (780 kg ha^{-1}) than yields obtained by farmers (250 kg ha^{-1}) who did not adopt IPM in their fields. The increased yields are due to IPM as well as the use of the variety ICCV 37 supplied by ICRISAT.

Monitoring *Helicoverpa* by pheromone traps

Population of adult *Helicoverpa* was monitored in Kothapally village from 2000 by using pheromone traps with the pheromone lures obtained from the Natural Resources Institute (NRI), UK.

Village-level HNPV production

Among various options, the availability of good quality HNPV was considered a prime component for spread of IPM. This project quickly identified and initiated village-level production to cater to the needs of farmers. Many farmers and extension workers from this village were given training on HNPV production, storage, and usage on different crops. The villagers quickly adopted the technology and produced 2000 larval equivalents (LE) of virus and used on cotton, pigeonpea, and chickpea crops. Besides the village-level production, 11650 LE HNPV was supplied to the farmers through ICRISAT to cover cotton, pigeonpea, and chickpea crops.

The project has given high priority for training village 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. A slide show emphasizing cropping systems, various pests and diseases and their management was organized for the whole village including children. Video shows on correct use of plant protection emphasizing the importance of IPM were displayed in the village twice during the season. Farmers were trained on HNPV production at ICRISAT, Patancheru and were assisted to take up village-level HNPV production. Extension handouts on packages of practices for chickpea and pigeonpea crops in local language were distributed.

Future of IPM at Kothapally

In the coming years, ICRISAT will be involved in development of technologies for high quality insect pathogens to strengthen the existing IPM activities (viral and fungal pathogens). Basic research needs to be conducted on the insect host plant interaction and cultural operations on pests and on natural enemies. Potential plant products that are safe and effective in pest management should be identified and developed. Insecticidal resistance in both pests as well as natural enemies should be monitored. Village-based or regional-based IPM approach should be developed rather than pest-wise or crop-wise approach. Training clients (researchers, extension workers, NGOs, and farmers) at all levels in IPM concepts is needed.

Monitoring

To evaluate the impact of watershed management continuous monitoring of all the parameters is done. An automatic weather station was installed to continuously monitor the weather parameters (Figs. 2 and 3; Table 6). To monitor the groundwater levels 64 open wells in the watershed were geo-referenced and regular monitoring of water level and quality was done (Fig. 4). Runoff, and soil and nutrient losses are monitored using automatic water level recorders and sediment samplers (Fig. 5; Table 7).

Quantification of BNF in farmers' fields was carried out using N difference method and ^{15}N isotope dilution method. Pheromone traps were installed to monitor *Helicoverpa* populations. Changes in cropping intensity, greenery, water bodies, and groundwater levels were monitored. Geographical information system (GIS) maps indicating soil types, soil depths, and crops grown during rainy and postrainy seasons have been prepared. Crop productivities were recorded for each crop every year.

Impact

Improved greenery

The normalized difference vegetation index (NDVI) has been used to monitor the impact of the

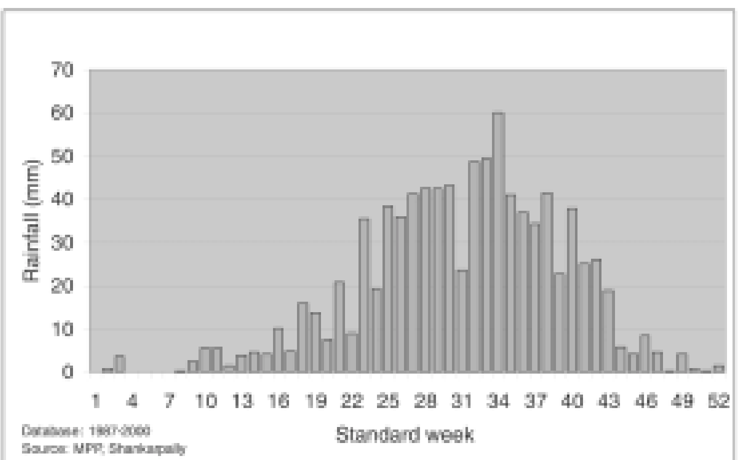

Figure 2. Average weekly rainfall recorded at Shankarpally Mandal, Andhra Pradesh.

Month	Rainfall (mm)	Max. temp. (°C)	Min. temp. (°C)	Solar radiation (MJ m^{-2})
1999				
6	54.50	32.49	22.02	16.81
7	139.24	30.56	20.99	17.36
8	150.59	29.06	20.46	15.84
9	115.05	29.11	20.36	14.64
10	50.90	30.49	18.34	15.81
11	0.00	29.59	12.57	17.08
12	0.00	28.07	9.54	15.56
2000				
4	4.09	41.56	23.60	22.83
5	138.00	37.99	23.54	22.25
6	165.30	31.75	22.26	15.15
7	132.29	29.96	21.71	15.08
8	460.09	30.26	21.88	14.04
9	103.69	32.14	20.86	18.03
10	12.40	34.35	19.78	17.55
2001				
1	12.70	32.62	15.08	16.09
2	1.30	30.99	14.84	12.64
3	4.80	39.09	20.50	20.29
4	27.70	39.24	22.48	20.22
5	12.20	41.15	25.85	22.37
6	112.29	33.89	22.60	17.20
7	19.60	31.97	22.65	14.86

Table 6. Monthly weather data recorded at Adarsha watershed, Kothapally, 1999–2001.

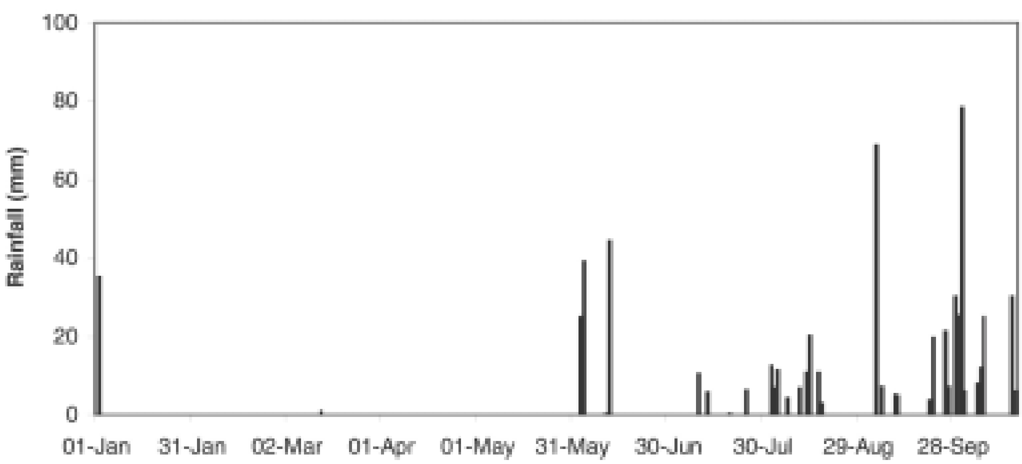

Figure 3. Rainfall recorded at Adarsha watershed, Kothapally, 2001.

Table 7. Annual rainfall, runoff, and peak runoff rate at Adarsha watershed, Kothapally, 2001.

Description	Treated watershed	Untreated watershed
Annual rainfall (mm)	612	612
Runoff (mm)	22	31
Peak runoff rate ($m^3 s^{-1} ha^{-1}$)	0.027	0.022

Figure 4. Location map showing open wells in Adarsha watershed, Kothapally.

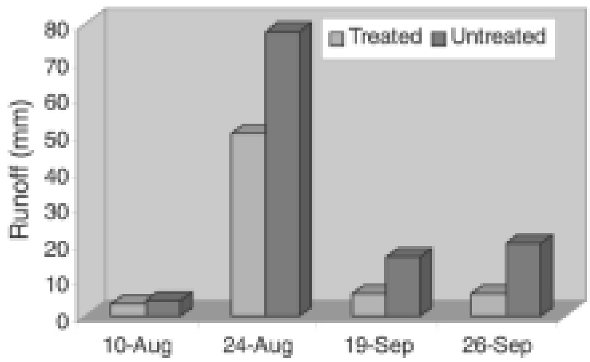

Figure 5. Runoff from two sub-watersheds at Kothapally, 2000.

implementation of action plan. An increase in the vegetation cover which reflects an improvement in the vegetation cover was observed. The spatial extent of moderately dense vegetation cover which was 129 ha in 1996 has increased to 152 ha by 2000.

Increased groundwater levels

The groundwater levels and other related observations (pumping hours, area irrigated from each well and distance between the well and check-dam) from watersheds were collected. At Kothapally watershed, throughout the season higher groundwater levels were recorded from the well near the major check-dam compared to water levels in wells away from the check-dam (Fig. 6). This clearly shows the effectiveness of the improved watershed technologies in increasing the groundwater recharge thereby improving the availability of water for agricultural and other uses.

Improved productivities and incomes for farmers

At Kothapally, farmers evaluated improved crop management practices along with improved land management practices such as sowing on BBF landform and 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 (Table 8). In intercropped maize with pigeonpea, improved practices gave a four-fold increase in maize yield (2.7 t ha^{-1}) compared with farmers' practices where the yields were 0.7 t ha^{-1}. In sole sorghum the improved practices adopted increased yields three-fold within one year. In 1999/2000, farmers achieved highest system productivity, total income, and profit from improved maize-pigeonpea and improved sorghum/

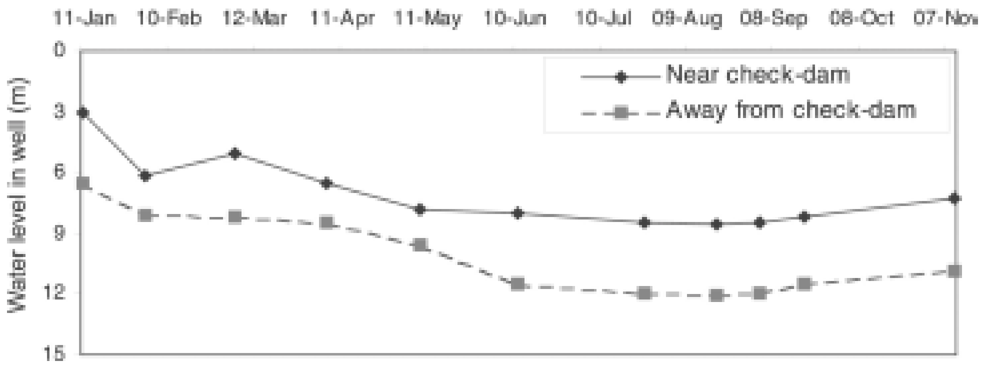

Figure 6. Effect of check-dam on groundwater recharge in Adarsha watershed, Kothapally during 2000.

Table 8. Average crop yield (kg ha^{-1}) with improved technologies in Adarsha watershed, Kothapally, 1999–2001.

Crop	1998 Baseline yield	1999	2000	2001
Sole maize	1500	3250	3750	3300
Intercropped maize	-	2700	2790	2800
(Farmers' practice)		700	1600	1600
Intercrop pigeonpea	190	640	940	-
(Farmers' practice)		200	180	-
Sole sorghum	1070	3050	3170	2600
Intercrop sorghum	-	1770	1940	2200

pigeonpea intercropping systems. Along with the highest system productivity the cost-benefit ratio of the improved systems was greater (1:2.47) compared to the farmers' traditional cotton-based systems (Wani 2000). In 2000/01, 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 the flat landform treatment. Furthermore, even on flat landform treatment farmers harvested 3.6 t ha^{-1} maize and pigeonpea using improved management options compared to 1.72 t ha^{-1} maize and pigeonpea using normal cultivation practices.

Similar benefits from improved BBF landform and also improved management options were reported by the farmers in shallow soils and with other cropping systems. The rainfall during 1999 in this area was 559 mm, which is 30% below normal rainfall, and in 2000 the rainfall was 958 mm, which is 31% above normal. In spite of this variation in the rainfall received in 1999 and 2000, the productivity of the crops marked a sustainable increase during 1999/2000 and 2000/01.

Of all the cropping systems studied in Adarsha watershed, maize/chickpea and maize/pigeonpea proved to be more beneficial to farmers (Table 9). Farmers could gain about Rs 19590 and Rs 17802 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.

Table 9. Benefit-cost ratio of different cropping systems at Adarsha watershed, Kothapally, 2001.

Cropping system	Total productivity (kg ha^{-1})	Total cost (Rs ha^{-1})	Total income (Rs ha^{-1})	Profit (Rs ha^{-1})	Benefit-cost ratio
Improved					
Maize/chickpea	4700	6883	26473	19590	1:2.85
Maize/pigeonpea	3753	6342	24144	17802	1:2.81
Maize	3000	4150	12260	8110	1:1.96
Sorghum	3000	3850	13860	10010	1:2.60
Chickpea	850	5250	18000	12750	1:2.43
Pigeonpea	1090	4890	17120	12230	1:2.50
Traditional					
Maize/chickpea	2750	5915	16650	10735	1:1.82
Maize/pigeonpea	1715	4452	12769	8317	1:1.87
Sorghum/pigeonpea	1116	4050	11610	7560	1:1.87
Cotton	1163	16990	26748	9758	1:0.57
Maize	1600	3360	7500	4140	1:1.23
Chickpea	-	4260	11600	7340	1:1.72
Sorghum	1011	3050	7055	4005	1:1.31

Human Resource Development

Farmers are exposed to new methods and technologies for managing natural resources through training and field visits to on-station and other on-farm watersheds. Farmers and landless families were trained and encouraged to undertake income generating activities in the watershed, which can help sustain the productivity at watershed level. Various training sessions were held for farmers on improved management options like providing training on farm implements, IPM, and integrated nutrient management options. Along with the farmers, watershed committee members and agriculture and extension officials were trained at ICRISAT on different aspects of integrated watershed management. Research scholars and apprentices from various universities of India, Thailand, Vietnam, and New Zealand conducted research on integrated watershed management. Special emphasis was laid to educate women farmers and increase awareness on new management options. More women were trained in vermicomposting technology at Kothapally. Educated youth were trained in skilled activities like NPV production and vermicomposting, which helped them in generating income (Table 10).

Technology Imbibing into Other Watersheds

Around ten watershed farmers from Nawabpet (Yellakonda watershed, Sainnaguda watershed, Lingampally watershed, Maitaphkanguda watershed, and Gullaguda watershed) and Adilabad adopted the improved practices which proved to be beneficial in Adarsha watershed, Kothapally and they are in the process of evolution. Farmers adopted BBF landform in their fields. Use of tropicultor for sowing, fertilizer application, and intercultivation activities impressed them very much and they bought tropicultors for their respective villages. Improved cropping systems like sorghum/pigeonpea, maize/pigeonpea, sole sorghum, chickpea and maize cropping systems were taken up in about 206 ha in these watersheds. Improved soil and water conservation measures have been initiated in these watersheds. Farmers are found to be keenly interested in adopting *Gliricidia* plantations, vermicomposting, and HNPV production in their respective villages.

Table 10 Various training programs conducted on integrated watershed management at Kothapally, 2000–01.

Stakeholders	Number of training courses	Participants
Farmers	5	675
Agricultural officials	3	80
Government officials/nodal officers	3	60
Non-governmental organization/ Project implementation agencies	1	30
Research scholars/Apprentices from various countries	-	14
Visitors	-	800

Why is Adarsha Watershed a Model Watershed?

The Adarsha watershed is said to be a model watershed as all the activities are through community initiatives and the strength lies in local participation of people, especially through women empowerment. The project improved the livelihoods of the poor by increasing the farm productivities, farm incomes, groundwater levels, and improving greenery. The capacity of local governments and community-based organizations has been enhanced through watershed management and decision-making processes. This project is aware of the need to involve local residents and community-based organizations, given that residents possess unique, first-hand knowledge about local resources and environmental threats.

Conclusion

On-farm trials were conducted by ICRISAT in 1980s and the results on station were replicated in farmers' fields. But even after 15 years in the same village, the improved practices were not adopted by the farmers of the village; they went back to their traditional practices. The researchers found the loopholes for low adoption of the technology package. A new model of integrated watershed management was developed by ICRISAT with the lessons learned on farm. Contractual mode of farmer participation did not achieve good results, so a higher degree of farmer participation through consultative and cooperative mode was initiated and found to be successful in the watershed. Gender issues were considered high priority. As women are the key players in development of the society, keen interest was taken to empower women in various income generating activities like vermicomposting and HNPV production within the village. On-farm trials were conducted in farmers' fields by providing them only with technical backstopping; no subsidies were given. Social auditing was done by the villagers themselves. To sustain the productivity in the SAT, a holistic approach of integrated watershed management still needs to be scaled up through appropriate policy and other institutional support and the on-site and off-site impacts need to be studied.

Acknowledgments

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Conjuctive Use of Water Resource Technology and Extension in Improving Productivity of Rainfed Farming: An Experience at Lalatora, Madhya Pradesh, India

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Abstract

Although Vertisols and associated soils in Lalatora, Madhya Pradesh, India are a productive group of soils, these soils have several constraints to high agricultural productivity. Low cropping intensity, waterlogging during the rainy season, and lack of farmers' inability to use modern technology are the major constraints. On-farm studies made during 1999–2001 showed that use of improved varieties of crops such as soybean and chickpea along with improved water harvesting and nutrient management (including application of micronutrients) and integrated pest management significantly increased crop productivity and income of the farmers. There is a need to further test the package of practices for improving productivity and farm income.

The concept of sustainable development cannot be discussed only in the light of economic development. The social and environmental changes and the people should be considered. Sustainable socioeconomic development is a challenge and an opportunity. Along with economic development, sustainable social development has become an integral part of the entire development process as it aims at "the improvement of the well-being of the people". The success and failure of the development program and technology interventions largely depend upon the actors involved in the process. The major stakeholders in the process of development are those who make use of natural resources. The participation of these users is very important for the management of natural resources as well as for technology adoption and success. A process oriented step-by-step approach is very effective for sustainability. Farming systems research (FSR) is a successful example of this approach, which has been tried out in many developing countries. Integration of the roles of scientist, extensionist, and farmers is the key to success in FSR approach.

The project has adopted a holistic process, i.e., FSR approach, to improve the productivity of soybean-based rainfed farming with technological interventions for sustainable use and management of natural resources. A consortium model for management and development of integrated participatory watershed is evaluated at Lalatora watershed in Vidisha district, Madhya Pradesh, India. The project aims to develop and apply environment-friendly technological options to increase the productivity in this area of medium to high water-holding capacity soils.

Area, Climate, and Physiography

Lalatora village of Vidisha district of Madhya Pradesh is located in an extensive watershed totaling about 10525 ha, lying between latitude 28°8'3" and 24°16' N and longitude 77°20'45" and 77°30'15" E at a height of 415 m above mean sea level. The Lalatora watershed is a micro-watershed within the Lateri-1 milli and is located in the northwest corner of Vidisha district. Madhya Pradesh is the largest state in India and extends into three agro-ecological zones (7, 8, and 9), which are characterized as having 120 to 180 days length of growing period; soils are largely Vertisols where the parent material is mainly alluvial. The catchment area represents the four major rivers, viz., Yamuna, Ganga, Narmada, and Godavari. The state is

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divided into six physiographic regions; the district of Vidisha is located in the Vindhya Plateau Zone.

Surface hydrology

Two digital runoff recorders along with automatic pumping sediment samplers were installed at the Lalatora watershed to monitor runoff and soil erosion from untreated and treated sub-watersheds. To monitor the outflow from entire Lalatora watershed, one digital runoff recorder was installed at the major drain. There is a significant reduction in runoff from the treated sub-watershed compared to untreated sub-watershed (Table 1). In 1999, the significant reduction in runoff from treated sub-watershed (24% less than the untreated sub-watershed) was observed. During 2001, large reduction in runoff volume (81% less compared to untreated sub-watershed) was recorded. The difference in the runoff between the treated and untreated sub-watersheds was greater during 2001 compared to 1999. This is mainly due to the fact that starting from 1999, more area was brought under improved technologies including check-dams and structures in the treated sub-watershed. The peak runoff rates from the treated sub-watershed were also significantly lower compared to untreated sub-watershed (Table 1). During 1999, the peak runoff rate in the treated watershed was only one-third that of untreated watershed. During 2001, the peak runoff rate in the treated watershed was 30% lower than untreated watershed. During three years (1999–2001), the highest peak runoff rate of 0.218 $m^3 s^{-1} ha^{-1}$ was recorded from the untreated watershed.

During all the three years (1999–2001), few major storms contributed 50–75% of the seasonal runoff (Fig. 1). During 1999, one single storm on 5 September resulted in more than 50% seasonal runoff from both treated and untreated sub-watersheds. Similar trend was seen during 2000 and 2001. The effectiveness of treated watershed in controlling runoff from small and medium storms is shown in Figure 1 for 2001. During 2001, runoff from all the small and medium storms were totally controlled in the treated watershed except for one large storm on 12 July 2001.

Groundwater hydrology

At Lalatora, 12 open wells were monitored at fortnightly intervals to record the groundwater fluctuations. The mean water level in open wells before watershed development was about 6.5–9.5 m. The water level in open wells increased substantially in subsequent years after implementing watershed development work, particularly construction of the check-dams and other water harvesting structures. During 2000, the mean water level in the wells near check-dams was consistently around 1.5–2.0 m up to October, whereas the water level in the wells located away (about 1000 m) from the check-dams was at about 8.5 m throughout the year (Fig. 2). Even during rainy season the wells away from check-dams did not show significant increase in water level, while the water levels in the open wells near the check-dams had significant increase particularly during the rainy season.

The Lateri block is considered the most underdeveloped area within the district of Vidisha, with very limited irrigation and no major or medium-scale industry. The average rainfall is 1000 mm. The soils of the area range between medium black to red soils.

Table 1. Seasonal rainfall, runoff, and peak runoff rate from two sub-watersheds at Lalatora, 1999–2001.

Year	Rainfall (mm)	Runoff from two sub-watersheds (mm)		Peak runoff rate ($m^3 s^{-1} ha^{-1}$)	
		Untreated[1]	Treated[2]	Untreated[1]	Treated[2]
1999	1203	296	224	0.218	0.065
2000	932	234	NR[3]	0.019	NR[3]
2001	1002	290	55	0.040	0.027

1. Untreated = Large watershed with most of the areas untreated.
2. Treated = Small watershed with major areas treated with improved technologies including hydraulic structure.
3. NR = Not recorded.

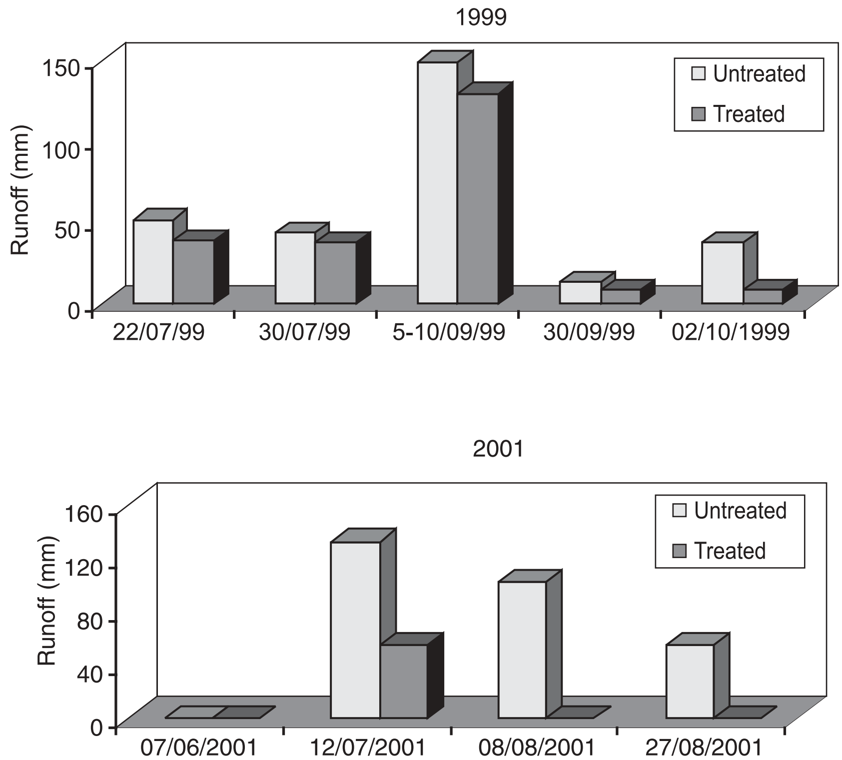

Figure 1. Daily runoff events from the treated and untreated sub-watersheds during 1999 and 2001 at Lalatora.

Agriculture is the main occupation in the block, but employment is seasonal due to lesser crop intensity because of low irrigation availability. About 20% of the population migrates seasonally. The postrainy season (rabi) is the main cropping season with 35,000 ha sown area while 10,000 ha is sown during the rainy season (kharif). Double cropping is undertaken in only 3750 ha (Rangnekar 1999). An automatic weather station was established in the watershed. Daily weather readings are collected and are maintained.

Soils

The Lalatora watershed in particular is spread on the Deccan Trap basalt where the parent material is mainly alluvial. The physiography of the area is level to very gently sloping land where certain pockets towards the north of the area are highly gullied creating a certain amount of relief, which may create further problems of management. Five soil series have been identified. These are Vertisols characterized by gray, very deep, dark grayish brown to olive brown with a clayey surface horizon and calcareous B horizon. The predominant clay mineral is montmorillonite. These soils have greater micropore volume due to high amount of very fine clay present in the soil (NBSSLUP 2000). About 60% soils are medium (30 to 60 cm depth) while 20% are deep (>60 cm depth) and 20% are shallow (<30 cm depth).

Socioeconomic Status

A baseline socioeconomic and natural resource inventory survey was conducted through a stratified detailed household survey and participatory rural appraisal (PRA) methods. Primary data have been collected from 396 households from 7 villages covering top, middle, and lower toposequence positions in Lalatora watershed. The data have been collected using an interview schedule prepared by trained investigators. The sample for the study is presented in Table 2. Low literacy rate, poor resources, and inadequate extension are the main reasons for backwardness of the community.

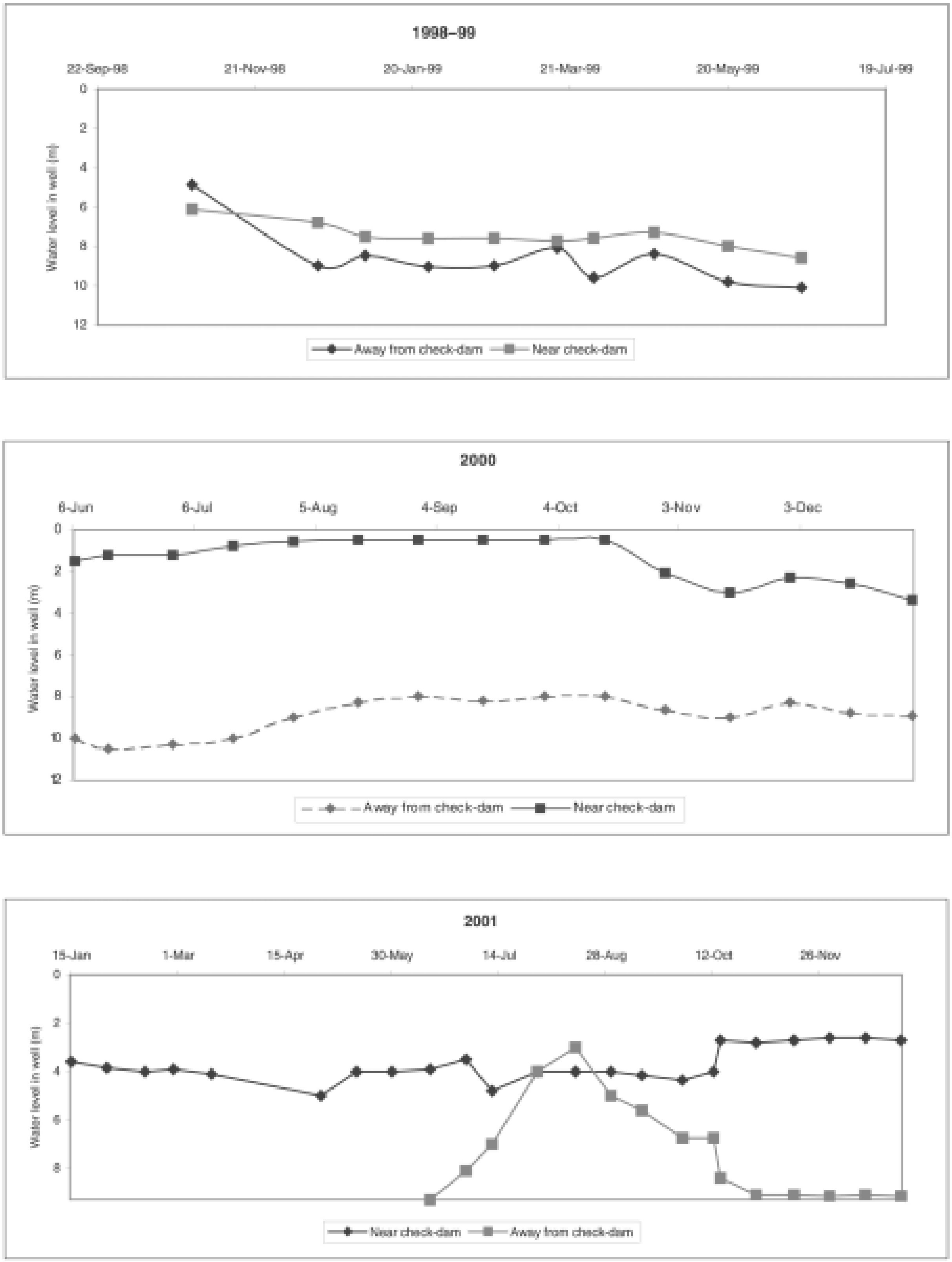

Figure 2. Groundwater levels in open wells at Lalatora watershed, 1998–2001.

Table 2. Sample area (ha) for the study at Lalatora.

Region	Marginal farmers	Small farmers	Medium farmers	Large farmers	Landless laborers	Total
Upper area	15	15	18	14	9	71
Middle area	16	28	30	16	10	100
Lower area	17	27	29	34	23	130
Lalatora micro-watershed	23	20	14	12	26	95
Total	71	90	91	76	68	396

Table 3. Occupation categorization (%) of family members[1].

	Work					Migration		Unemployment	
Gender	Agri	Agri + NFW	NFW	Trade	Agri + Trade	For Agri	For NFW	Always	Sometimes
Male	28.8	9.8	12.2	19.3	15.7	2.7	-	2.1	9.2
Female	24.5	13.3	30.3	8.5	6.9	2.7	0.5	2.7	10.6
Overall	27.4	11.1	18.7	15.5	12.6	2.7	N	2.3	9.7

1. Agri = Agriculture; NFW = Non-farm work; N = Negligible.

Family information

Ninety-four percent of the households are male-headed and 6% are headed by females, mostly widows. Main source of income for 56% of the households was from agriculture, 28% from non-agricultural labor, 14% from agricultural labor, and around 2% from the services sector. The occupational categorization of individual family members is presented in Table 3. Lalatora has 56% small farmers (57), 29% medium farmers (30), and 15% large farmers (15). Literacy status revealed that 52% are illiterate, 29% reach up to primary education, 12% complete secondary education, and 7% complete high school education.

Social structure

The average size of the household is 9.4 persons of which 5.3 are male and 4.1 are female. The family size of the landless laborers is much smaller at 5.5 persons per household, perhaps due to lower income and assets. The availability of labor is seasonal and a greater family size would require them to migrate for work. The recent study (Vadivelu et al. 2001) revealed that in most of the cases people with some landholdings enter into share cropping contracts and these people 'crowd-out' the share croppers from the share cropping market. The obvious reason is that the landholders would assume to have a better knowledge of agricultural operations and would also be in a position to repay the borrowed money from the landlord (through growing wheat from their own land).

Land-use Pattern

About 60% soils are black soils, medium in depth (30 to 60 cm depth), 20% are deep black soils, more than 60 cm deep, and 20% are shallow soils (30 cm depth). In the Lateri block 53% of the land is used for agriculture, 17% is classified as wasteland, 25% as forest land, 4% as grazing land, and 1% as fallow land. The average landholding of the farmers from the study area is around 4 ha. The average landholding size is 4 ha, with 2.73 ha of dryland and 1.27 ha of irrigable land.

The primary data collected revealed that only soybean is grown in large areas (Rangnekar 1999). The other major rainy season crops are sorghum and maize, while pulses are grown in smaller areas. Soybean was the crop preferred by 74% of the farmers in kharif followed by rice (21%), sorghum (3%), and maize (2%). In the rabi season, wheat was preferred by 46% of the farmers followed by chickpea (43%), rice (6%), and lentil (5%).

During the rainy season, out of an average 2.73 ha of dryland, only 0.26 ha is cultivated. During the rainy season, 88% of land in Lalatora is kept fallow by the farmers. The fallow lands are largely rainfed lands without any source of irrigation and farmers traditionally grow postrainy season crops on stored soil moisture and use supplemental irrigation obtained on payment from the neighbors. Soybean is the only crop cultivated during this season with an average grain yield of 0.95 t ha^{-1}, whereas in the postrainy season, 71% area is under wheat and 24% under chickpea.

Relationship between Soil, Rainfall, and Cropping Pattern

The soils have a higher clay content characterized by greater water-holding capacity with poor drainage and problems due to waterlogging. The average annual rainfall is about 1000 mm with high intensity of rainfall resulting in runoff and soil erosion. The problem in the rainy season is ponding of water caused by high rainfall intensity.

Farmers prefer to grow the rainy season crop (soybean) under irrigation. Also, the delayed harvest of soybean does not affect the growth of the postrainy season crop chickpea and/or wheat. In drylands, farmers prefer to leave the plots fallow as sequential cropping is risky. A study by Pandey (1986) indicated that in only 9 out of 29 years, the residual moisture is sufficient for sequential cropping. Another study by Rosenzweig and Binswanger (1993), using data over 10-year period, indicated that risk-coping mechanisms (post-ante consumption smoothing mechanisms are stronger) in wealthier farmers are higher and they generally tend to take the risks.

The average yield of all the crops in Lateri block except soybean is lower than the state average. It is pertinent to note that Madhya Pradesh is the largest soybean growing state in India where more than 5 million ha produce about 4 million t of soybean with a production of 750–1062 kg ha^{-1}, which amply supports the project objective of studying sustainability of agriculture in the rainfed tropics.

On-farm Participatory Trials

Methodology

Detailed soil survey and soil analysis was carried out. Geohydrological study of soil losses and water runoff are being recorded to monitor the effect of water and soil conservation work carried out in the watershed. Automatic weather station is commissioned to record the microclimatic data. Participatory approach was adopted in water and soil conservation activity by motivating and mobilizing people's participation in watershed development. Medium and small farmers, who were willing to participate in the on-farm participatory trials (OFPTs), were selected. The plot size was 0.15 to 0.25 ha. All the farmers involved in the trials were given training on the recommended practices and record keeping.

Government partnership

The Government of Madhya Pradesh has supported the management of natural resources through the watershed development programs under the Rajiv Gandhi Watershed mission. The major activities carried out under this mission were water harvesting, soil conservation, improving vegetative cover, and empowering community with emphasis on weaker section of the society.

Study on existing farming system

The information was gathered by using the following tools to understand the existing agricultural system including soil, crop husbandry, and socioeconomic aspects of the families:

- Baseline survey: socioeconomic survey; and crop production data
- Group discussions
- Transect walk and PRA
- Secondary data collection

Constraints analysis

In the soybean-based farming system in Lalatora watershed area, the following important constraints were identified jointly with farmers:

- Soybean cultivation has low productivity ranging from 900 to 1200 kg ha^{-1}.

- Soils were deficient in boron (B) and sulfur (S).
- Waterlogged conditions prevailed many a times if not continuously in the growing season.
- Risk of erratic rainfall and insufficient moisture in the soils.
- Market fluctuation affected the price realization by farmers.

Selection of interventions

The following interventions were selected to improve productivity of soybean and chickpea to suit local conditions and resources:

- Evaluation of best-bet options for soybean-based systems.
- Evaluation of response to micronutrients (B as borax at 10 kg ha^{-1}, S as gypsum at 200 kg ha^{-1}, and combination of both).
- Broad-bed and furrow (BBF) system (1 m broad-bed and 30 cm wide furrow) was formed with tractor-drawn implement.
- Introduction of improved seeds of soybean (JS 335) and chickpea (ICCV 2, ICCV 10, and ICCC 37) varieties.
- Seed treatment with *Rhizobium* (or phosphate-solubilizing microorganisms) culture to enhance nutrition and thiram for disease control.
- Use of nuclear polyhedrosis virus (NPV) for controlling *Helicoverpa* (pod borer) attack on chickpea.
- Water and soil conservation measures.

On-farm trials: The approach

The approach of farmer-managed trials was adopted. The trials were basically managed by farmers with technical advice provided by scientists and non-governmental organization (NGO) staff for planning, conducting, and monitoring the trials. This approach was advantageous as scientists received feedback and accordingly user-friendly interventions were devised. There was no change in other agronomic practices, which are generally adopted by the farmers. The guiding principles adopted for on-farm trials (OFTs) were:

- Farmers were provided scientific information about the constraints and possible solutions for increasing productivity.
- Farmers were involved from the beginning and the OFTs were planned in partnership with the farmers.
- Inputs for OFTs were provided at subsidized rates initially.
- Trained NGO staff collected records of inputs and outputs for OFTs along with neighboring non-trial farmers as controls.
- Farmers evaluated the OFTs in their own way.
- In 1998 rabi season, one on-farm trial was conducted with chickpea variety ICCC 37 for evaluation by farmers and seed multiplication.
- In 1999 kharif, OFTs were conducted on soybean JS 335 along with best-bet options put together by scientists from Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Central Research Institute for Dryland Agriculture (CRIDA), and Indian Institute of Soil Science (IISS). A multi-pronged integrated pest management (IPM) strategy was also adopted using physical method (plowing in summer), chemical method, and biological method (use of pheromone traps).
- In 1999/2000 rabi season, one trial was conducted on chickpea using 3 varieties (ICCV 2, ICCC 10, ICCC 37), combined with seed treatment and reduced tillage.
- In 2000 kharif, OFTs were conducted on soybean using improved variety JS 335, BBF, micronutrient amendments (B and S), and nutrient budgeting.
- In 2000/01 rabi season residual effects of B and S amendments on wheat and chickpea yields were evaluated. Nutrient budgeting trials for soybean-based systems were continued.
- In 2001 kharif the following OFTs were conducted on soybean:
  - Cultivation on fallow land using short-duration soybean variety Samrat.
  - Micronutrient trials using B and S.
  - Landform trials comparing BBF.
  - Mixed cropping with maize.
  - Introduction of new crops (pigeonpea, groundnut, and maize).

Performance of On-farm Participatory Trials

During 1998/99 rabi season interactions with farmers at Lalatora revealed that most farmers were using traditional chickpea variety Katila. They were very keen to evaluate improved chickpea varieties developed by ICRISAT. Five farmers volunteered to evaluate ICCC 37 and breeders' seed of ICCC 37 was provided to these farmers. The farmers had agreed to return double the quantity of seeds provided as their contribution for building seed bank at Lalatora. On an average, farmers harvested 20% more grain yield of ICCC 37 with maximum yield of 1680 kg ha^{-1} as against the yield of 950 kg ha^{-1} from the traditional variety (Table 4). The farmers were happy with the bold shiny seed and high yield. During 1999/2000 rabi season more farmers came forward to evaluate improved chickpea varieties and also reduced tillage for chickpea crop production.

Use of improved chickpea varieties ICCV 10, ICCV 2, and ICCV 37 resulted in higher yields (957 to 1471 kg ha^{-1}) over the local variety (923 kg ha^{-1}). The variety ICCV 10 was found more promising than other varieties evaluated. The combinations of improved variety with seed treatment and reduced tillage exhibited better production than improved variety alone (Table 4). Profitability of improved practices over traditional practices was higher by Rs 6421 ha^{-1}. Improved variety with seed treatment yielded 59% higher yield than the local variety. The gross profit was also significantly higher.

Breeders' seeds were provided initially to the farmers for evaluating the performance of chickpea varieties. The farmers were helped in roguing the odd plants in the chickpea fields under evaluation. Four women self-help groups (SHGs) consisting of 40 members purchased seeds and with the help of BAIF staff stored treated seeds in government godowns until planting of the next rabi crop. Through this mode, the four SHGs sold 1200 kg of quality seeds in the village and earned the profits. In addition, individual farmers used their own seeds of improved varieties and also provided on cost to farmers of nearby watersheds.

Evaluation of Best-bet Option

During 1999 rainy season, the scientists from JNKVV, CRIDA, and ICRISAT put together a best-bet combination option for soybean-based systems. This

Table 4. Performance of farmer participatory evaluation of chickpea varieties at Lalatora[1].

Variety	No. of farmers	Area covered (ha)	Yield (kg ha^{-1})	Increase (%) over control
1998				
ICCC 37	5	1.8	Av. 1150 Max. 1680	
1999				
ICCV 10	14	3.75	Av. 1471 Max. 2500	59
ICCV 2	5	1.25	Av. 1280 Max. 1600	38
ICCC 37	25	6.25	Av. 957 Max. 1700	4
Control (traditional farms)	14	4	Av. 923	

1. Interventions included improved variety, seed treatment, non-nodulating seed, and reduced tillage; no intervention in control.

option consisted of use of improved variety of soybean (JS 335), seed treatment with thiram along with *Rhizobium* and phosphate solubilizing microorganisms, application of diammonium phosphate (DAP) at 50 kg ha^{-1}, and IPM. In the first year, 27 farmers evaluated this option for soybean covering 40 ha (Table 5). Average increase in soybean yield was 34% above the baseline/control plot yield of 950 kg ha^{-1}. The range of soybean yields with best-bet option varied from 0.81 to 1.06 t ha^{-1}. Detailed analysis of benefit-cost ratio for the farmers who evaluated this option was worked out and the net profit was Rs 5575 ha^{-1} (Vadivelu et al. 2001).

Response to micronutrient amendments

In 1999 season, soil samples from Lalatora were collected and analyzed. The analysis revealed that these soils were deficient in B and S. These results were shared with the farmers and the implications were explained. Remedial measures were also suggested. During 2000 rainy season 13 farmers came forward to evaluate effects of B, S, and B+S amendments (10 kg borax = 1 kg B ha^{-1}, 200 kg gypsum = 30 kg S ha^{-1}, and 1 kg B + 30 kg S ha^{-1}). The farmers evaluated these treatments in strips, monitored the plant growth during the season, and harvested separately.

The results showed that B, S, and B+S treatments significantly increased soybean yields (1710 to 1780 kg ha^{-1}) and the yields were 34–39% higher than the best-bet option treatment (Table 5), which served as control treatment without B, S, and B+S amendments. Farmers found these trials educative and they were happy to harvest increased yields of soybean, which also resulted in increased income.

During the postrainy season these plots were maintained and six farmers planted wheat following normal practices to evaluate the residual benefits of B, S, and B+S amendments. Residual benefits of B and S amendments for soybean in kharif season increased wheat yields by 30 to 39% over the untreated control plot yields. Total systems productivity increased by 63 to 73% due to single dose of 1 kg B and 30 kg S application. The economic analysis of these trials showed that farmers' net incomes increased by Rs 8190 to 8850 ha^{-1} due to B and S amendments, respectively.

The economic analysis of the OFT in 2001 showed that intervention of combined application of B and S gave maximum benefit amounting to Rs 26454, followed by only B (Rs 26609) and S application (Rs 25955). All these three interventions proved to be beneficial to the farmers with 1.8 benefit-cost ratio as compared to control with traditional practices (1.3) and gave almost 49% higher benefits to the farmers. These amendments not only increased the incomes, but also improved the water-use efficiency through increased productivity. The farmers were impressed with these results. Besides Lalatora farmers, other

Table 5. Performance of soybean variety in on-farm trials at Lalatora.

Variety	No. of farmers	Area covered (ha)	Yield (kg ha^{-1})	Interventions	Increase (%) over control farm
1999					
JS 335	27	40.5	1275	Improved seed; seed treatment and application of DAP	34
Control (traditional)	14	6	950	No intervention	
2000					
JS 335	13	6	1730	Boron application	35
JS 335	13	6	1710	Sulfur application	34
JS 335	13	6	1780	Micronutrients	39
JS 335	6	3	1500	Broad-bed and furrow	17
Control (JS 335)	13	6	1280	Best-bet option	

farmers from the neighboring watersheds of Anandpur, Lateri, Khairkhali, and Mahauti also indented in advance their B and S requirements with the BAIF staff.

During 2001 kharif season, 12 farmers further continued evaluation of B and S amendments on the same plots. The results revealed that the response to B and S amendments was 10 to 16%, which was almost half that of the response observed in 2000 kharif season. The probable reasons for the reduced benefits due to B and S amendments could be: (i) occurrence of 45 days drought (dry spell) during reproductive stage of soybean, (ii) application of B and S after sowing of the crop due to continued rains in the beginning of season, and (iii) improved availability of B and S from the previous amendments.

Evaluation of broad-bed and furrow landform treatment

Three farmers evaluated BBF landform for soybean production and observed 17% increase in soybean yields over their normal practice. Considering the fact that the black soils of this region are prone to waterlogging, BBF technology was suggested for evaluation. The BBF practice proved better (1500 kg ha^{-1}) than the traditional cultivation practices of the farmers (Table 5), which involved planting on flat surface. There was initial resistance to BBF due to signs of low and slow germination as a result of poor sowing practices. This lacuna has been rectified with provision of modified seed drills for BBF operations and adequate field training to the farmers. With further improvements in planting on BBF, during 2001 kharif season, 11 farmers evaluated BBF landform treatment. During the drought season also, BBF increased soybean yields by 16% over and above the yields of best-bet option. However, farmers feel and perceive that they lose some land in furrows and more crop lines could be sown in the field. Availability of equipment for BBF preparations and planting are perceived as constraints by the farmers.

Technology Exchange

Ultimate success of any technology depends on its acceptance by the farmers. If the technology is not economically viable, socially acceptable, and not user-friendly, it would be rejected by the farmers. This was ascertained by the feedback received from the farmers. Based on the encouraging demand-driven experience, extension of technology dissemination was initiated by organizing:

- field days, field exposure visits, and scientist visits;
- increasing awareness through enhanced interactions with extension officials;
- promoting seed banks to ensure timely seed supply through SHGs (4 SHGs procured and supplied 1.2 t seeds to 12 farmers, in addition to project supply and farmers' own seeds);
- field demonstrations;
- providing literature about improved options;
- linkages with other agencies (*swayam sidha*, market access); and
- government organization, NGO, and farmer visits.

These activities have proved to be very effective in dissemination of the technologies. The impact is clearly seen by increased demand for improved varieties in large numbers from non-operational project areas. Another interesting feature was attracting financial support from the Government of Madhya Pradesh for undertaking physical structures for water conservation.

Adoption and Farmers' Perceptions on Interventions

Adoption status and farmers' opinion on various interventions carried out during the project are reported in Table 6. The most important constraint of waterlogging in the rainy season requires adequate drainage systems. Eighty-one per cent of the respondents categorize the adoption as 'partial'. Most of the innovations that were identified as non-adoption are either due to lack of technical knowledge or the expensive nature of the operation. One hypothesis is that the problem lies more in the nature of the perceived higher cost, which the farmer is not willing to invest. This calls for a properly designed program which will provide sufficient subsidy with reasonable contribution from the farmers. Farmer interest in the interventions is given below:

- All farmers appreciated:
  - Introduction of new crop variety;
  - Seed treatment;
  - Use of biofertilizer.

Table 6. Adoption of soil and water conservation (SWC) measures.

SWC measures	Adoption status[1] Not adopted	Partly adopted	Fully adopted	Causes for non-adoption[1] Ignorance	Technical constraints	Very expensive	Inconvenient
Land leveling	2.08	91.67	6.25	NR[2]	45.37	46.15	8.48
Waterway	9.38	81.24	9.38	NR	45.37	54.63	NR
Farm pond	34.49	51.72	13.79	NR	47.12	52.88	NR

1. Data indicate respondents (%).
2. NR = No reply.

- Most farmers appreciated:
  - Mixed cropping;
  - Micronutrient application.
- The practice of reduced tillage was appreciated by less than half of the participating farmers.
- BBF landform was appreciated by least number of farmers.

Summary and Conclusion

The major constraint in the watershed area is low cropping intensity, as majority of the dryland is left fallow during the rainy season. Waterlogging and soil erosion are the other constraints. Lack of initiative by the farmers is due to their perception that higher costs are involved in undertaking these investments and they expect the Government to take a lead role. The yields of most of the crops are lower than the state average, except soybean. In general the yields are less than 1 t ha^{-1}; however, there is huge variation in the yields over years. The education level is poor particularly in the women's group. The infrastructural facilities in terms of electricity, roads, and telecommunications are also poor.

Farmers were happy to evaluate improved options, which increased their farm incomes. Along with the improved crops/varieties, farmers appreciated much the technologies to harvest rainwater through farm ponds, best-bet options, amendments with selected nutrients, use of NPV, and the concepts of village-based seed banks and vermicomposting.

All the participating farmers opined that the introduction of improved varieties of chickpea and the improved practices have given higher yields than local practices and local variety and they were satisfied with the interventions. All the interventions suggested in the project were user-friendly, except BBF in which the availability of implement and skill to use were the constraints encountered by the farmers. Availability of the improved variety, quality seeds, and credit were other constraints faced by farmers. Work load and its distribution should be analyzed further as some practices may involve more women participation or vice versa.

Acknowledgments

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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.

1. Vietnam Agricultural Science Institute (VASI), Hanoi, Vietnam.
2. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India.

- 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

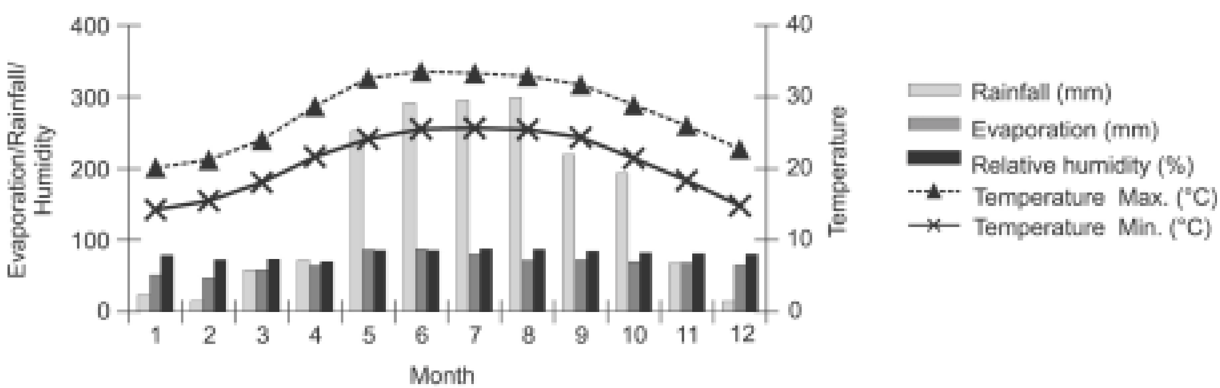

Figure 1. Climate of Hoa Binh Province, 1984–98.

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

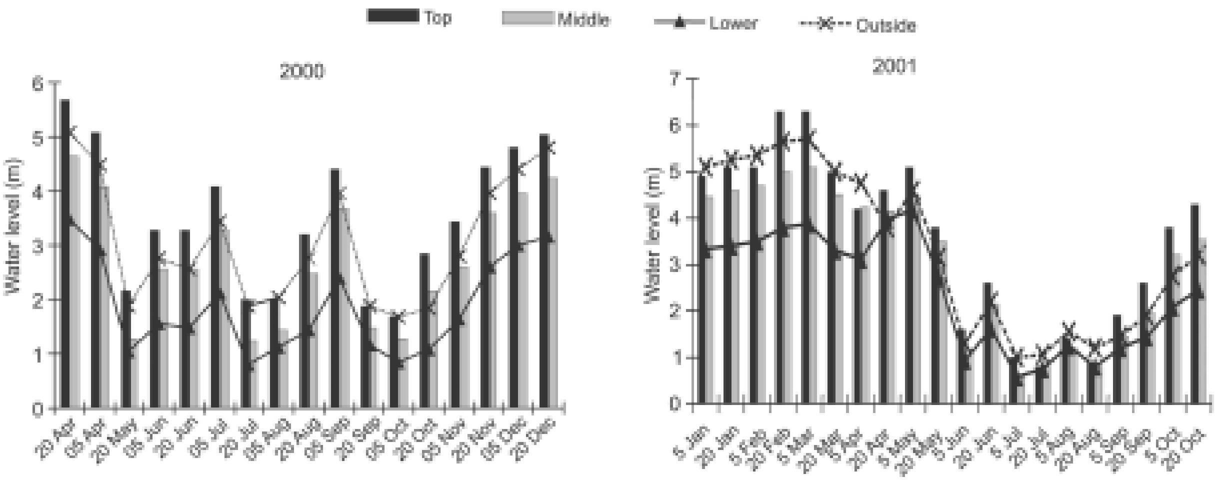

Figure 2. Groundwater level in the open wells along the toposequence in the benchmark watershed.
(Note: 0 = Ground level.)

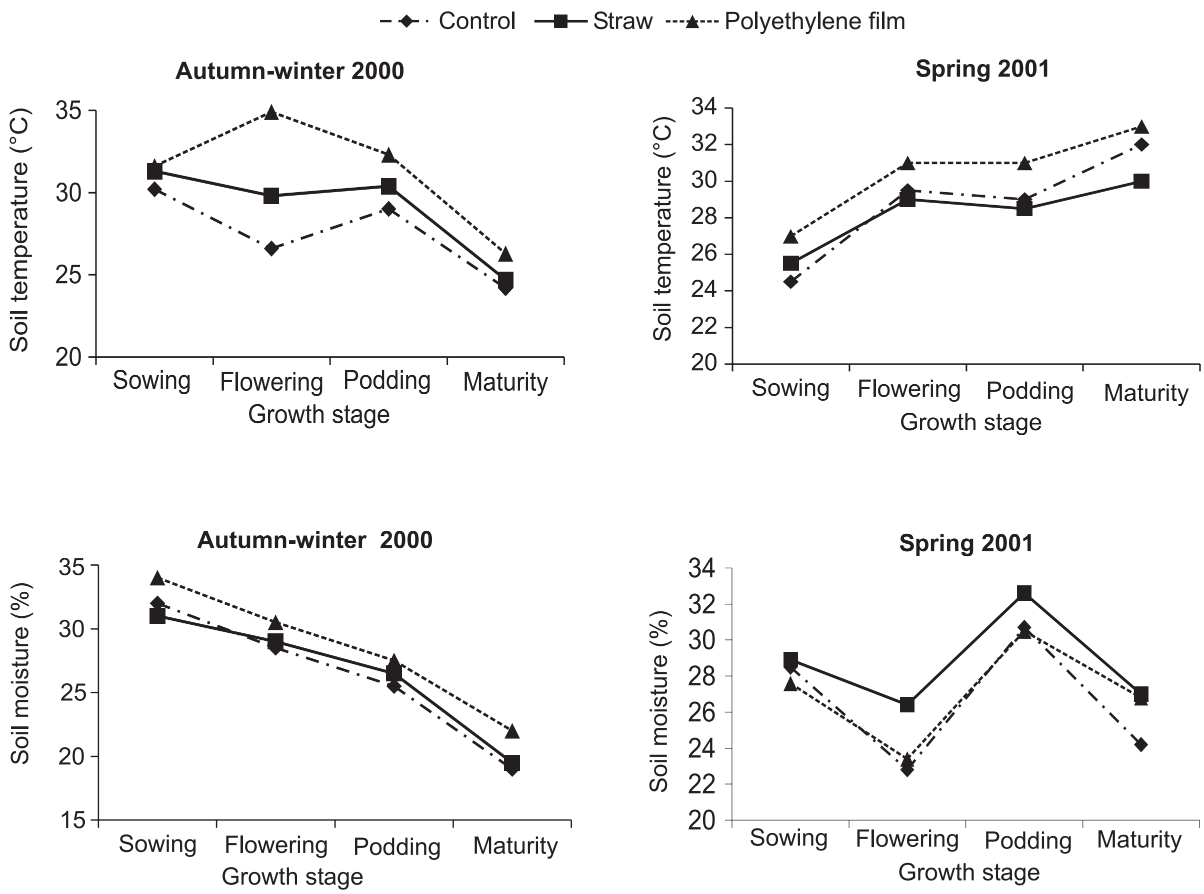

Figure 3. Changes in soil temperature and moisture in mulch and normal cultivation of groundnut.

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.

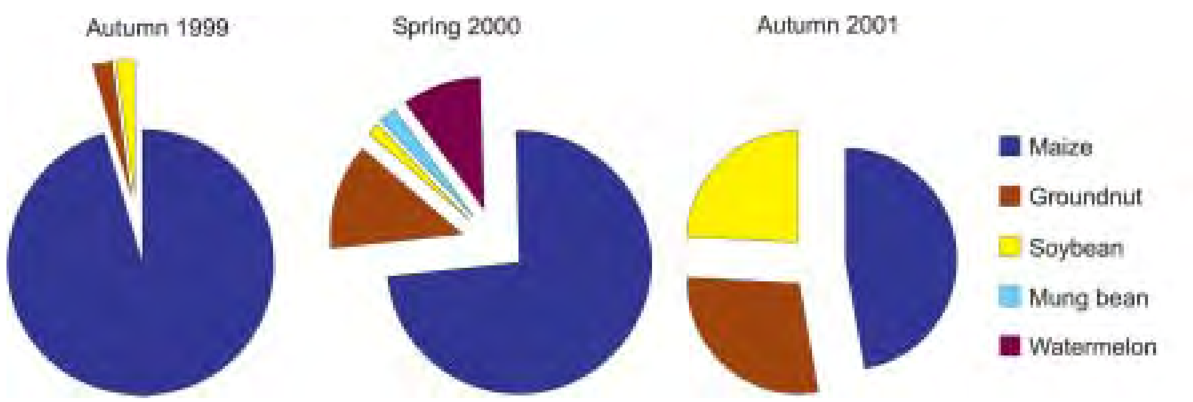

Figure 4. Proportion of land under various crops in Thanh Ha watershed.

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

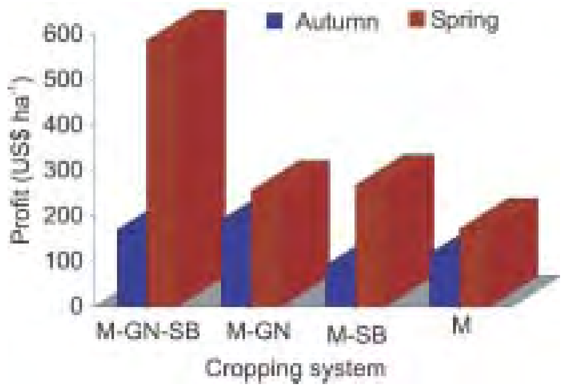

Figure 5. Influence of land use planning on household income, Thanh Ha, 2000.
(Note: M = maize, GN = groundnut, SB = soybean, and MB = mung bean.)

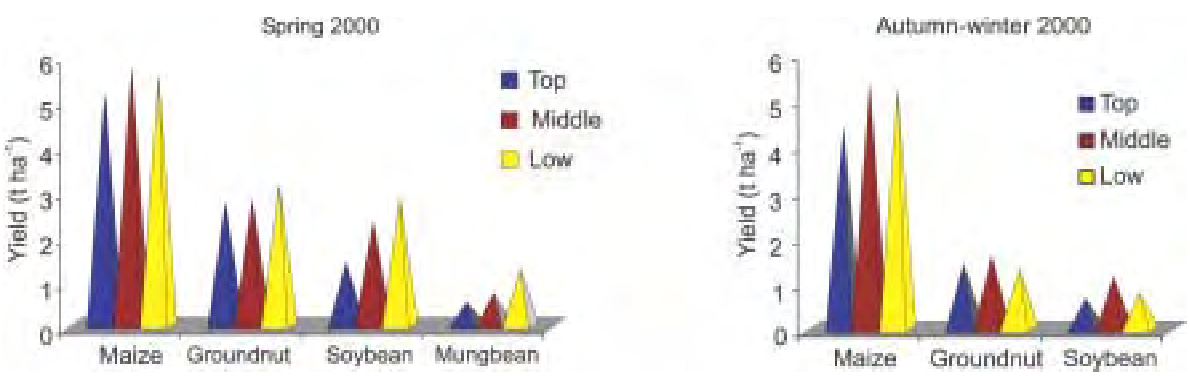

Figure 6. Influence of toposequence on crop productivity in Thanh Ha.

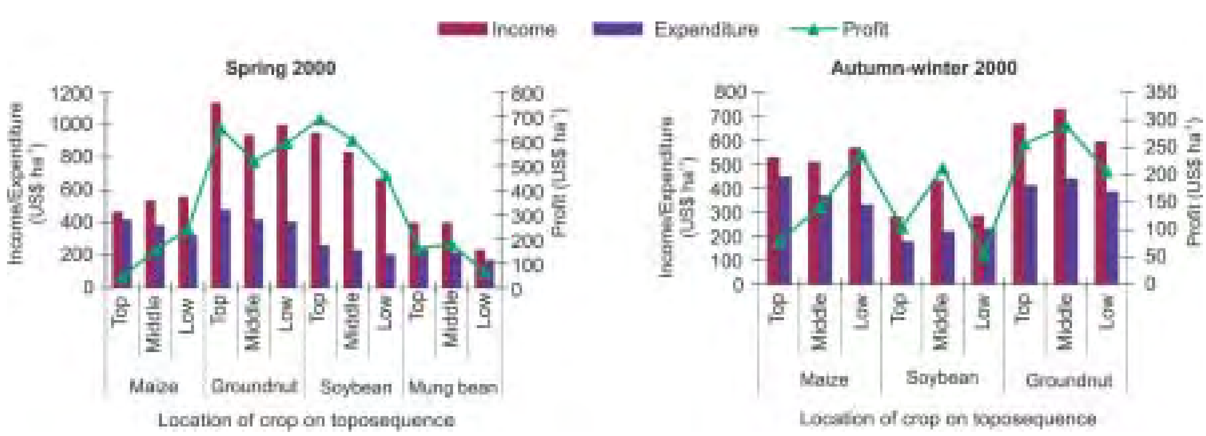

Figure 7. Influence of toposequence on crop profitability in Thanh Ha.

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.

Improving Management of Natural Resources for Sustainable Rainfed Agriculture in Northeastern Thailand

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Abstract

Lands of northeastern Thailand are sloping and fragile. A large proportion of these soils are degraded due to soil erosion. Degraded soils are one of the major constraints for agricultural production in this region. ICRISAT in collaboration with the Department of Agriculture, Land Development Department, and Khon Kaen University, Thailand started a project in 1999 with the financial support from the Asian Development Bank to improve the management of natural resources for sustainable rainfed agriculture through integrated watershed approach. This paper summarizes all the research work carried out for three years during the project period. This includes selection of benchmark site in the ecoregion, baseline surveys, establishment of monitoring devices and various interventions in cropping systems, land and water management and fertility management areas, and human resource development. The initial results of research indicate a reduction in soil erosion and improvement of crop yields due to various interventions. There is sufficient scope to scale up this work in the ecoregion. The details of various activities undertaken and the outputs are presented in the paper.

Agricultural production in northeast (NE) Thailand compared to other regions is diverse but mainly dependent on rainfed production and constrained due to moderate to low seasonal rainfall, lack of water during the dry season, undulating terrain, and poor soils. In NE Thailand only 8% area is irrigated and remaining 92% is either rainfed or partially irrigated with the water harvested from higher slopes. Besides, in most part of the northeastern region the underground water is mostly saline because of the underlying rock salt geological formations.

Soils are mostly degraded primarily due to the predominance of fragile shallow and eroded soils. The common land use practices are mainly in the form of shifting cultivation; however, farmers draw a distinction between shifting cultivation and the more common practice of “land rotation farming”. Under such a practice, land is fallowed for 3–5 years for soil fertility regeneration. With increasing population landholdings are becoming smaller and smaller resulting in intensifying crop production to fulfill the demands of food. Alongside, however, the soil erosion has also increased and serious soil degradation is taking place. Due to frequent plowing of land, bush regrowth gets reduced so that there is little vegetative cover to protect the land. Therefore, land degradation by soil erosion has lately increased, mainly due to the adoption of inappropriate new production technologies.

Significantly, more than 95% lowland paddy in NE Thailand is also grown under rainfed agriculture. The cropping systems in rainfed agriculture include maize as a cash crop on the high slopes and upland rice on the lower slopes; tree crops and fruit trees are usually

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grown close to supplementary water resources on the lower slopes. Sometimes, legumes and cereals are rotated with upland rice and maize, according to soil fertility and economic returns. Cassava is another major crop.

The Environment and Natural Resource Degradation

The basic constraints of rainfed agriculture impact several soil degradation processes individually or interactively at different levels of land use hierarchy. At the highest level of toposequential hierarchy, soil erosion from steep slopes is extremely severe because the land preparation is done along the slope by tractors. This practice substantially increases soil erosion. Forest fires, particularly during the extended dry periods, and unavailability of water during dry periods constrain establishing plantations on steep slopes. In the mid-slopes, the second level of toposequential hierarchy, some soil conservation practices can be applied to reduce soil erosion by flexible land preparation, introduction of smaller plots (<1 ha), which shorten slope lengths, and growing alternative crops. For the relatively flat undulating area, the third level of toposequential hierarchy, soil erosion is low due to the presence of trees and more care taken by farmers to conserve lands. Therefore, classification of land types is needed for matching appropriate technology options to combat soil erosion. Moreover, where the soil erosion is not severe, nutrient depletion may well be the cause of decline in productivity in low input intensified systems (Table 1). In the intensified production systems, soil acidification is taking place either in the subsoil or in the topsoil or in both. All these problems have resulted in decline in crop productivity, and have eventually restricted introduction of alternative crops. Some off-site effects are unabated soil erosion, which has led to public health problems of poor quality water, siltation of reservoirs resulting in a decline of water and fish resources, and related environmental issues. Other off-site effects of land degradation include further encroachment and clearing of forest for new fertile land by the farmers thus setting in motion a continuous cycle of decline in reserve forest resources. This is a vicious problem for sustaining natural resources in the rainfed agricultural areas.

To reduce the negative effects of conventional farming practices on the degradation of land, Thai institutions and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), with the assistance from the Asian Development Bank (ADB), had initiated a pilot rainfed agriculture project in 1999 in NE Thailand. The objectives of the project are to:

- Evaluate the degree and potential of land degradation in NE Thailand.
- Screen and identify appropriate existing technologies to control soil degradation.
- Evaluate improved conservation-effective land and water management technologies to rehabilitate degraded soils.
- Field test new technologies to sustain productivity and minimize land degradation.

Selection of Benchmark Watershed Site

In March 1999, a team of scientists from the Department of Agriculture (DOA), Land Development Department (LDD), and Khon Kaen University (KKU) in Thailand and ICRISAT identified Tad Fa watershed for on-farm benchmark research and development. The site is situated about

Table 1. Nutrient loss (t yr^{-1}) in different regions of Thailand.

Region	Nitrogen	Phosphorus	Potassium
Northern	38,288	4,467	75,588
Northeastern	18,896	1,212	91,644
Eastern	17,890	1,074	30,860
Southern	17,310	453	13,254

Source: Land Development Department.

150 km northwest of Khon Kaen. It is at a junction of three big watersheds namely Mae Khong in the northeast, Chi in the east, and Pasak in the southwest (Fig. 1). Tad Fa watershed represents the “ecoregion” covered by these three watersheds which cover 47,000, 49,480, and 15,780 km^2 respectively. Tad Fa watershed has 2,500 ha land, which is a part of “Nam Chern” sub-watershed (2,920 km^2) in the Chi watershed. The Tad Fa watershed falls in two provinces. The eastern part of river Tad Fa is in Khon Kaen Province which has nearly 700 ha while the western side is in Petchabun Province. All the research and development work was carried out in the eastern part of Tad Fa watershed called Huay Lad covering 200 ha cultivated land spread in two villages, Ban Tad Fa and Ban Dong Sakran.

Research and Development

The following research and development activities were undertaken:

- Collection and analysis of ecoregional database to identify constraints in the ecoregion and yield gap analysis to find out the scope for yield improvement in the ecoregion.
- Participatory rural appraisal (PRA) of Tad Fa (eastern part) watershed to identify and prioritize the constraints for enhanced crop production on sustainable basis while conserving the natural resources.
- Strategic research to overcome nutrient constraints as well as to quantify land degradation.
- On-farm development and evaluation of various technologies through farmer participatory approach.
- Continuous monitoring and evaluation of improved options.
- Human resource development of the national agricultural research system (NARS) researchers and farmers through various training programs, workshops, and field days.

Ecoregional Database Analysis

The report contains information on the agroecology of three main watersheds (Mae Khong, Chi, and Pasak) surrounding Tad Fa. Biophysical and

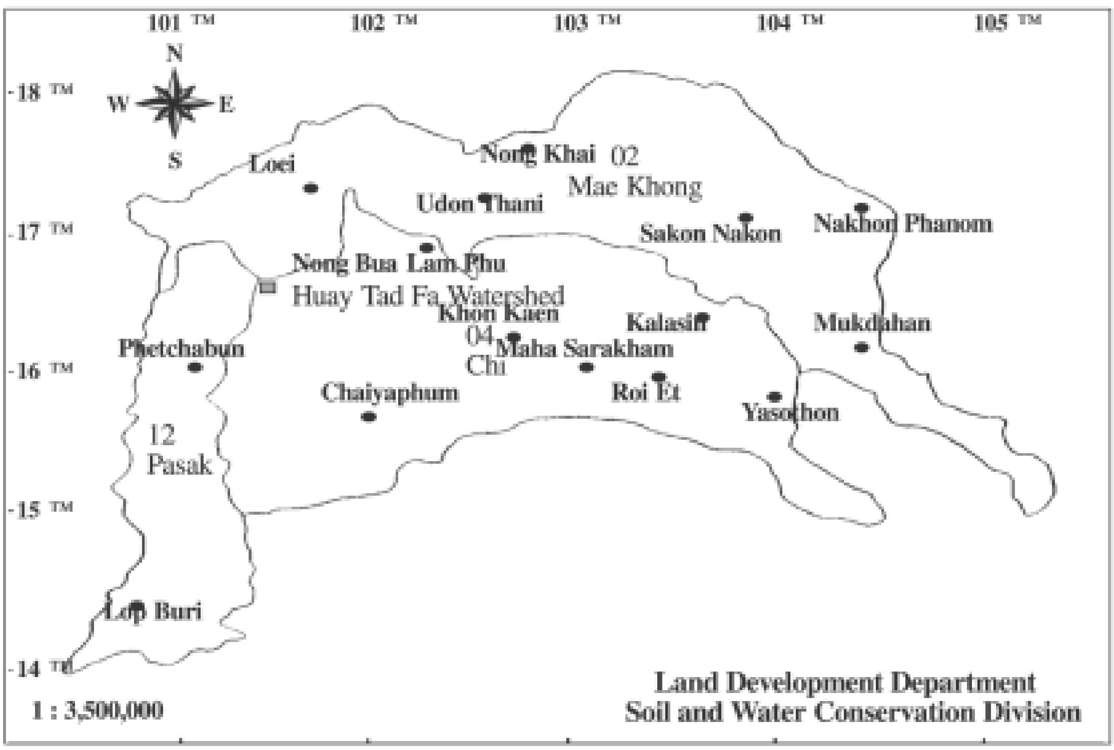

Figure 1. Tad Fa wataershed in NE Thailand.

socioeconomic data were collected from secondary sources. Tad Fa watershed is tropical (26–28ºC). The annual rainfall is 1200–1400 mm and evaporation is 1900–2000 mm. Topographically it has sloping-upland complexes; soils are mostly Ustults and the land use is mostly comprised of forestry, agroforestry, horticulture, and field crops.

Physical constraints

No rainfall in the dry season (November to March) is a major constraint. A less important constraint is the high relative humidity in the wet season (June to October) which encourages pests and diseases in dryland crops like maize.

Relief is a major constraint in hilly and mountainous terrain. The steep and uneven slopes make cultivation difficult and result in rapid runoff of rainfall, accompanied by sheet and gully erosion. Flooding of lowland is also a major constraint resulting in low yields during intensive rains.

Low soil fertility affects large areas in highlands and strongly leached soils on slightly higher terrain in lowlands. Shallow soil depth and lateritic gravel aggravate the fertility problem. Loss of applied nutrients occurs during the wet season, especially on steep slopes. Shallow soils have reduced water-holding capacity in the soil profile, limit rooting depth, and increase erosion hazard.

Technological constraints

A large number of technological innovations are available to overcome physical constraints like irrigation, drainage, flood control, systems of highland agriculture and forest conservation, application of fertilizers and pesticides, weed control, and seed supply. But these technologies should be modified as per the characteristics of the location and problem.

Institutional constraints

Since Thailand has a well developed research, training, extension, and agricultural credit system there are minor institutional constraints. However, farmers' groups or cooperatives to manage natural resources are not prevalent.

Socioeconomic constraints

Farmers are economically poor and education in the family in this region is quite low. Thai farmers are quite hard working and adaptable. Since 1975 even population growth has been checked which may result in stopping further fragmentation of land. The government has provided infrastructural support and even guarantees minimum farm-gate price for certain crops.

Yield Gap Analysis

Five major crops (rice, maize, soybean, groundnut, and sunflower) of NE Thailand were chosen for the study. Experiment station yields, representative country yields, and regional yields have been compared with the crop yields harvested by farmers in NE Thailand. The average yield of rice in NE Thailand is 1.8 t ha^{-1} compared to experiment station yield of 3.4 t ha^{-1} (Table 2). The yield gap is 1.7 t ha^{-1}; however, it is only 0.2 t ha^{-1} when compared with the country's average yield. The average yield of maize in NE Thailand is 2.5 t ha^{-1} while experimental station yield is 4.7 t ha^{-1}, and the country's average yield is

Table 2. Average crop productivity of five crops in different regions of Thailand in 1998.

	Yield (t ha^{-1})				
Region	Rice	Maize	Soybean	Groundnut	Sunflower
Northeastern	1.8	2.5	1.2	1.3	1.5
Northern	2.8	2.9	1.2	1.5	1.5
Central Plain	2.9	3.1	1.2	1.5	1.5
Southern	2.1	2.6	1.3	1.1	–
Country	2.0	2.8	2.8	1.4	1.5

2.8 t ha^{-1}. The NE region is further subdivided into highland, upland, and lowland areas. Maize yield is 1.5 t ha^{-1} in highlands, 2.4 t ha^{-1} in uplands, and 3.5 t ha^{-1} in lowlands. Even though water may not be limiting for the rainy season maize, it clearly indicates the degradation of soil in the highlands and uplands.

Participatory Rural Appraisal of Tad Fa Watershed

A PRA was conducted in 1999 in the eastern part of Tad Fa watershed, which was further divided into three parts based on three streams namely Samtada, Lad, and Wang Deun Ha. In addition to these three agricultural areas, two additonal forest watersheds were identified, one in the north and another in the south of these agricultural watershed areas. The PRA on socioeconomic aspects was conducted in all the three agricultural watershed areas. The objectives of this survey were:

- To understand the existing socioeconomic situations in Tad Fa watershed in order to plan a research program for sustaining agricultural production.
- To select a catchment which is representative of the agroecology where research and development work will be carried out.

The survey indicated that there are three regions, based on soil quality, in the watershed. The middle portion is the most fertile while the regions to the north as well as to the south are less fertile. The soil depth ranges from 0.5 m to 2 m. The soil is sandy loam at the surface and is clayey loam to loam at subsurface. There are nearly 80 farm ponds in eastern Tad Fa, of which only 4 store water throughout the dry season, while others dry in summer because of very porous subsoil and high seepage losses. Farmers have planted fruit trees only around their houses and not on steep slopes as desired (and recommended) by the government.

In Tad Fa watershed upland rice is mainly grown for home consumption. Maize is the main cash crop. Ginger has been tried since two years by few farmers but is very risky due to disease problems and price fluctuations. Soybean is not grown because of high vegetative growth and very poor grain yields. Rice (local variety) is grown only in poor soils or less fertile patches since more vegetative growth has been observed in the fertile lands. A very small amount of urea is mixed with the rice seeds at sowing. Only maize and ginger crops are fertilized. Rice is planted in June and harvested in October. About 2.5 to 3.0 t ha^{-1} grain yield is obtained. Often, maize is grown twice a year depending on the onset of monsoon. The first crop is grown during March to July and second crop during July to November. Farmers apply about 150 kg ha^{-1} of NPK (15:15:15) fertilizer and harvest 3 to 3.5 t ha^{-1} of grain yield. Ginger is grown in March/April to December. A heavy dose of NPK fertilizer at 600 kg ha^{-1} is applied.

Farmers have identified the following constraints: land tenure, lack of capital, lack of water resources, costly agricultural inputs, price fluctuation, lack of government support, lack of transport facilities, soil erosion, forest fires, and labor shortage. Since these are displaced farmers, they do not have much capital to invest. But highest priority is given to children education. There is only one primary school in the village and children have to go to other villages for high school education. Second priority is given for housing. As most of the farmers have poor temporary houses, they wish to build new houses.

Farmers give third priority for agriculture. Fortunately, the land is reasonably fertile. Rice is grown as a subsistence crop without much fertilizer application. Maize, which is grown as a cash crop is fertilized. However, farmers have to invest a sizeable capital on labor because household labor is scarce; all operations like land preparation, seeding, weeding, and harvesting are given on contract to service providers. Few farmers have tried the risky ginger crop with huge investment and most of them have suffered heavy losses.

Overcoming Nutrient Constraint

Most of the farmers apply chemical fertilizers to their cash crops to harvest good yields. Chemical fertilizers are one of the costliest inputs and there was a need to search other alternatives or supplement sources to overcome nutrient constraints. There is not much scope to use farmyard manure 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 nitrogen (N) fertilizer. Legumes were evaluated to quantify 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.

Based on the N difference method N_2 fixation varied from 20 to 104 kg N ha^{-1} and net N benefit to the succeeding crop was estimated at 2 to 51 kg ha^{-1}. Following legumes, a maize crop was grown with 40 kg N ha^{-1} along with the organic matter from the legume residues. Grain yield of succeeding maize crop was significantly ($P \leq 0.05$) higher by 27 to 34% in treatments following black gram, rice bean, and sunnhemp over the yield of maize crop (Table 3). Although N_2 fixation was highest in sword bean (104 kg N ha^{-1}) the benefits were not translated in terms of increased maize yields. 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, sword bean could play an important role for sustaining land productivity.

Growing black gram, rice bean, and sunnheamp in the system would help in reducing N requirement for the succeeding maize crop. 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 biological nitrogen fixation (BNF) and soil N sparing effect over a maize crop varied from 15 to 64 kg N ha^{-1} (Table 4). These results revealed that for quick benefits for succeeding maize crop farmers would be benefited by growing legumes such as rice bean, sunnhemp, and black gram.

Table 3. Dry matter (kg ha^{-1}) of maize grown after five different crops at Ban Koke Mon in the rainy season 2000.

Treatment	Stover	Cob	Seed[1]	Total
Rice bean	7069	816	4541 a	12425
Sunnhemp	6634	786	4720 a	12141
Sword bean	6689	659	3642 b	10991
Black gram	6786	875	4488 a	12149
Maize[2]	5560	697	3525 b	9781
F test	NS[3]	NS	*	NS
CV (%)	14.57	14.41	13.36	13.13

1. Figures followed by the same letter do not differ significantly at $P \leq 0.05$; * = Significant at $P < 0.05$.
2. The maize crop received nitrogen (N) from legume crop residue plus 40 kg N ha^{-1} in the form of chemical fertilizer.
3. NS = Not significant.

Table 4. Nitrogen benefit realized from legumes in maize-based systems.

Crop	N fixed by legume (kg ha^{-1})	Net N benefit expected[1] (kg ha^{-1})	Total N uptake by succeeding maize (kg ha^{-1})	N benefit realized from legume over maize[2] (kg ha^{-1})	Expected benefit from BNF + N saving benefit (kg ha^{-1})
Rice bean	20	2	75.9	19.1	15
Sunnhemp	90	31	76.1	19.3	44
Sword bean	104	51	62.1	5.3	64
Black gram	27	8	68.9	12.1	21
Maize	-	–13	56.8	-	-

1. N_2 fixed – Seed N.
2. Total N uptake by succeeding maize – Total N uptake by maize grown after maize.

Table 5. Maize grain yield (t ha^{-1}) across toposequence in NE Thailand during 1999 to 2001[1].

Toposequence	1999	2000	2001
Steep (>15%)	3.1 (3)	4.5 (4)	2.1
Moderate (5–15%)	3.6 (6)	4.8 (5)	2.9
Mild (2–5%)	4.1 (2)	5.3 (4)	3.4

1. Figures in parentheses refer to the number of farmer fields at each slope.

Quantification of Land Degradation

In NE Thailand, types of land degradation (e.g., biological and chemical) are not fully studied. To study the effect of land degradation on crop productivity, sites in the toposequence were identified and crop yields were monitored during 1999, 2000, and 2001 (Table 5). Soil samples at these spots up to 110 cm depth were collected and analyzed for physical, chemical, and biological properties (Table 6). The maize grain yield data clearly indicated the loss of productivity on steep slopes and on moderate slopes when compared to mild slopes. The clay and organic matter content at these spots indicated that precious clay and organic matter have been eroded from the steep slopes. Most of these changes have occurred in the topsoil layers which are very important for crop production. A new methodology to quantify land degradation called Soil Fingerprint method is being used.

Fingerprint technique (FPT) is an approach for monitoring land degradation as it impacts soil quality. FPT primarily utilizes characteristics of landform and some soil physical properties as a basic guideline for comparable paired sites. Usually the comparison is based on pairing of the virtually similar location with different land use system, namely forest as control (less disturbed) site and agriculture plot as degraded site. Thereafter, further soil chemical analysis is done to identify soil profile similarities and depths of undisturbed horizon using both general soil chemical properties and soil charge fingerprinting characteristics of each horizon. Once the profiles are considered comparable, the discrepancies in soil depth and physical properties of comparable profiles were considered as soil loss through erosion and soil physical degradation, respectively. FPT-based information could be used as a good first approximation to estimate loss of soil organic matter, clay, mineral bases, and soil fertility under different land uses. These soil parameters are important for the evaluation of soil and land degradation, which is a major constraint to the sustainability of agriculture in the tropics.

The watershed was surveyed to identify suitable sites for soil degradation study using FPT. From the landscape layout, it was found that at least 7 sites were considered physically suitable. Land use history was further investigated using a rapid rural appraisal (RRA) technique. From the 7 sites, only 5 transects were found suitable. These transects were used as the final study sites. Soil physical analysis was completed for all samples. In general, the charge fingerprints indicated that soils under 30 cm depth have similar charge fingerprinting.

On-farm Development and Evaluation of Various Technologies through Farmer Participatory Approach

Out of 700 ha of land in the eastern part of Tad Fa, we selected the middle portion of the watershed called Huay Lad, which had about 200 ha of land under cultivation; also the two villages, Ban Tad Fa and Ban Dong Sakran, were located in this area. Most of the farmers from Ban Tad Fa village had land in the northern Huay Samtada.

We concentrated in the Huay Lad area (Dong Sakran village) for research and development work. There were 49 farm ponds in the Huay Lad. We identified two micro-watersheds for our research. One micro-watershed was "traditional", which had moderate slope and nearly 70% land had fruit trees and in the remaining area other annual crops like maize and upland rice were grown. The other micro-watershed had moderate as well as steep lands and mostly annual crops like maize and upland rice were grown. All the interventions were carried out in this micro-watershed. In almost 80% of this micro-watershed, "hillside ditches" were dug for soil conservation on contour. Vetiver and maize were planted along the side of "hillside ditches". It was suggested that all farmers should plant crops like maize along the contour instead of usual up and down the slope. One automatic runoff and sediment sampling system was installed at the lowest point of each micro-watershed to

Table 6. Biological and chemical properties of soil samples from toposequence in Ban Tad Fa watershed in NE Thailand.

Topsequence	0–10[1]	10–20	20–30	30–50	50–70	70–90	90–110
Organic C (g kg^{-1} soil)							
Top	28	27	26	14	13	9	7
Middle	31	29	26	18	12	10	10
Lower	40	34	29	20	35	20	19
LSD = 1.15							
Total N (mg kg^{-1} soil)							
Top	2073	2085	1956	1755	1324	1249	1092
Middle	1967	1771	1785	1376	1178	1352	1012
Lower	2336	2287	1971	1563	2345	1630	1462
LSD = 621.2							
Net "N" mineralization (mg kg^{-1} soil 10d^{-1})							
Top	11.89	10.03	6.80	5.52	2.30	1.97	1.47
Middle	14.22	11.16	8.93	6.07	3.84	3.75	3.04
Lower	15.11	14.49	12.72	9.04	5.73	4.53	4.70
LSD = 6.034							
Biomass C (mg kg^{-1} soil)							
Top	366	304	275	258	178	149	133
Middle	362	300	240	206	173	124	100
Lower	384	328	276	213	128	145	112
LSD = 86.3							
Clay content (g kg^{-1} soil)							
Top	330	350	380	330	330	0	0
Middle	390	380	430	420	370	230	0
Lower	450	450	450	490	550	550	590
LSD = 2.4							
Fine sand (g kg^{-1} soil)							
Top	90	70	70	180	140	0	0
Middle	80	80	80	130	120	160	0
Lower	60	60	60	70	60	60	40
LSD = 1.6							
Gravel (g kg^{-1} soil)							
Top	190	150	130	100	140	0	0
Middle	130	120	100	80	250	150	0
Lower	140	140	130	110	120	100	90
LSD = 1.9							

1. Soil depth in cm.

monitor runoff and soil loss. The area of the traditional micro-watershed was 17.8 ha with 4 farmers while that of the improved micro-watershed was 12 ha with 5 farmers. Two farmers had land in both micro-watersheds. An automatic weather station was installed near the research area to monitor rainfall, temperature, sunshine, humidity, wind velocity, and soil temperature on a continuous basis at fixed intervals of time.

Soil survey of the entire Huay Lad agricultural land was done and detailed soil map and land use map was prepared. Majority of the soil was silty clay loam with a very small fraction of clay loam. Almost all the clay loam had 2–5 and 5–12% slope while a small proportion of silty clay loam had 2–5% slope and the rest had 5–12, 12–20, and even 20–35% slope. There were 13 distinct soil series and their variants in Huay Lad.

Detailed baseline survey of all the 10 households involved in the micro-watershed was done. This will be used to measure the impact of interventions. The survey covered size of family, age, education, source of income, size of landholding, land use, crops grown, agricultural implements, animals reared, and financial status of farmers. Even though all farmers recognized soil erosion as a cause for land degradation none of them have seriously followed any measures to check soil erosion. Since the history of cultivation of these lands is only about 80 years, the soils are still rich in organic matter and support reasonable crop production. But farmers apply chemical fertilizer to their maize crop, which is a major cash crop and is grown on moderate and steep slopes. Upland rice is mostly grown on mild slopes without much fertilizers since these soils are not eroded. Even though planting of fruit trees and other trees on steep slopes is recommended, farmers have planted fruit trees on mild slopes where they have some water sources to irrigate these trees during dry periods of establishment. The results of on-farm research are given below:

- Comparison of groundnut yields grown in the two rainy seasons:

  Early season (first crop) gave higher yield of fresh pods (3.7 t ha^{-1}) when compared to second season yield of 2.5 t ha^{-1}. These low yields in both the seasons may be due to phosphorus (P) deficiency in the soil.
- Evaluation of the performance of soybean in the benchmark watershed area:

  Five soybean varieties were grown. The grain yields were low ranging from 510 to 875 kg ha^{-1}. In Thailand yields less than 1.2 t ha^{-1} are considered uneconomic. The experimental fields had less than 5 ppm of P as against the threshold level of 15 ppm. Thus the performance of soybean was poor perhaps due to acute P deficiency. Weed competition was also severe, as farmers do not adequately weed the crop. At present soybean crop does not hold promise in Tad Fa watershed.
- Productivity of upland rice at two toposequential slopes:

  Rice is a popular crop among all farmers and is grown in the lower part of the toposequence. Often farmers grow only traditional varieties and mainly for home consumption on 0.5 to 1.0 ha of land. Nearly 75% of farmers grow "Lao Taek". Mild slope (2–5%) and very mild slope (<2%) did not affect the rice yield significantly; the mild slope produced 3.5 t ha^{-1} when compared to 3.4 t ha^{-1} in very mild slope area.
- Evaluation of the productivity of relay cropped rice bean at different sites in the toposequence: Rice bean is a popular legume crop grown in sloping land ecologies of NE Thailand. In about 40% of the maize growing area rice bean is relay planted. It is sown in the standing crop of maize at the flowering time. Since it is sown without any land preparation (unlike sequential planting) relay planting is a soil conservation efficient system. In steeper slope (>15%), the yield (970 kg ha^{-1}) is 25–30% less compared to moderate slope (5–15%) (1270 kg ha^{-1}) or mild slope (2–5%) (1360 kg ha^{-1}). Poor soil as well as less amount of soil moisture may be responsible for low yields at steep slopes. This system has to be popularized with most of the maize farmers who sometimes try a second crop of maize, which suffers due to terminal drought or sometimes they are not able to plant the second crop due to late onset of monsoon and late planting of first maize crop.
- Response of maize to fertilizer at upper and lower slope of toposequence:

  Most farmers apply fertilizers at 150 kg ha^{-1} of NPK (16-20-0). To see the maize performance without fertilizers at the upper and lower portion of toposequence, a small trial was carried out in different farmers' fields. At the upper site maize produced 2.6 t ha^{-1} and at the lower site it produced 4.1 t ha^{-1} of grain without application of any fertilizer while the yields were 4.1 and 6.7 t ha^{-1} respectively with fertilizer. This again reveals the degradation of soil at the upper end of toposequence and indicates that in terms of economic losses land degradation has resulted equivalent to 2 t of maize grains ha^{-1} yr^{-1}. Such differences are variable in some years.
- Minimum tillage and contour cultivation:

  In order to reduce tillage on steep slopes which may trigger enhanced soil erosion, hand dibbling was tried on steep slopes and tractor planting on contour on moderate and mild slopes. Minimum tillage was as effective as tractor planting. Grain yield of maize was 4.1 t ha^{-1} on steep slope, 4.5 kg ha^{-1} on moderate slope, and 4.9 kg ha^{-1} on mild slope.

- Maize relay cropping with legumes:
  Rice bean was relay cropped with maize on two slopes. On moderate slope, yield was 980 kg ha^{-1} while on mild slopes 1060 kg ha^{-1} was recorded. This small increase on mild slopes may be due to higher moisture retention at lower ends. In another trial a new legume crop, black gram, was grown as relay crop with maize. Compared to rice bean it produced only 290 kg ha^{-1} while the former gave 810 kg ha^{-1}. Black gram was shaded by maize and also was severely suppressed by weeds. Many pests attacked the foliage as well as the pods. Black gram may not be suitable as relay crop with maize.
- Fruit tree planting and intercropping:
  Our continued efforts resulted in planting of 625 fruit tree seedlings of longan, litchi, and mango in 4 ha in the watershed. Few farmers grew maize as an intercrop between the fruit trees providing shade for trees as well as helped in suppressing fast-growing *Mimosa* weeds. Farmers harvested maize grains providing direct income until the trees started producing fruits. In this process farmers need not suffer for a few years till the trees start bearing fruits. But some technologies should be improved to reduce competition to fruit trees by maize and *Mimosa*.
- Community-based banana dryer:
  The farmers of Tad Fa get very low returns for their banana crop. The scientists of DOA analyzed this problem and came up with a practical solution of value addition to their product and also to increase the shelf life by drying the ripe banana and then selling. This is possible in summer months. In rainy season they cannot do it efficiently and the product may get spoiled. To overcome this problem, with the help of KKU engineers they developed solar dryers as there is no electricity in the village. On a trial basis DOA plans to install community-based solar dryers with a very nominal charge for maintenance. If this intervention succeeds, then the farmers will not only get additional income but also the funds generated for the community will help to buy additional dryers.
- Minimum tillage cultivation for maize:
  As mentioned earlier, farmers plow the land deep with hired tractors. Due to our persuasion a few farmers followed minimum cultivation. The grain yield of maize cultivar CD-DK 888 was 4020 kg ha^{-1} while that of Suwan 1 was 2100 kg ha^{-1}. These yields are fairly good. Also, the cost of cultivation was less and minimum tillage prevents soil erosion from the sloping lands.
- Sequential cropping of groundnut:
  Groundnut was planted in July as a sequential crop after maize. The variety Khon Kaen 5 produced 4980 kg ha^{-1} fresh pods while Native (red seed) produced 4540 kg ha^{-1} fresh pods.

Human Resources Development

The following activities were undertaken during the project period to develop human resources of partner NARS:

- A training course on database management system for sustainable rainfed agriculture was held at ICRISAT, Patancheru, India from 15 November to 3 December 1999. One Thai researcher attended the training.
- A traveling workshop was organized from 27 August to 12 September 2000. Two Thai researchers participated and traveled to all the project sites in India, Thailand, and Vietnam.
- A training workshop on “Impacts of Variability of Natural Resources on the Performance of Community Scale Watershed” was held from 16 to 29 November 2000 at ICRISAT and two Thai researchers participated.
- A training workshop on “On-farm Participatory Research Methodology” was held at Khon Kaen from 26 to 31 July 2001. Two scientists, each from DOA and LDD, attended this workshop.
- A training program on “Farmer Participatory Research” was conducted by the faculty of KKU for the staff of DOA and LDD involved in the Tad Fa watershed. This training was held in two sessions. The first one was held at Nam Nao from 10 to 12 May 2001 and a total of 18 staff from DOA and LDD attended. The second one was held from 18 to 20 October 2001 at ChumPhe and 22 members attended.

Lessons Learned and Future Strategy

- Land degradation in general and soil erosion in particular has been perceived as a major constraint for sustainable agricultural production in the study area not only by the agricultural scientists but also by the farmers.
- Since the cultivation history is only about 80 years, the soils are reasonably productive at present but poor productivity has been noticed both on steep and moderate slopes of the toposequence. Farmers apply fertilizers to cash crops on these sites.
- Land degradation in the watershed on a toposequense is evident and clearly demonstrated by the varying yields of maize from 300 to 3000 kg ha^{-1} during different cropping seasons depending on rainfall. Farmers recognize these effects and are ready to work along with scientists to develop measures for soil and water conservation.
- Farmers have recognized water conservation as an important aspect and are willing to contribute resources (cash and in kind) for undertaking rainwater harvesting structures.
- Due to lack of capital as well as the fear of evacuation as they do not have permanent tenure, farmers had not taken up major soil and water conservation and management practices.
- Since the government has recognized the settlement as villages in 1998 the farmers are optimistic of ownership of their lands and started heeding the advice of scientists and policy makers to plant more fruit trees in the agricultural land. Looking at the response of the farmers since two years we are hopeful that fruit tree planting will cover a large area in the near future, which not only will reduce soil erosion but also will improve the economic status of the farmers in a sustainable way.
- Since the underground parent material is very porous, almost all the dug tanks do not hold water for summer. We may have to look either for improvement of these structures or for possibilities of using groundwater and sharing the same for the drier months by the community.
- There is a need to evaluate the soil conservation practices like hillside ditches, vetiver planting, and contour planting of crops.
- The annual cash crops are very much influenced by markets. Crops like ginger and pineapple have disappeared from this area. Maize crop was being cultivated as a cash crop for a long-time on steep and moderate slopes. Since one year the prices of maize are falling down. Many farmers have started growing vegetables as cash crops. We believe fruit trees will stabilize the situation in the future.
- Finally, this watershed approach with more focus on soil conservation and rainwater harvest should be extended to other areas in the ecoregion with emphasis on both community as well as individual farmers.

Acknowledgments

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Improving Management of Natural Resources for Sustainable Rainfed Agriculture in Ringnodia Micro-watershed

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Abstract

The current productivity of rainfed lands in Madhya Pradesh, India is about 1.0 t ha^{-1} although there is scope to obtain >3 t ha^{-1}. To assess and evaluate the potential of improved soil, water, and nutrient management options through integrated watershed management at Ringnodia in Indore in western Madhya Pradesh, a micro-watershed of 390 ha was delineated. Soybean is a major crop during the rainy season and yield of <1 t ha^{-1} is obtained in the micro-watershed. Landholdings in the watershed are generally small. The input use is low with little soil and water conservation measures in vogue among farmers. About 30–40% of the total rainfall is lost through runoff, carrying productive soils and nutrients while crops experienced drought stress in the rainy as well as postrainy seasons. With a critical advisory support from scientists, the watershed farmers could augment water storage capacity in the village through construction of percolation/storage tanks and renovation of existing ponds. For safe disposal of water from the watershed, waterways were developed and wire mesh bound boulder structures were constructed to reduce soil loss and runoff. These water storage structures could store up to 30 ha-m water representing about 70% of total runoff from 100 ha cultivated area and thus reduce runoff and soil losses. This increased groundwater recharge, which manifested in increased water table in most wells including the abandoned ones.

The scenario analysis suggested various cropping options for enhanced yield with limited irrigation (soybean-wheat) or under rainfed conditions (pigeonpea/sorghum intercrop). Sorghum/pigeonpea intercrop was, however, less popular amongst the farmers. The introduction of extra-short-duration pigeonpea opened avenues for diversification and its adoption is likely to increase. Under rainfed conditions, double cropping could be practiced in two out of three postrainy seasons. Soybean yields increased marginally by gypsum application and also by planting on mini-ridges. The medium-duration chickpea cultivar JG 218 gave higher yield than short-duration cultivars ICCV 2 and ICCC 37 indicating sufficient moisture for the traditional types. Pests were the major yield reducers in soybean and adoption of integrated pest management options nearly tripled soybean yield.

In another micro-watershed at the College of Agriculture, Indore interaction between land and water conservation measures and efficient cropping systems was examined. Soybean/pigeonpea strip crop and soybean-wheat systems were more productive than soybean-chickpea and soybean-linseed systems. Chickpea and wheat could easily be established with minimum tillage when planted in moist seed zone at 15 cm depth after the harvest of soybean.

The state of Madhya Pradesh comprises about 14% of the total rainfed area of India. Soybean-based production systems dominate the agricultural scenario and have appreciably improved the economic status of farmers of rainfed areas of the state. Soybean is grown in about 4 million ha representing 75% of total soybean area in India. It fits well in the double cropping pattern with wheat and

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other rainfed crops. The introduction of soybean in the state in the 1970s has substantially minimized the incidence of rainy season-fallows and thus directly contributed to sustainability of rainfed agriculture. Since 1987, when the soybean variety JS 335 was released by Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Indore, Madhya Pradesh and improved production technology was available, soybean area increased fourfold and production fivefold. Soybean has greater tolerance to waterlogging than most other crops including cereals grown earlier in the region, which perhaps is the single most important reason for its widespread and rapid adoption.

Although the production of soybean is increasing due to substantial increases in area under the crop and its yield, there is still a large yield gap of about 1.2 t ha^{-1} that needs to be bridged (Singh et al. 2001). Soybean area in India is likely to increase to 10 million ha by 2010, a larger portion of which would be in Madhya Pradesh. With intensification of soybean production systems, about 20 million t of soybean can be produced. Unfortunately, at the current level of productivity, there is appreciable underutilization of land, water, nutrients, and climatic resources. Well-documented congruent relational data sets are needed on water balances, nutrient turnover, weather and crop development interaction, and seed viability to first understand and to tackle the problems associated with the low productivity and unsustainability. There are a number of socioeconomic and technological constraints that are responsible for low yields of soybean, resolution of which in integrated fashion can help in bridging the gap between the realizable and realized yields. This is possible through a holistic management of natural resources of soil, water, biotic, abiotic, and socioeconomic constraints.

The research partnership between JNKVV and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India primarily focused on enhancing productivity of the soybean-based production systems. It also covered other aspects of enhancing farm productivity and sustainability such as diversification and crop intensification. The partners identified two benchmark watershed sites, one at Ringnodia village in Sanwer Tahsil of Indore district for on-farm strategic and applied research, and another at the College of Agriculture, Indore for conducting on-station strategic research.

Ringnodia Micro-watershed

Characterization

Site selection

Ringnodia, a 390-ha micro-watershed, is a part of the National Watershed Development Project for Rainfed Areas (NWDPRA), Solsinda, located at 20 km from Indore city (22°51’ N and 75°51’ E) on Indore-Ujjain highway at an altitude of about 540 m above mean sea level (Fig. 1). The watershed is located in the middle and lower reaches of Khan River. The topography of the Ringnodia micro-watershed can be divided into three sections: a recharge zone of 18.2 ha with a slope of 8% or more, a transition zone with slope of 2–8%, and a cultivated area of 327 ha with a slope of 2% or less, comprising medium to deep Vertisols.

This watershed was selected because the cropping intensity was very low (<130%), the rainy season crop yield was low (<1 t ha^{-1}), and irrigated area was <30% (mainly through tube wells and open wells). Due to lack of soil and water conservation measures most of the runoff water eroded the valuable productive lands. The watershed had two ponds that were in dilapidated state and stored very little water due to silting and heavily breached bunds. While lack of water conservation and soil erosion due to high velocity runoff in the transition zone was a major problem in the upper reaches of the watershed, waterlogging was common in the lower reaches of the watershed. A few main watercourses had developed from the several field washes that carried the runoff water towards the lower reaches, forming deep gullies. In the postrainy season, crops were grown on <30% area and generally suffered from drought.

Weather

The mean annual rainfall at Indore is about 960 mm, a major portion of which is received between 25 and 41 standard meteorological week (SMW) (Fig. 2). The rate of evaporation (mm day^{-1}) increases steadily from the 2nd SMW and attains a peak during the 21st SMW,

Figure 1. Location map of Ringnodia micro-watershed in Indore district of Madhya Pradesh, India.

and thereafter, shows a steep decline up to 29th SMW, and a gradual decline up to 37th SMW. The rainfall and evaporation patterns showed that the period between 26th and 37th SMW is surplus water period. Sowing during the rainy season is usually taken up from the 23rd SMW.

At Ringnodia, rainfall was near normal in 1999 whereas it was 44% less in 2000 and 28% less in 2001 (Fig. 3). In 2000, the beginning of the rainy season was considerably delayed and there were very little rains after 15 August; hence, the postrainy season crops could be grown in <10% area only. The beginning of the rainy season was normal in 2001. Further, about 70 mm rainfall in October, after the harvest of soybean, helped in sowing the postrainy season crops.

Soils

The soils of the Ringnodia micro-watershed are shallow to deep black with variable depth (~0.5 to >0.9 m depth). They occur on bare hill slopes to flat topography. The cultivated soils are mostly clay loam in texture with high moisture retention capacity, normal to somewhat alkaline in reaction (soil pH 7.5–9.3), and electrical conductivity (EC) values <1.00 dS m^{-1} at 25°C for most soils indicating normal soils. The soils in general were low to medium in soil fertility status with respect to available nitrogen (N), phosphorus (P), and sulfur (S), while they were high in potassium (K) content.

The deep soils (>0.9 m) hold about 225 mm plant available water to a meter depth. The soils of watershed are classified into six soil series:

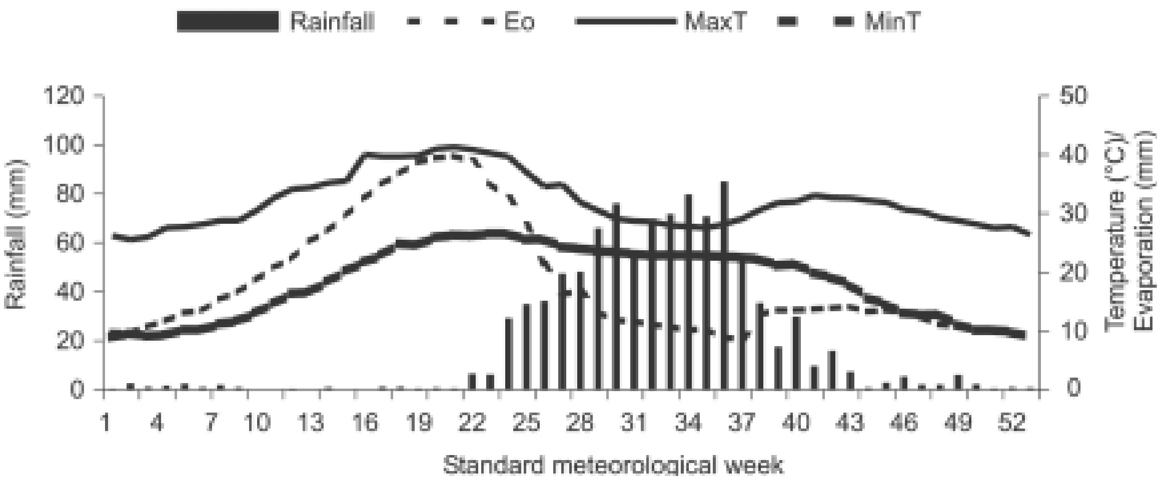

Figure 2. Weather at Indore during 1971–95.

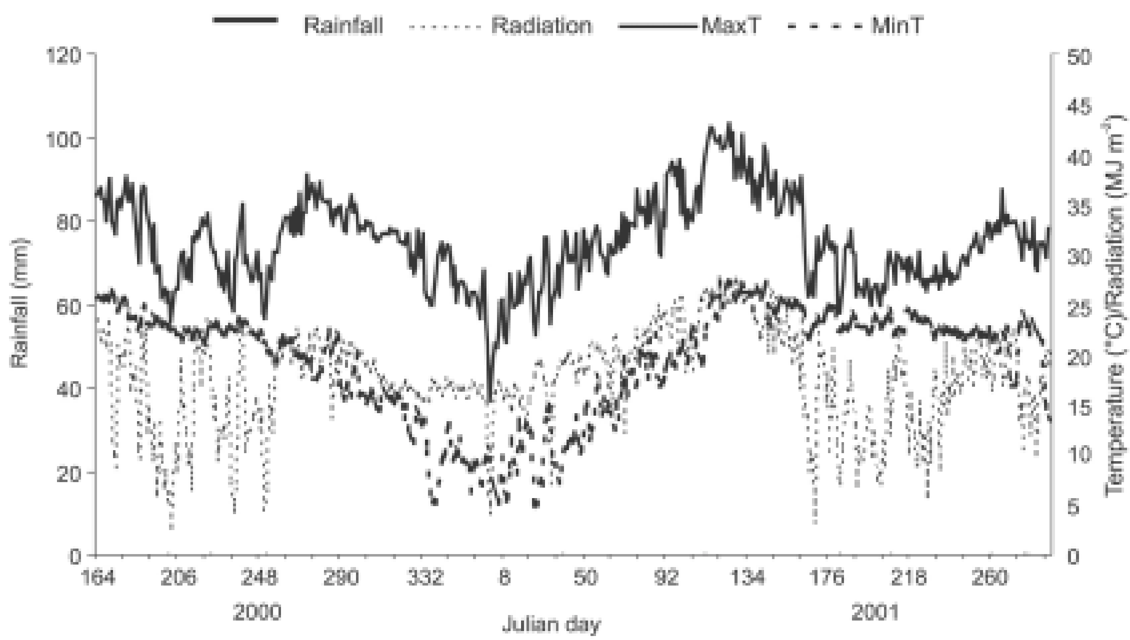

Figure 3. Daily weather during 2000–01 at Ringnodia micro-watershed recorded through automatic weather station.

Panchdaria, Runija, Kamliakheri, Sarol, Baloda, and Malikheri. The deep black soils belong to Sarol and Baloda series, which comprise members of fine montmorillonitic hyperthermic family of Vertic Ustochrepts and Pellusterts, respectively. The shallow soils belong to fine clayey montmorillonitic hyperthermic family of Lithic Ustochrepts.

Land use pattern

Soybean or soybean mixed with a small population of maize was the dominant cropping system during the rainy season. There was very little rainy season fallow. This is in contrast to Lalatora watershed in Vidisha district of Madhya Pradesh, where soybean was generally grown only on irrigable lands as prospects of an irrigated postrainy season crop were assured (Vadivelu et al. 2001). However, unlike the previous rainy seasons, in 2001 there was considerable diversification with other crops such as sorghum, groundnut, pigeonpea (ICPL 88039, JA 4, and local), vegetables, sole maize, and green fodder crops. There was a noticable increase in sorghum area which was attributable to shortage of cereal grain for domestic consumption as most farmers could not take wheat crop in the preceding postrainy season. This is how farmers seem to adjust their cropping patterns to drought conditions in the region.

The rains during September/October have a strong bearing on the prospects of postrainy season crops. In 2000, there was scanty rainfall (<12 mm) in September/October and hence the area under the postrainy season crops was drastically reduced. Some farmers whose tube wells had water managed to establish chickpea and wheat crops. In 1999 and 2001, there were good rains during September and October, which facilitated planting of wheat and chickpea as well as potato in some areas.

Socioeconomic profile

The village has a total population of 855 persons, which includes 435 males, 420 females (466 adults and 389 children). Literacy is about 40%. Agriculture provides the major source of income for 56% of the villagers. They also depend on livestock and poultry, and work in the nearby industries. The landholding in the village varies from >4 ha for the large landholders constituting about 9% of the total farmers, 2 to 4 ha for medium landholders (26%), and <2 ha for small landholders (65%).

The gross annual family income from all sources was US$4000 for the large landholders, US$3200 for the medium landholders, and less than US$2800 for the small landholders. The medium and small landholders also depended on other sources of income such as working as farm labor. There were 14 tractors, 14 cultivators, 10 disc harrows, 7 seed drills, 10 potato planters, 50 sprayers, and 50 threshers in the village. Livestock was maintained by all categories of farmers. There were 143 buffaloes, 59 cows, 92 oxen, and 60 goats in the village. The large landholders spent about 32% of income on agricultural inputs and management of crops, whereas medium and small landholders spent only about 10%. The village had 14 open wells and 19 tube wells, and two silted ponds (prior to our intervention) spread in about 9 ha area.

Major constraints identified through participatory rural appraisal

Through a participatory rural appraisal (PRA) the following constraints were identified:

- Poor resource base (poor soil fertility) and lack of awareness and adoption of improved land and water management practices.
- Water scarcity as a consequence of poor rainwater management practices.
- Less crop diversification.
- Temporary waterlogging on flat lands in lower reaches during the rainy season.
- Soil erosion in the transition zone during the rainy season. Silt loaded runoff in the initial stages of seedling establishment adversely affected soybean crop in the lower reaches.
- Lack of credit to buy quality seeds and other inputs.
- Lack of awareness about practicing improved package of practices, e.g., seed treatment with fungicide and *Rhizobium* culture, recommended fertilizer doses, method of fertilizer application, plant protection measures, and weed management practices.
- Absentee landlordism: some farmers were living in Indore city and thus were unable to give adequate attention to crop management.

Development of Ringnodia micro-watershed

Prior to undertaking any development works in the watershed, most of the runoff originating in the hillock region used to flow through the cultivated area. This water flowing at a great velocity carried considerable soil to the crops in the lower reaches. Soybean crop being sensitive to such deposition in the early stages (Sullivan et al. 2001) was adversely affected. The turbid water eventually reached the ponds and over the years reduced their capacity to store water to the extent that these could barely store 10% of the total runoff. As the storage capacity of these ponds had become very limited, this water used to eventually flow wildly out of the village and join main watercourses to Solsinda and Katkaya Nala (Fig. 4), and eventually to Khan river that joins Kshipra river at Ujjain. In general, the watershed was having fern type catchments. In this type of catchment, runoff is more since discharge is spread over a longer period.

Land and water conservation measures

To conserve natural resources of water and soil, the following measures were undertaken:

- Participatory rural appraisal and topographic survey of the watershed and its instrumentation for undertaking developmental works were completed. A watershed committee has been formed to mobilize and motivate farmers to enlist their participation in the developmental works.
- Storage structures/percolation tanks were constructed in three sections (Table 1) covering about 0.3 km in early 2000 for recharging groundwater and protecting the cultivated area from flooding in the lower reaches. These structures received about 80% of the rainfall as runoff from about 9.5 ha hillock area. It was, however, realized during the rainy season 2000 that the storage structures could protect only a small part of the watershed (<2 ha) as large gullies were still forming in the cultivated area due to runoff from an adjacent 7.5 ha hillock area. A 0.3-km long diversion bund in an area contiguous to the storage structures was therefore, constructed prior to the rainy season 2001 to reduce velocity of runoff from this barren hillock region and safely dispose it through the watercourses.
- Twenty-five loose and wire mesh bound boulder structures were constructed to reduce velocity of runoff and retain silt upstream and thereby stabilize watercourses.
- Waterways were improved for safe disposal of water from fields.
- A temporary bund was constructed on the main waterway to increase discharge to ponds.
- Deepening, shaping, strengthening by pitching, and repair of the breached bunds of village ponds were carried out to increase storage capacity. These ponds can now store about 20–30 ha-m water representing about 75% of the total runoff of the 100-ha catchment in the upper reaches in a normal rainfall year (Fig. 5). The de-silting of the ponds served twin purposes: enhancement of storage capacity of ponds, and application of the silt in fields for improving soil fertility.

All these works were undertaken in a farmer participatory mode with financial assistance of US$4000 from the District Collector, Indore, under the XI Finance Commission. These works also created lot of awareness and interest in soil and water conservation works among farmers of the nearby villages and extension agencies operating in the area.

Quantification of the benefits of soil and water conservation

In the rainy season 2000, the runoff from the treated and untreated areas was small (<15 mm) and the differences were marginal. The construction of a 0.3-km long diversion bund in 2001 resulted in 34% reduction in runoff. Most of the runoff had occurred prior to planting of the rainy season crops.

In 2001, soil loss was high (about 0.9 t ha^{-1}) in the untreated area compared to 0.1 t ha^{-1} in the treated area. The organic carbon content in the silt lost through runoff from the treated and untreated areas was 0.76% and 0.84% and available N was 0.014% and 0.015%, respectively. The organic carbon loss due to runoff was 7.6 kg ha^{-1} from the untreated area and 1.14 kg ha^{-1} from the treated area. The N loss due to runoff was less than 1 kg ha^{-1} from both areas.

There was no appreciable difference in water balance and the water use efficiency between the

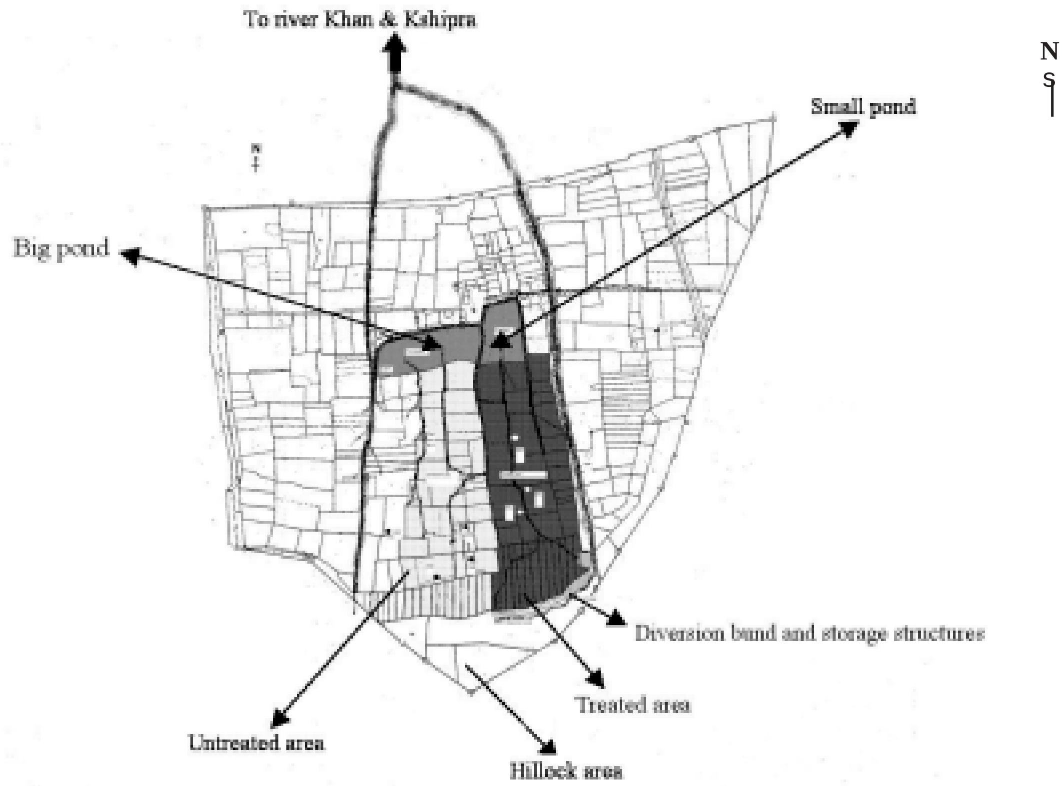

Figure 4. Ringnodia micro-watershed map.
(Note: The dark area is treated area and gray adjacent area is untreated control, both extending up to pond area.)

treated and untreated areas. The water use ranged from 329 mm for shallow soils to 400 mm for deep soils in the treated area. Since there was very little runoff during the cropping period (no waterlogging or silt deposition), the differences due to land and soil management were unlikely to have occurred between the treated and untreated areas. The water use efficiency ranged from 3.5 kg mm^{-1} ha^{-1} in shallow soils in the treated area to 7.6 kg mm^{-1} ha^{-1} in medium soils in the untreated area.

The storage structures constructed in the transition zone increased water table of the wells (groundwater recharge) (Fig. 6). The difference in the water table across wells near to the storage structure and farthest point was up to 3 m when measured with respect to uniform reference level.

Strategic research on best-bet options

Devising efficient cropping options

The development and application of simulation models of crops is well established in studying crop response to changes in genotype, cultivar, soil, weather, climatic patterns, and management practices. To identify best production system, we have generated scenarios of crop production using the APSIM (Agricultural Production Systems Simulator) (McCown et al. 1996). This model allows modeling of crop and pasture production, residue decomposition, and soil water and nutrient flow to be readily configured to simulate various production systems, including crop sequences and intercropping, and soil

Table 1. Salient features of water storage structures constructed in transition zone at Ringnodia micro-watershed during 1999.

Feature	Segment 1	Segment 2	Segment 3
Area contributing to pond (ha)	4.5	3.5	1.5
Type	Earthen bund	Earthen bund	Earthen bund
Shape	Semi-circular	Trapezoidal	Trapezoidal
Length of bund (m)	110	100	65
Surface area (m^2)	4400	2500	1625
Top width of bund (m)	3.2	3.2	3.2
Storage-capacity (maximum) (ha-cm)	140	80	48
Excavation/earthwork (m^3)	1620	1200	460
Excavation (%)	14.7	12	9.6
Function	Water storage	Percolation	Percolation

Figure 5. Water storage in the renovated big pond in Ringnodia micro-watershed after the first major runoff event in June 2001.

(Note: This existing tank did not store any water due to breached bund and silting prior to our intervention as shown in the inset.)

and crop management to be dynamically simulated using conditional rules.

The long-term scenarios for the 18 growing seasons derived using the APSIM model (McCown et al. 1996, Robertson et al. 2001) suggested that among the rainfed systems, pigeonpea/sorghum intercrop was the most productive cropping system with >5 t ha^{-1} total production and least variable (Fig. 7). In the postrainy season, systems involving partially irrigated wheat were most productive. Indeed, soybean-wheat rotation is practiced in about 64% of the total arable area in the postrainy season in the region. Rainfed cropping systems involving only legumes either as intercrops (soybean/pigeonpea) or sequential crops (soybean-chickpea) were less productive. The introduction of extra-short-duration pigeonpea as intercrop with soybean was not very productive, probably because of its matching life cycle duration with soybean. A provision of limited supplemental irrigation to chickpea could further boost the prospects of only legume-based systems. However, a legume-cereal system should be more appropriate, cost effective, and highly remunerative diversified farming system as it can derive maximum benefit of N-fixing capability of legumes and can meet the farmer's varied requirements of food and fodder.

Diversification with pigeonpea

Very few farmers in the micro-watershed grew pigeonpea as an intercrop with soybean. Thus, pigeonpea observation trials were laid out to introduce pigeonpea (variety JA 4) as a sole crop in the prevailing cropping system at two locations. Also, three trials of soybean/pigeonpea intercropping system were laid out. The 1999 rainy season was slightly adverse for soybean crop as there occurred a long dry spell after sowing and heavy rains during the reproductive period causing a severe setback to its productivity. Pigeonpea crop grown either alone or as an intercrop with soybean could resist these aberrations (Table 2). However, due to operational inconvenience in planting (sowing in different rows posed difficulty with existing planters) and harvesting (due to crops of dissimilar maturity period), farmers did not favor this system. Further, with medium-duration pigeonpea, there was little prospect of a second crop in the postrainy season. It gave <0.3 t ha^{-1} during 2000 due to terminal drought. In 2001 none of the farmers grew soybean/pigeonpea intercrop.

As medium-duration pigeonpea suffers from terminal drought and does not allow double cropping, extra-short-duration pigeonpea genotype ICPL 88039 that matures in 120 days was introduced in the

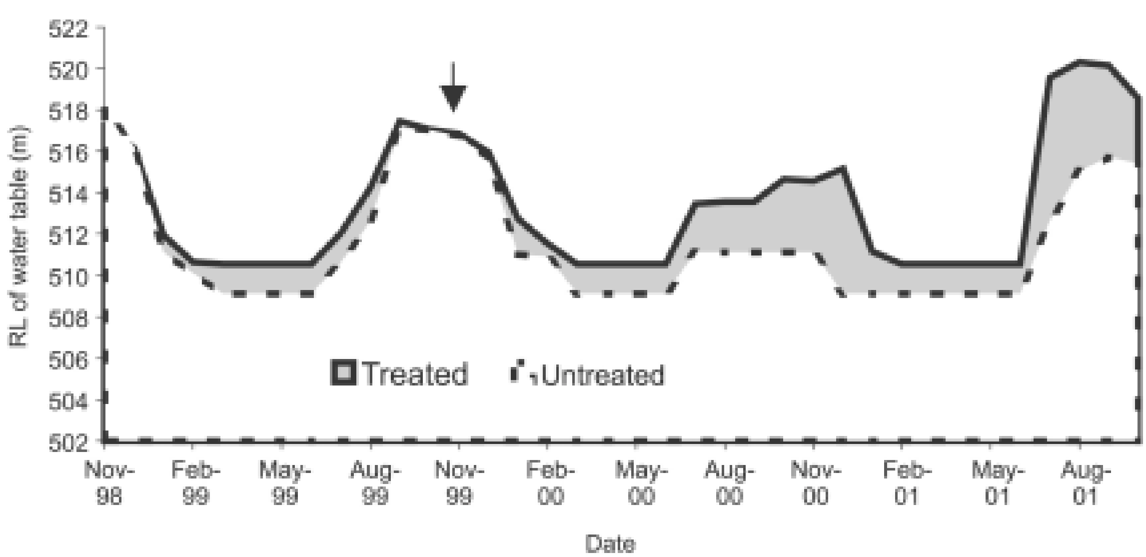

Figure 6. Water table fluctuations in terms of reduced level (RL) in the nearest (treated) and farthest (untreated) wells to the water storage structures in Ringnodia micro-watershed.
(Note: The arrow indicates date of construction of storage structures.)

Table 2. Productivity of soybean and pigeonpea as sole and intercrops in farmers' fields in Ringnodia micro-watershed, rainy season 1999.

Treatment	Yield (kg ha^{-1}) Location 1	Location 2	Location 3	Mean	LER[1]	Gross returns[2] (Rs ha^{-1})
Sole soybean	960	780	765	835	1.0	6680
Soybean/pigeonpea					1.7	18285
Soybean	782	636	652	690		
Pigeonpea	940	826	786	851		
Sole pigeonpea	1330	1140		1239	1.0	18585

1. Land equivalent ratio.
2. Calculated on the basis of price in January 2000.

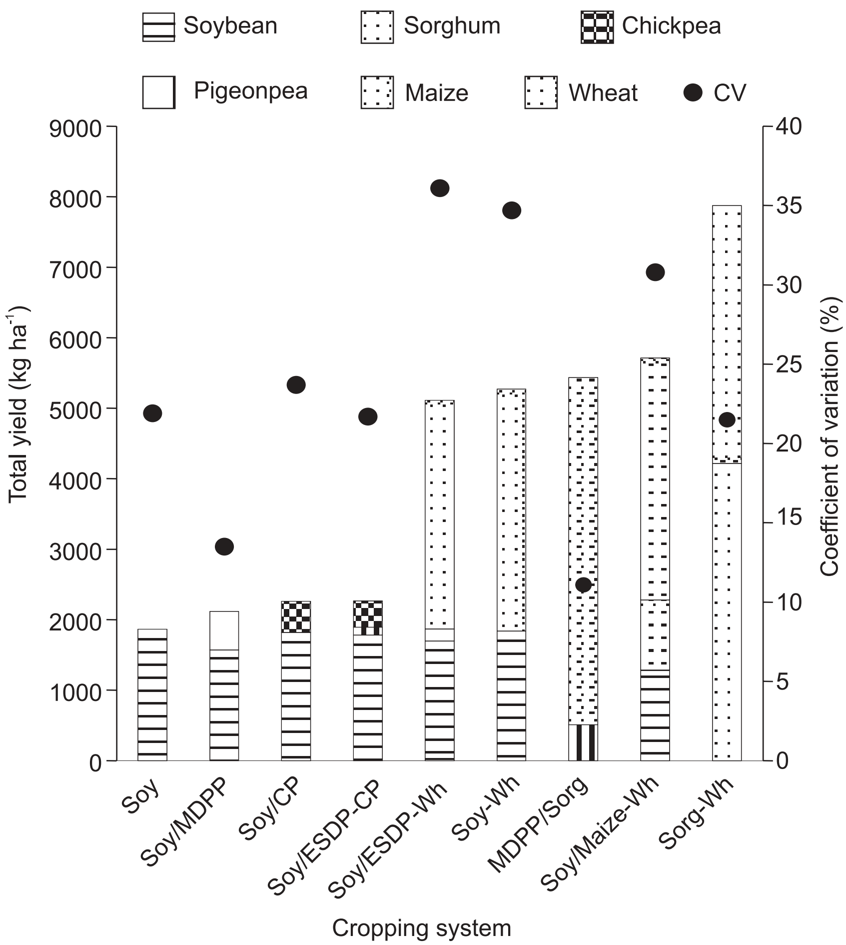

Figure 7. Long-term scenarios (mean of 18 years from 1984–2001) for different cropping system options and coefficient of variation (CV) for Ringnodia micro-watershed.

(Note: Soy = soybean, ESDP = extra-short-duration pigeonpea, MDPP = medium-duration pigeonpea, CP = chickpea, Wh = wheat, - = sequential cropping, / = intercropping.)

watershed with 24 farmers growing the crop in about 0.05-ha plots. The extra-short-duration pigeonpea escaped terminal drought on both shallow (0.62 t ha^{-1}) and deep soils (1.03 t ha^{-1}) and gave higher yield than medium-duration cultivars. There are indications that the adoption of extra-short-duration pigeonpea may increase in near future as not only farmers of Ringnodia but also farmers in adjacent villages who bought seed from Ringnodia farmers chose to continue growing the crop in 2001.

Land configuration

Waterlogging is a major constraint, particularly on flat lands in normal to high rainfall years when there are heavy silt loaded inflows from upper reaches. We evaluated broad-bed and furrows (BBF) landform and found that in spite of below normal rainfall in 2000 season soybean yield from flat landform and BBF was same. However, farmers were reluctant to adopt this measure due to operational difficulties in planting, intercultural operations, and reduced plant population.

Alternatively 5 to 10 cm high 'mini-ridges' were evaluated. These were made using a small duck-foot shaped spade between two tines. While making the ridges, this spade removed pre-emergence weeds and made the soil loose thereby ensuring good plant stand. In 2001, although yield of soybean obtained on mini-ridges was 8.5% greater than the adjacent flat beds, the difference was statistically not significant, probably due to below normal rainfall.

Integrated nutrient management

Five farmers evaluated recommended doses of fertilizer with soybean and found no increase in yields with fertilizer or *Rhizobium* application suggesting that N availability did not limit soybean yield in this watershed. During 2001, 12 farmers evaluated response of soybean to 30 kg S application through 200 kg ha^{-1} gypsum. Application of gypsum increased soybean yields by 70 kg ha^{-1} (5.4% more) over the non-gypsum plots.

Integrated pest management

Insect pest damage was one of the major biotic constraints for the yield gap between the potential and the realized yield in the watershed. Although farmers have access to insecticides they do not spray recommended quantities in time. They required an exposure to integrated pest management (IPM) options so that they could control the pests without depending on high doses of insecticides. A combination of insecticides and herbal preparations like Neemol and cow urine were found to be effective in reducing pest population (Tables 3 and 4). The

Table 3. Girdle beetle damage and semilooper larvae on soybean in farmers' fields at Ringnodia micro-watershed during the rainy season 2000/01[1].

Treatment	Girdle beetle damaged plants[2]		Semilooper larvae[2]		Seed yield (t ha^{-1})
	Before	After	Before	After	
T1	1.10	0.37	0.34	0.28	1.56
T2	0.77	0.57	0.38	0.26	1.24
T3	1.08	0.78	0.48	0.41	1.04
T4	1.88	1.80	0.47	0.70	0.54
SEm	0.06		0.04		0.06
CD at 5%	0.17		0.10		0.19

1. Data is mean of values obtained from seven farmers' fields.
   T1 = Two sprays of Quinalphos 25 EC, 2 ml L^{-1} at 1.0 L ha^{-1}; T2 = One spray of Quinalphos 25 EC, 2 ml L^{-1} at 1.0 L ha^{-1} followed by Neemol spray (20 days after Quinalphos spray); T3 = Two sprays of Neemol at 5 ml L^{-1} (20 days interval) at 2.5 L ha^{-1}; T4 = Absolute control.
2. Number m^{-1} row length at 72 h before and after spray.

Table 4. Effect of integrated pest management on pest control and soybean yield.

Treatment	Girdle beetle damage[1] (%) 33 DAE	45 DAE	Cumulative	Grain yield ($t\ ha^{-1}$)
Monocrotophos at 30 & 45 DAE ($1\ L\ ha^{-1}$)	10.6	39.0	24.8	1.71
Neemol at 30 & 45 DAE ($1.5\ L\ ha^{-1}$)	15.4	53.1	34.6	1.56
Cow urine ($50\ ml\ L^{-1}$)	15.2	61.2	38.2	1.40
Control	21.0	76.0	48.5	1.11
SEm	0.85	2.63	1.57	0.077

1. DAE = Days after emergence of soybean crop.

yield increase was up to three times in the IPM plots. The increase in yield was largely due to effective control of girdle beetle and semilooper larvae.

Fruit trees and *Gliricidia* plantation

In a quest for diversification of income sources, planting of several fruit trees such as jack fruit, papaya, custard apple, and *jamun* was encouraged. Each farmer was given two seedlings of each type that were planted in the backyard or on field boundaries. The mean survival of different fruit tree species varied from 40 to 100%. *Jamun* and custard apple were best established. A low rainfall in 2000 affected the survival of other tree species. Thus, there appears to be a scope for introducing selected fruit trees and diversifying farmers' income sources. *Gliricidia* seedlings were distributed among farmers for generating foliage to improve soil N and organic matter. In 2000, *Gliricidia* seedlings failed to survive as they were planted on diversion bund and hillock area where little individual care could be provided and moisture stress was acute.

Technology exchange

The adoption of BBF technology was very low in the Ringnodia micro-watershed as probably farmers were not fully aware of its benefits. To familiarize with the BBF system five farmers of Ringnodia village were taken to a neighboring benchmark site in Lalatora during May 2001. They learned about BBF on deep black soils and its advantages. They also exchanged their views about the features of short-duration soybean Samrat which could be used for double cropping.

Impact on crop productivity

Impact assessment was done in 2001. The data based on sample farmers of Ringnodia micro-watershed, revealed the overall impact of the interventions made with respect to soil and water management (Table 5).

Table 5. Increased productivity ($t\ ha^{-1}$) of important crops grown in Ringnodia micro-watershed based on sample survey.

Landholders	1998/99 Soybean	1998/99 Wheat	1998/99 Chickpea	1998/99 Potato	2000/01 Soybean	2000/01 Wheat	2000/01 Chickpea	2000/01 Potato
Small	0.70	1.60	0.50	15.54	0.85	1.68	0.71	18.90
Medium	0.75	2.40	0.60	16.10	0.92	2.51	0.79	19.80
Large	0.80	2.30	0.60	17.00	0.96	2.47	0.80	21.40
Increase (%)					21	6	36	17

College of Agriculture Micro-watershed

Background and treatment details

The productivity of soybean-based cropping systems in Madhya Pradesh is constrained by prolonged wet spells during the months of July and August and dry spells during the reproductive stage of soybean. Inadequate and imbalanced nutrition management practices followed by farmers also contribute to low and unstable productivity of soybean. Other production constraints include weeds, insect pests, and diseases. The strategic research work at the College of Agriculture micro-watershed in Indore was taken up to sustain productivity of soybean-based cropping systems to conserve and optimally utilize natural resources, and to determine soybean cultivar parameters for modeling.

A 2-ha micro-watershed was delineated in the 'C' block of the College of Agriculture farm (22°43' N and 76°54' E, about 540 m above mean sea level), Indore. The soils of the watershed are Vertisols belonging to Sarol series with medium fertility and low organic matter and are more than a meter deep. The plant available water-holding capacity was about 230 mm to a meter depth.

There were two main plots accommodating two land configuration treatments, flat (control) and BBF, and four subplot treatments of cropping systems, soybean (JS 335)-chickpea (JG 218); soybean (JS 335)-linseed (ILS 252); soybean (JS 335)-wheat (Sujata); and soybean (JS 335)/pigeonpea (JA 4) (4:2) strip cropping system. The treatments were laid out in a split plot design. The gross subplot size was 40 m × 15 m. The planting dates were: 4 July 1999, 6 July 2000, and 22 June 2001 for the rainy season crops, soybean and pigeonpea; 26 October 1999 and 10 October 2001 for the postrainy season crops, linseed, chickpea, and wheat. The harvesting dates were October 21 and 25, in 1999 and 2000, respectively, for soybean; 3 January 2000 for pigeonpea; 28 February 2000 for chickpea and linseed; and 23 March 2000 for wheat. There were no postrainy season crops in 2000 due to insufficient moisture in surface layers and the postrainy season crops of 2001 were planted on 6–10 October. The pigeonpea crop planted in 2000 failed due to terminal drought.

Observed and simulated performance

Soybean yields were high (2 t ha^{-1}) in 2001, but in the previous two seasons they were very low. The observed yield was compared with APSIM simulated yield. In 2001, the observed yield and other parameters were very similar to simulated yield (Table 6). However, in the previous two seasons, the observed yield was significantly less than the simulated yield (Fig. 8). This low yield could be attributed to various factors, such as weed incidence and damage by stray cattle. There was only a marginal advantage of about 60 kg ha^{-1} yield of soybean due to planting on BBF, which was statistically not significant. This could be because waterlogging did not occur in any of the seasons.

Table 6. Observed versus APSIM predicted parameters of the phenological stages, yield, and total dry matter of soybean variety JS 335 sown on 22 June 2001.

Parameter	Observed	Predicted
Days to flowering	42	48
Days to maturity	100	99
Yield (t ha^{-1})	1.89	1.94
Total dry matter (t ha^{-1})	5.45	5.19
Harvest index (%)	34.7	37.4

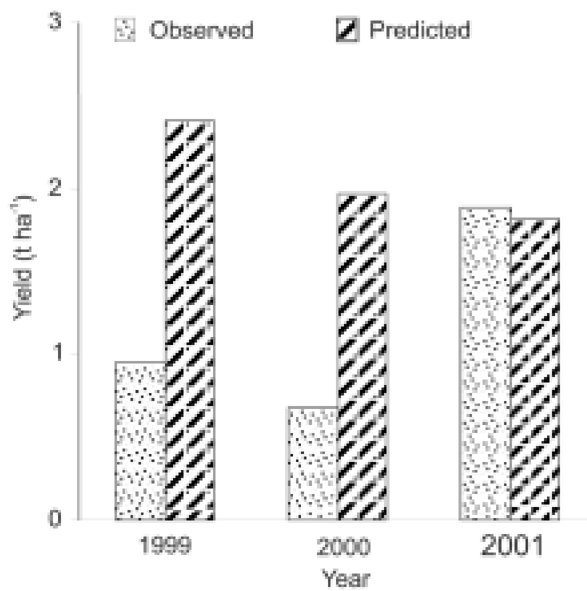

Figure 8. Simulated and observed soybean yields at the College of Agriculture micro-watershed, Indore.

Among the component crops, yield of pigeonpea and wheat was better than that of chickpea and linseed. In 2001, the postrainy season crops of wheat, linseed, and chickpea were planted under zero tillage and rainfed conditions as per the treatments. The establishment and growth of chickpea was better than wheat whereas linseed failed to establish.

Water balance

The field water balance of the College of Agriculture micro-watershed was computed for 2000 and 2001 rainy season considering all components. In 2000 and 2001, soil moisture at sowing was 340 and 201 mm, and at harvest was 237 and 275 mm, and rainfall was 231 and 375 mm, respectively. The runoff was negligible in both the years. The water use by the soybean crop grown on flat and BBF systems was 333 mm in 2000 and 283 mm in 2001 with no appreciable difference between them. The water use efficiency for soybean under different cropping systems was 1.81–2.2 kg mm^{-1} ha^{-1} for sole crop in 2000, and 5.25–5.51 kg mm^{-1} ha^{-1} for intercrop to 5.70–7.37 kg mm^{-1} ha^{-1} for sole crop in 2001 regardless of land treatments.

Lessons Learned from On-farm and On-station Strategic Research Work and Way Forward

As is apparent from the production statistics of Madhya Pradesh, soybean yield has doubled during the past 11 years; area has increased four times and total production five times. The increase in area under the crop has occurred partly through reduction in rainy season fallows, and partly by substitution of crops such as sorghum. While a sizable area under rainy season fallows still exists in the state (Vadivelu et al. 2001), the scope of increasing productivity exists only through increased crop yields and cropping intensity in the postrainy season. Using soil and water conservation measures and appropriate crop and nutrient management practice in Ringnodia micro-watershed, yields as high as 2 t ha^{-1} can be realized with ease in a normal rainfall year.

The Ringnodia micro-watershed presented an opportunity to explore the possibility of increasing crop yields as well as cropping intensity through farmers' participation, which was low to begin with and the soil and water resources in the village were poorly managed. It was possible to increase the water storage potential up to 70% of the total runoff potential. Also, the potential for soil erosion and waterlogging was substantially reduced. Farmers had good insight about the problems, but lacked initiative and resources to undertake massive development works. Their cooperation, catalyzed by our intervention, made a difference to the village resources in several ways as mentioned earlier.

Farmers were eager to construct more water storage structures as they have now realized the value of water storage without which their crops would suffer, wells would go dry, and even drinking water would become scarce. The open and tube wells could provide better insurance against drought provided the ground recharge could be enhanced. Farmers were interested in finding an alternative to soybean as prices have been low over the years.

Tractor mounted seed drill designed to sow on BBF was not found to be suitable for soybean as it had poor depth control, but was found to be appropriate for chickpea sowing as it could sow deep in the moist zone. Trees provide insurance against aberrant weather. Plantation efforts did not progress due to limited rainfall. However, custard apple and *jamun* had good survival ability. As some common land was available in the village there may be scope to develop these trees as a common property resource.

Acknowledgments

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Use of Satellite Data for Watershed Management and Impact Assessment

R S Dwivedi[1], K V Ramana[1], S P Wani[2], and P Pathak[2]

Abstract

Over-exploitation of natural resources for meeting the increasing demand for food, fuel, and fiber of the ever growing population has led to environmental degradation and calls for their optimal utilization based on their potential and limitations. Information on the nature, extent, and spatial distribution of natural resources is essential. Spaceborne multispectral measurements made at regular intervals hold immense potential of providing such information in a timely and cost-effective manner, and facilitate studying dynamic phenomenon. The geographic information system (GIS) provides an ideal environment for integration of information on natural resources with the ancillary information for generating derivative information which is useful in decision making. The study was taken up to generate the action plan for land and water resources development and to monitor the progress of its implementation in the Adarsha watershed, Kothapally, Ranga Reddy district, Andhra Pradesh, India. The approach involves generation of thematic maps on various natural resources through a systematic visual interpretation of satellite data, integration of such data with the ancillary information and generation of action plan in the GIS environment, and monitoring vegetation development as a sequel to implementation of action plan by generating Normalized Difference Vegetation Index (NDVI) from the Indian Remote Sensing Satellite (IRS-1C/-1D) Linear Imaging Self-scanning Sensor (LISS-III) data. Soil erosion by water is the major land degradation process operating in the watershed. There has been an improvement in the vegetation cover owing to implementation of various soil and water conservation measures, which is reflected in the NDVI images of pre- and post-implementation periods.

Soil erosion by water and wind is the major land degradation process in the arid and semi-arid regions of the world. Globally, about 1.965 billion ha of land is subjected to some kind of degradation. Of this, 1.094 billion ha of land is subjected to soil erosion by water and 549 million ha of land to soil erosion by wind. On an average 25 billion tons of topsoil from croplands is being washed into oceans. In India alone, out of 329 million ha geographical area, 150 million ha land is affected by wind and water erosion (GOI 1976). Annually about 6000 million tons of soil is lost through soil erosion by water (Das 1985). Also, shifting cultivation, waterlogging, and salinization and/or alkalization have affected an estimated 4.36 million ha, 6 million ha, and 7.16 million ha of land respectively (GOI 1976). Frequent floods and drought further compound the problem. Soil degradation contributes to an increase in atmospheric carbon dioxide through rapid decomposition of organic matter. In addition, rapid industrialization and deforestation have led to building up of greenhouse gases in the atmosphere resulting in global warming. Degradation of vegetation by deforestation for timber and fuel wood, shifting cultivation, and occasionally forest fire is a very serious environmental problem. Biodiversity conservation is equally important for the sustainability of vegetation. Optimal utilization of natural resources based on their limitations and potential is, therefore, a prerequisite for sustained agricultural production.

The Role of Remote Sensing

For optimal utilization of natural resources, information on their nature, extent, and spatial distribution is a prerequisite. Until the 1920s, such information had been collected by conventional surveys, which are labor-intensive, cost-prohibitive,

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and impractical in the inhospitable terrain. During the 1920s and early 1970s, aerial photographs were used for deriving information on various natural resources including lands subject to degradation by various processes (Bushnell 1929, USDA 1951, Howard 1965, Iyer et al. 1975). Since the launch of the Earth Resources Technology Satellite (ERTS-1), later renamed as Landsat-1, in 1972, followed by Landsat-2, -3, -4, and -5, SPOT-1, -2, -3, and -4, and the Indian Remote Sensing Satellites (IRS-1A, -1B, -1C, and -1D) with Linear Imaging Self-scanning Sensors (LISS-I, -II, and -III), spaceborne multispectral data collected in the optical region of the electromagnetic spectrum have been extensively used in conjunction with the aerial photographs and other relevant information supported by ground truth, for deriving information on geological, geomorphological, and hydro-geomorphological features (Rao et al. 1996a, Reddy et al. 1996); soil resources (Singh and Dwivedi 1986); land use/land cover (Landgrebe 1979, Raghavaswamy et al. 1992, Rao et al. 1996b); forest resources (Dodge and Bryant 1976, Unni 1992, Roy et al. 1996); surface water resources (Thiruvengadachari et al. 1996); and degraded or wastelands (FAO 1978, Karale et al. 1988, Nagaraja et al. 1992, Dwivedi et al. 1997a, 1997b). Futhermore, spaceborne multi-spectral data have been operationally used for integrated assessment of natural resources and subsequent generation of action plans for land and water resources development and for assessment of the impact of their implementation.

Biomass has been used as a surrogate measure to evaluate the impact of the implementation of action plan for land and water resources development. High absorption of incident sunlight in the visible red (600–700 nm) portion and strong reflectance in the near-infrared (750–1350 nm) portion of the electromagnetic spectrum has been used to derive vegetation indices, which indicate the abundance and condition of biomass. The index is typically a sum, difference, ratio, or other linear combination of reflectance factor or radiance observations from two or more wavelength intervals. The vegetation indices thus developed are highly correlated with the vegetation density or cover; photosynthetically active biomass (Tucker 1979, Wiegand and Richardson 1984); leaf area index (Wiegand et al. 1979); green leaf density (Tucker et al. 1985); photosynthesis rate (Sellers 1987); and amount of photosynthetically active tissue (Wiegand and Richardson 1987). Landsat-TM data have been used for deriving various vegetation indices which in turn were used to assess the impact of soil conservation measures in the treated watersheds (NRSA 1996, 1999). The study reported here was taken up to (i) generate the action plan for sustainable development of land and water resources, and (ii) assess the impact of the action plan in the Adarsha watershed using IRS-1B/-1C and -1D LISS-II and -III data (see Table 1).

Test Site

With an area of 1083 ha, Adarsha watershed in Kothapally is bound by geo-coordinates 17°21' to 17°24' N and 78°5' to 78°8' E and forms part of Shankarpally mandal (an administrative unit) of Ranga Reddy district, Andhra Pradesh, India. Vertisols and associated Vertic soils occupy 90% of the watershed area. However, Alfisols do occur to an extent of 10% of the watershed area. The main kharif (rainy season) crops grown are sorghum, maize, cotton, sunflower, mung bean, and pigeonpea. During rabi (postrainy season) wheat, rice, sorghum, sunflower, vegetables, and chickpea are grown. The mean annual rainfall is about 800 mm, which is received mainly during June to October.

Table 1. The details of remote sensing data used.

Satellite/sensor	Path/row nos.	Date of pass
IRS-1B LISS-II	26–56	25-11-1996
IRS-1C LISS-III	99–60	01-04-1996
IRS-1D LISS-III	99–60	02-04-2000 & 29-11-1999
IRS-1D PAN	99–60	01-12-1999

Database

We have used the Indian Remote Sensing Satellite (IRS-1B/-1C and -1D) Linear Imaging Self-scanning Sensor (LISS-II and -III) and Panchromatic sensor (PAN) data for deriving information on various natural resources and for generation of action plans for land and water resources development (Table 1). In addition, Survey of India topographical maps at 1:50,000 scale, and published soils and other resources maps and reports were also used as collateral information.

Methodology

The methodology involves database preparation, generation of thematic maps on natural resources, and their integration with the socioeconomic data to arrive at a locale-specific prescription for land and water resources development. The schematic diagram of the approach is given in Figure 1. Once action plan is implemented, the next logical step is to assess its impact on environment and the beneficiaries.

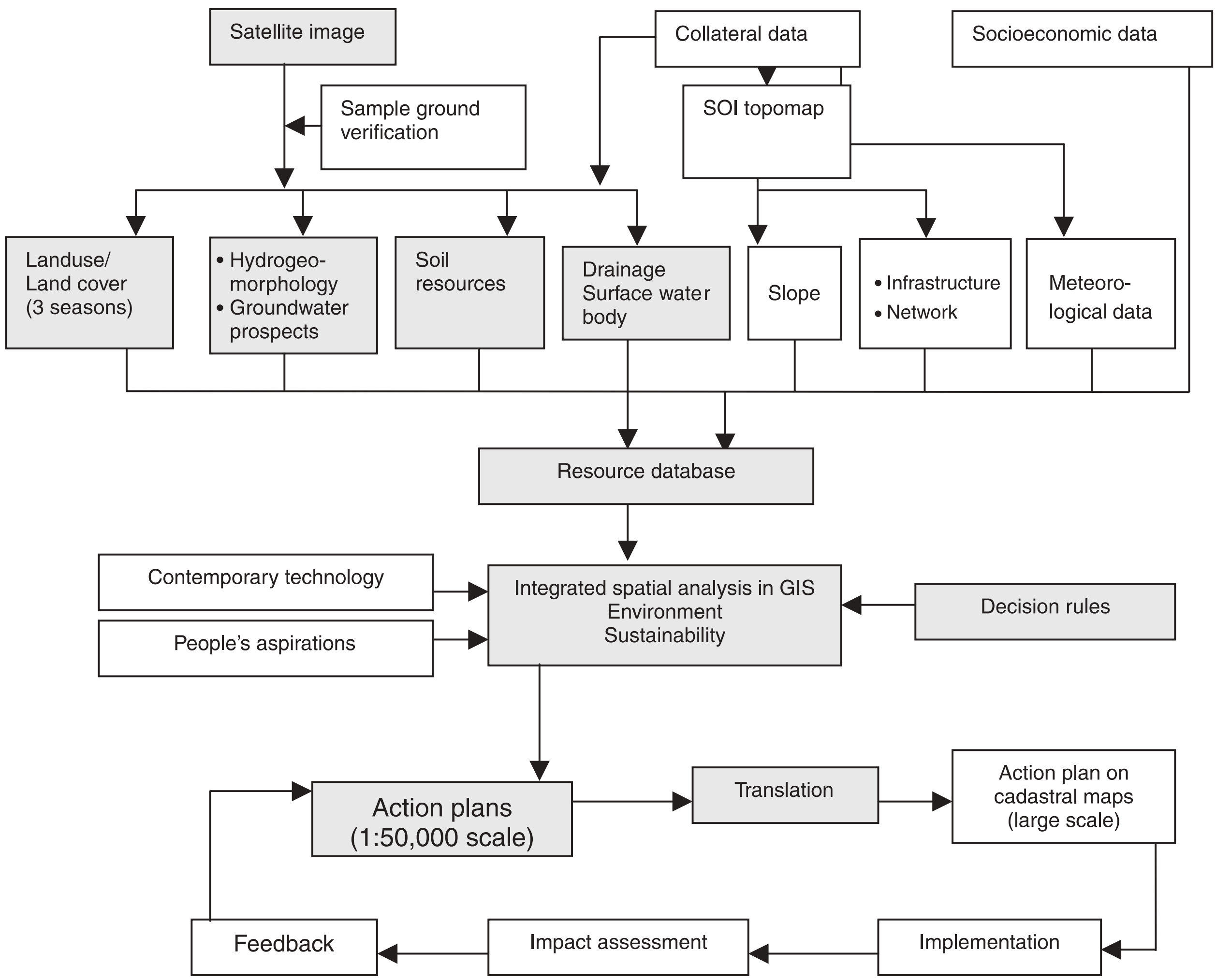

Figure 1. Schematic diagram of the approach.

Database preparation

The first step in generating the multi-sensor data sets is the geo-referencing of the image to a common map grid. When merging higher resolution data with the lower resolution images, usually high resolution image (here PAN data with 5.8 m spatial resolution) is used as a reference for respective enhancement of the lower resolution (LISS-III data with 23.5 m spatial resolution) data (Cliché et al. 1985). To begin with, the Survey of India topographical maps at 1:50,000 scale were scanned on a Contex FSS-800 scanner at 300 dots per square inch (dpi). The digital LISS-III was later co-registered to digital, topographic database on a Silicon Graphics Octane work station using 20 tie points (ground control point) and image-to-image registration algorithm. The IRS-1D PAN digital data was subsequently co-registered to LISS-III data following similar approach. Subsequently, the LISS-III data was resampled to 6 m pixel dimension using nearest neighborhood algorithms for further processing. The IRS-LISS-II data was also digitally co-registered to IRS-1C LISS-III data and resampled to 24 m pixel dimension. The three bands, namely 0.52–0.59 μm, 0.62–0.68 μm, and 0.77–0.86 μm of LISS-III data were digitally merged with PAN using Brovey transformation algorithm. The Brovey transformation is a formula-based process that works by dividing the band to display in a given color by the sum of all the color layers, i.e., red, green, and blue and then multiplying by the intensity layer.

Generation of thematic maps

Thematic maps on hydrogeomorphological conditions, soil resources, and present land use/land cover have been generated through a systematic visual interpretation of IRS-1B/-1C/-1D LISS-II and -III data in conjunction with the collateral information in the form of published maps, reports, wisdom of the local people, etc. supported by ground truth. The information derived on the lithology of the area and geomorphic and structural features in conjunction with recharge condition and precipitation was used to infer groundwater potential of each lithological unit. Soil resource maps of the area have been prepared by delineating sub-divisions within each geomorphic unit based on erosion status, land use/land cover, and image elements, namely color, texture, shape, pattern, and association. Soil composition of each geomorphic unit was defined by studying soil profiles in the field and classifying them based on morphological characteristics and chemical analyses data (USDA 1975, 1998).

In addition, derivative maps, namely land capability and land irrigability maps were generated based on information on soils and terrain conditions according to criteria from the All India Soil and Land Use Survey Organization (All India Soil and Land Use Survey 1970). Land capability classification is an interpretative grouping of soils mainly based on: (i) inherent soil characteristics, (ii) external land features, and (iii) environmental factors. The groupings enable one to get a picture of (i) the hazards of the soils to various factors which cause soil damage and deterioration or lowering in fertility, and (ii) its potentiality for production. The interpretation of soil and land conditions for irrigation is concerned primarily with predicting the behavior of soils under the greatly altered water regime brought about by the introduction of irrigation. For arriving at land irrigability classes, soil characteristics, namely, effective soil depth, texture of the surface soil, permeability, water-holding capacity, course fragments, salinity and/alkalinity, presence of hard pan in the surface, topography, and surface and sub-surface drainage are considered.

Land use/land cover maps have been prepared using monsoon (kharif) and winter (rabi) crop growing seasons and summer period satellite data for delineating single-cropped and double-cropped areas apart from other land use and land cover categories. Furthermore, micro-watersheds and water bodies have been delineated and the drainage networks have also been mapped. Slope maps showing various slope categories have been prepared based on contour information available at 1:50,000 scale topographical sheets. Rainfall data were analyzed to study the rainfall distribution pattern in time and space. Demographic and socioeconomic data were analyzed to generate information on population density, literacy status, economic backwardness, and the availability of basic amenities.

Generation of action plan

The generation of an action plan essentially involves a careful study of thematic maps on land and water resources, both individually as well as in combination, to identify various land and water resources regions or Composite Land Development Units (CLDU) and their spatial distribution, potential and limitations for sustained agriculture and other uses, and development of an integration key. It was achieved by scanning the thematic maps on a CONTEX FSS 800 black and white scanner at 400 dpi. It was followed by vectorization, projection to real world coordinates, editing map compilation and unionizing the thematic boundaries in a geographic information system (GIS) domain using ARC/INFO version-7 software. Each CLDU was studied carefully and a specific land use and soil and water conservation practice was suggested based on its sustainability. Subsequently, taking landform as a base an integration key in terms of potential/ limitations of soils, present land use/land cover, and groundwater potential, and suggested alternate land use/action plan was developed.

Implementation of action plan

The action plan and/alternate land use practices and drought-proofing activities emerging from this approach have been implemented by the district/mandal authorities using the state-of-the-art technology for each action item to fully exploit the contemporary developments in agriculture, science, and technology.

Impact assessment

Since vegetation condition is the reflection of soils and hydrological conditions which are altered in the event of implementation of suggested action plan, it has been taken as a surrogate parameter for assessment of the impact of such treatment in the watershed. The Normalized Difference Vegetation Index (NDVI) values from near infrared (NIR) and red (R) band responses in the IRS-1B/-1C/-1D LISS-II and -III data were generated on a Silicon Graphics work station as follows:

$$\text{NDVI (output DN)} = \frac{\text{NIR (DN)} - \text{R (DN)}}{\text{NIR (DN)} + \text{R (DN)}}$$

DN represents digital number in respective spectral bands. The equation produces NDVI values in the range of –1.0 to 1.0, where negative values generally represent clouds, snow, water, and other non-vegetated surfaces, and positive values represent vegetated surfaces.

Results

Natural resources

Lithologically, the watershed comprises of basalt and laterites. The moderately dissected plateau which is interspersed with structural valleys constitutes the major landform. While the undissected plateau has poor groundwater potential, the dissected plateau has poor to moderate potential. Structural valley has good groundwater potential depending on the nature of the fracture. Whereas Vertic Haplaquepts have developed over structural valleys the dissected plateau support the development of shallow soils namely Lithic Ustochrepts and Lithic Ustorthents. Vertic Ustochrepts, however, do occur in local depressions within the dissected plateau. The watershed is mainly used for raising both kharif and rabi crops. A few pockets of land, however, is wasteland mostly in the form of land with/without scrub. The land under kharif crops constitute the major land use and land cover category followed by double cropped land (Fig. 2).

Action plan

Since the watershed very often experiences drought, apart from alternate land use based on potential and limitations of natural resources, various drought-proofing measures such as vegetative barriers, contour bunding, stone check-dams, irrigation water management, horticulture, groundwater development with conservation measures, and fodder and silvipasture in marginal lands have been undertaken. The suggested optimal land use practices are intensive agriculture, intercropping system, improved land configuration, agro-horticulture, horticulture with groundwater development, and silvipasture.

Implementation of action plan

Various soil and water and conservation measures, e.g., broad-bed and furrows, contour planting,

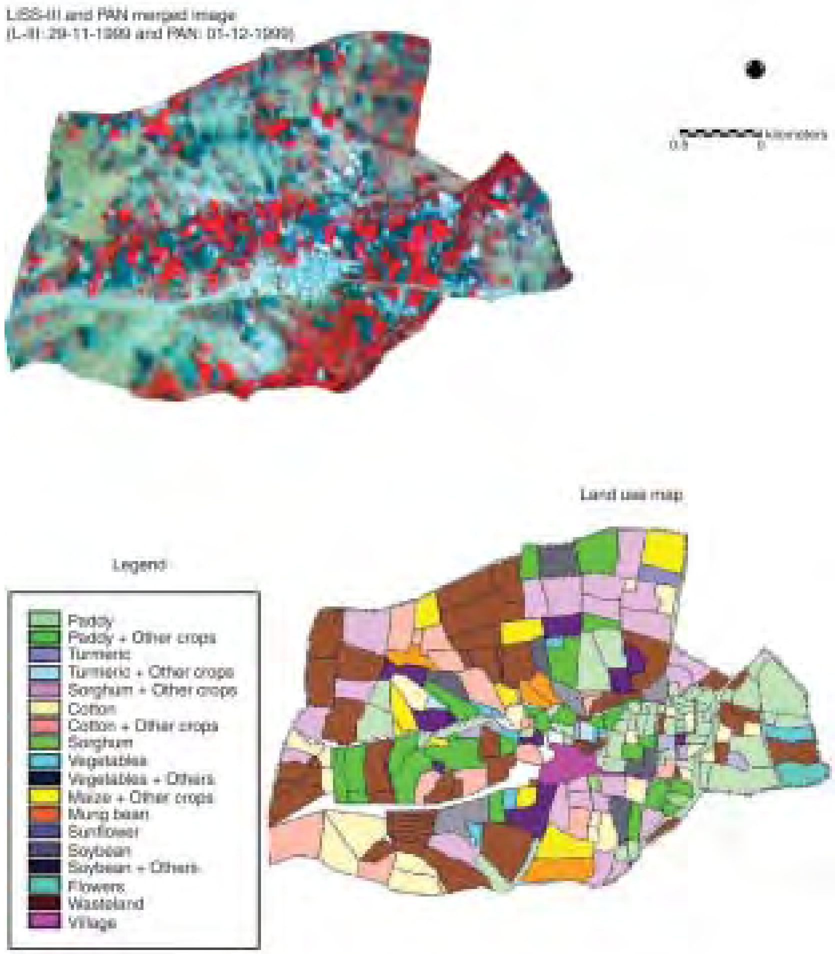

Figure 2. LISS-III and PAN merged image and land use map of Adarsha watershed, Kothapally, India.

waterways and drainage channels, field bunding, wasteland development, storage of excess water through construction of check-dams, dug out ponds, gabion structures, gully plugging, and increased cropping intensity have been undertaken in the watershed. In addition, integrated nutrient and pest management trials have also been conducted.

Impact assessment

Soon after implementation of the suggested action plan, the area undergoes transformation, which is monitored regularly. Such an exercise not only helps in studying the impact of the program, but also enables resorting to mid-course corrections, if required. Parameters included under monitoring activities are land use/land cover, extent of irrigated area, vegetation density and condition, fluctuation of groundwater level, well density and yield, cropping pattern and crop yield, occurrence of hazards, and socioeconomic conditions. Land use/land cover parameters include: changes in the number and aerial extent of surface water bodies, spatial extent of forest and other plantations, wastelands, and cropped area.

As mentioned earlier, NDVI has been used to monitor the impact of the implementation of action plan. A close look at the NDVI images of 1996 and 2000 reveals an increase in the vegetation cover which is reflected in improvement in the vegetation cover (Fig. 3). The changes in the vegetation cover can be seen in the satellite image as variations in the red-colored patches, and in the NDVI images as changes in yellow and pink colors. The spatial extent of moderately dense vegetation cover which was 129 ha in 1996 has risen to 152 ha in 2000. Though the satellite data used in the study depicts the terrain conditions during 1996, implementation activities started only in 1998. It is, therefore, obvious that it will take considerable time for detectable changes in the terrain and vegetation conditions.

Conclusions

The study vividly demonstrates the potential of spaceborne multispectral data in deriving information on natural resources. The GIS provides an ideal environment for integration of data on natural resources with the ancillary information and facilitates generation of action plan for development of land and water resources. After implementation of action plan, multi-temporal satellite data help in monitoring its success and progress. The change in vegetation cover in the Adarsha watershed as a result of adopting soil conservation measures during 1996 to 2000, is an indicator of the success of implementation of such action plans. High spatial resolution panchromatic and multispectral data from IKONOS-II and the future earth observation missions such as Resourcesat-1, Cartosat-1 and -2, Quick Bird, Almaz-1B, etc. may further enhance our capability of generating farm-level action plan for land and water resources development, and to study the success and progress of the implementation of such action plans.

Acknowledgments

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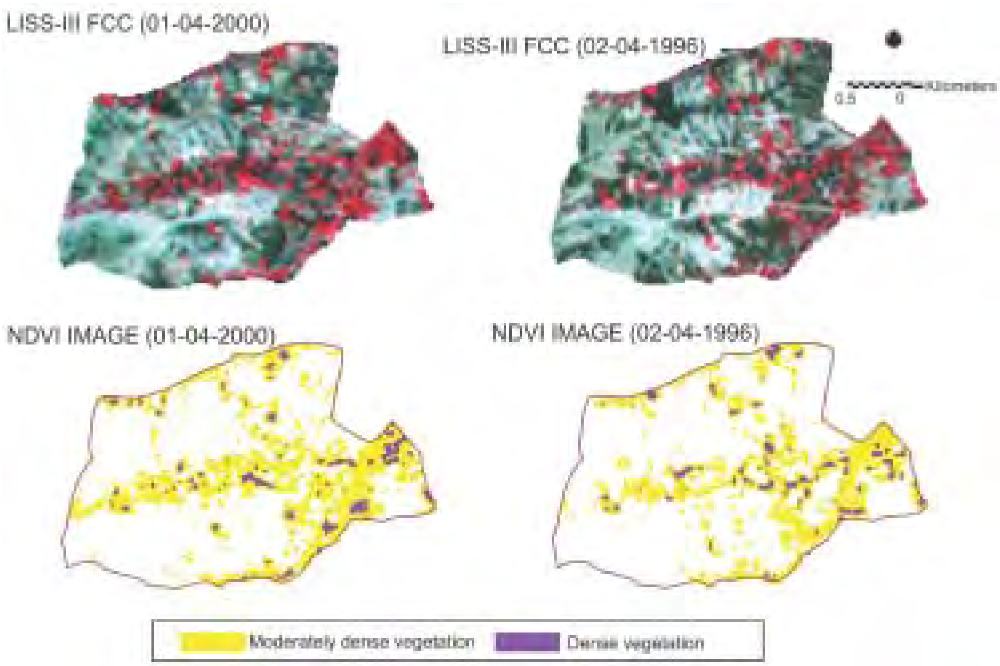

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Statistical Analysis of Long Series Rainfall Data: A Regional Study in Southeast Asia

J P Bricquet[1], A Boonsaner[2], T Phommassack[3], and T D Toan[4]

Abstract

Many developing countries have long series of rainfall data but these have not been analyzed for their trends and probable occurrence. A study of rainfall data at Hoa Binh in Vietnam (41 years), Luang Prabang in Laos (51 years), and Phrae in northern Thailand (28 years) was undertaken by the Management of Soil Erosion Consortium project. The initial analysis of rainfall data suggests that the data is homogeneous and indicates that there is a small decrease in annual rainfall in all 3 locations. The paper presents summary statistics and frequency analysis of annual rainfall and maximum daily rainfall respectively for the locations. The authors suggest that detailed and in-depth analysis of more rainfall stations including these 3 stations should be carried out for further study to incorporate the probabilistic information in decision making.

The occurrence of many extreme events in hydrology cannot be forecast on the basis of deterministic information with sufficient skill and lead time as those decisions which are sensitive to their occurrence. In such cases, a probabilistic approach is required to incorporate the effects of such phenomena into decisions. If the occurrence can be assumed to be independent of time, then frequency analysis can be used to describe the likelihood of any one or a combination of events over the time horizon of a decision (WMO 1983). Interpretation of precipitation has two major purposes. The first purpose is to evaluate the observations that sample a precipitation event or series of events. The evaluation of the observed sample includes consideration of extraneous influences, such as deficient or changing gauge exposure, and interpretation of the effects of physical environment, such as physiography. The other purpose is to describe the event in a form appropriate for display, subsequent analysis, or other applications.

Little is known about trends in rainfall in the Southeast Asia region. A study conducted by Manton et al. (2001) showed a gap in the Indo-Chinese peninsula. With the Management of Soil Erosion Consortium (MSEC) led by the International Water Management Institute (IWMI), it was possible to gain access to three recorded series in this region.

Location of the Study

The study was conducted for three stations relatively close to the MSEC project sites, namely Hoa Binh in Vietnam (20°49’ N, 105°20’ E), Luang Prabang in Laos (19°53’ N, 102°08’ E), and Phrae in northern Thailand (18°08’ N, 100°10’ E) (Fig. 1). The period of record is 41 years for Hoa Binh, 51 for Luang Prabang, and 28 for Phrae. For all stations, daily rainfall data are available.

Results of Analysis

Homogeneity of the data

The homogeneity of hydrological or meteorological data is the requirement for a valid statistical application. The most commonly used information about non-climatic influences comes from records of station movement, changes in instrumentation, problems with instrumentation, sensor calibration,

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changes in surrounding environmental characteristics, observation practices, and other similar features (Guttman 1998). The double mass curve analysis introduced by Kohler (1949) is a graphical method of identifying and adjusting inconsistencies in a station record by comparing its time trend with those of other stations. Changes in slope of double-mass curve may be caused by changes in exposure or location of gauge, change in procedure in collecting and processing data, etc. (WMO 1994). The data collected at all the sites within the region should be highly correlated, have similar variability, and differ only by scaling factors and random sampling variability. As shown in Figure 2, there is no change in the slope of the curve for both stations. So, we can consider all series as homogeneous. With very close correlation coefficient, it is also possible, if needed, to extend the series of Hoa Binh and Phrae but only for annual or monthly values.

Figure 1. Location of the three experimental stations (H) in Southeast Asia.

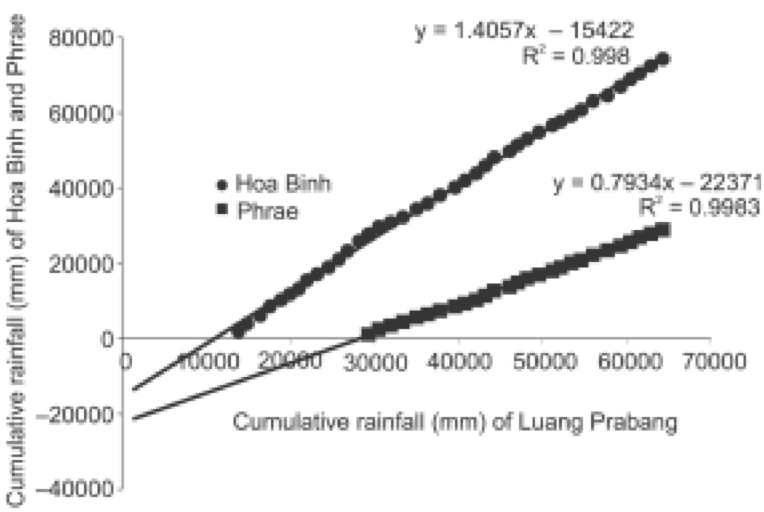

Figure 2. Double mass curve.

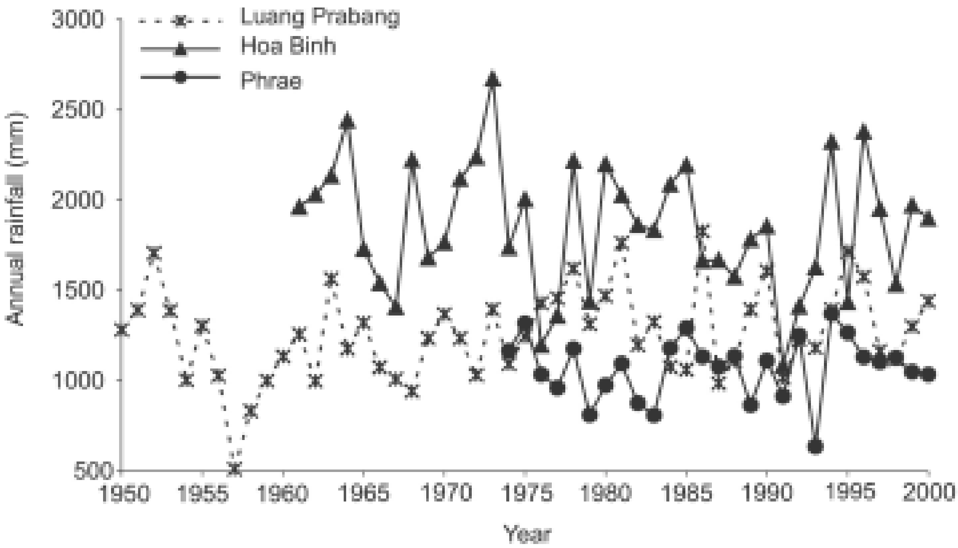

Figure 3. Variation of the annual rainfall at three experimental stations.

Annual rainfall analysis

Climatic normal is defined by the World Meteorological Organization (WMO) as "period averages of a climatic element such as temperature or precipitation computed for a uniform and relatively long period comprising at least three consecutive ten-year periods" (WMO 1983). Manton et al. (2001) assumes that the annual total rainfall had generally decreased between 1961 and 1998. The number of rainy days (with at least 2 mm of rainfall) has also decreased significantly in Southeast Asia. Looking at the variations of the annual total rainfall (Fig. 3) of the three stations, it is difficult to detect a trend of an increase or decrease in the annual rainfall. However, a small decrease may be detected but cannot be quantified.

The 1957 value of Luang Prabang seems very low. Checking the record, we cannot reject this very small amount of rainfall (511.1 mm). We can assume the same comment for the 1993 value for Phrae (635.9 mm). Standard statistical results are presented in Table 1. Annual rainfall usually follows a Gauss statistical distribution. Accordingly, the different return period values can be calculated with the Normal law (Table 2). The results indicated that all

Table 1. Summary statistics of the annual rainfall of three stations.

Location	Average	Variance	Standard deviation	Minimum	Maximum	Standard kurtosis
Hoa Binh	1856.7	127290	356.8	1085.2	2671.7	–0.473
Luang Prabang	1261.2	65058	255.1	511.1	1827.5	0.817
Phrae	1084.6	34107	184.7	635.9	1461.3	0.273

Table 2. Frequency analysis of the annual rainfall (mm) of three stations.

Location	0.01	0.1	0.5	0.9	0.99
Hoa Binh	1064.2	1420.8	1856.7	2292.7	2649.3
Luang Prabang	710.7	958.4	1261.2	1563.9	1811.6
Phrae	654.9	848.3	1084.6	1321.0	1514.3

stations had already reached annual values close to the millennium frequency (0.99) for the maximum values recorded. For the minimum values, all stations had already reached centennial frequency (0.01).

Maximum daily rainfall

Figure 4 presents the distribution of the maximum daily rainfall for the three stations. As usual for this type of data, we do not have a Gauss distribution and the data can be adjusted with a Log Normal distribution (Fig. 5). Standard statistics are given in Table 3.

The calculations of return period values are done following a Pearson 3 law (Table 4). The highest observed value for Hoa Binh station (416.4 mm) is probably a millennium occurrence. Also, all stations have reached maximum daily values equal to or higher than the centennial calculation. The same comment can be made for the lower values. Should we see here an increase in heavy precipitation events like in the United States (Karl and Knight 1998)?

Conclusions

This study is just a starting point for a deeper investigation on the climate in the region. As we can detect a decrease of the annual total rainfall for the three stations, we should continue this study with more stations from the region including South China. A limitation of such studies is the low spatial density of stations with homogeneous data.

Acknowledgments

This study is a contribution to MSEC led by IWMI and funded by the Asian Development Bank (RETA 5803). Special thanks to the National Departments of Meteorology of the different countries which provided the data.

Table 3. Summary statistics of the maximum daily rainfall of three stations.

Location	Average	Variance	Standard deviation	Minimum	Maximum	Standard kurtosis
Hoa Binh	156.1	4293.2	65.5	58.3	416.4	6.620
Luang Prabang	83.2	852.8	29.2	27.7	180.7	3.615
Phrae	90.2	1278.8	35.7	43.3	218.2	7.062

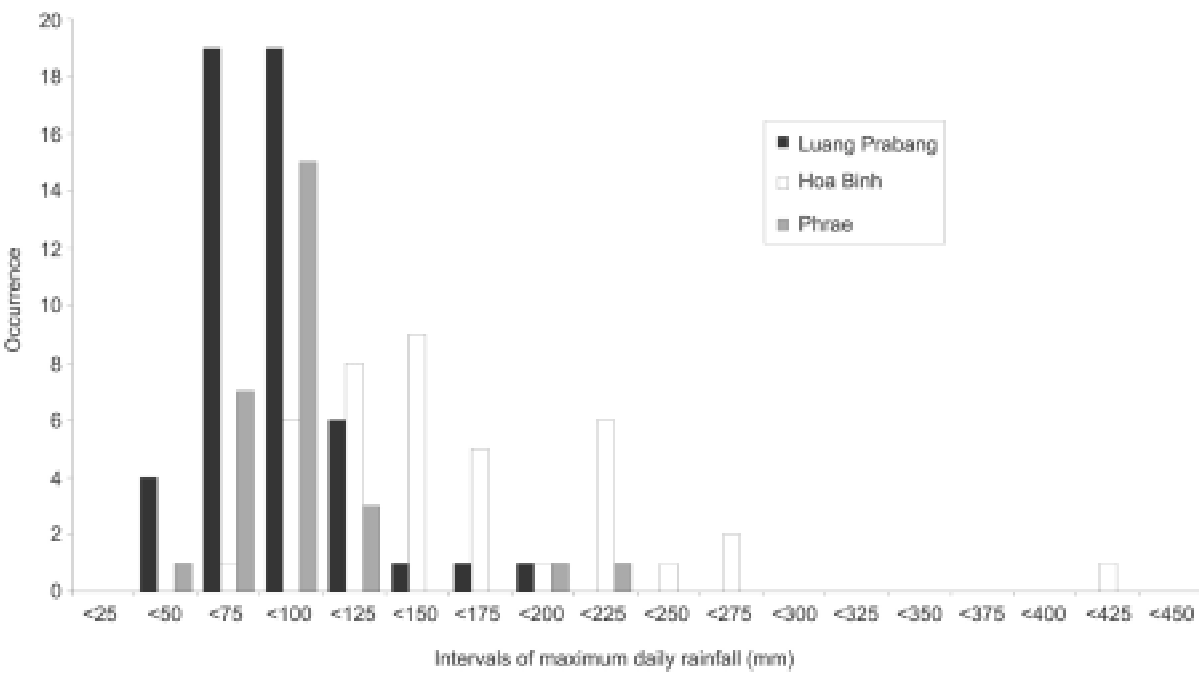

Figure 4. Frequency of maximum daily rainfall at three stations.

Table 4. Frequency analysis of the maximum daily rainfall of three stations.					
Location	0.01	0.1	0.5	0.9	0.99
Hoa Binh	64.4	90.2	142.6	238.6	378.9
Luang Prabang	34.7	50.7	79.2	121.0	168.1
Phrae	48.4	58.0	81.3	132.4	222.7

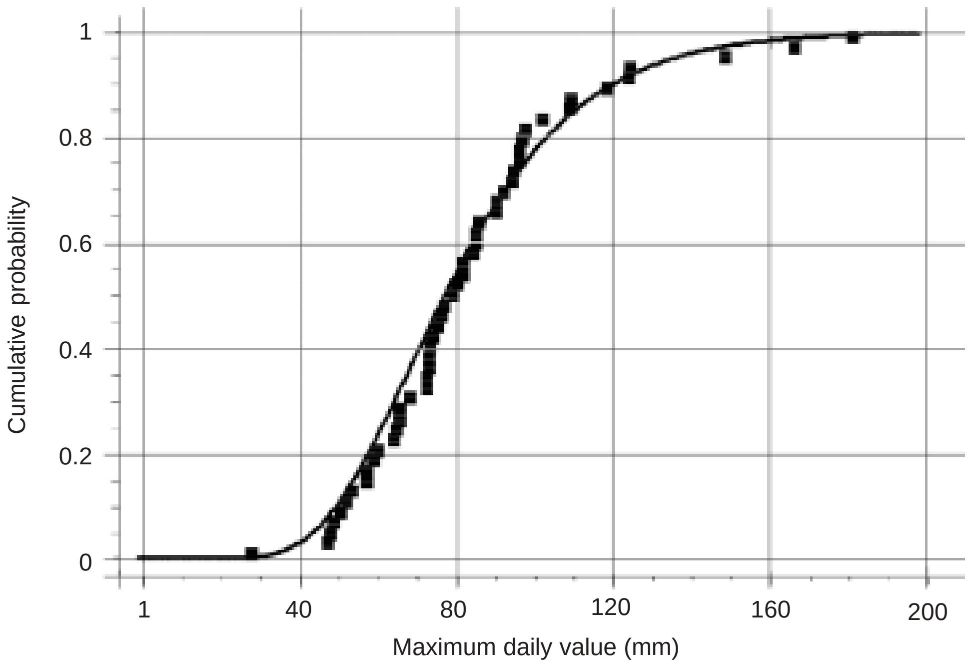

Figure 5. Adjustment of maximum daily rainfall at Luang Prabang.

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Factorial Analysis of Runoff and Sediment Yield from Catchments in Southeast Asia

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Abstract

The objective of this study was to evaluate the impacts of environmental factors (e.g., climate, topography, and land use) on runoff and sediment yield from 5 catchments and 21 sub-catchments located in five countries (Indonesia, Laos, Philippines, Thailand, and Vietnam) of Southeast Asia. Slope parameters were estimated using Arc-View software after catchment delineation with BASIN3 software. Land use was characterized from field surveys. Topographic attributes were derived from digital elevation models with a 10-m mesh. Precipitation amounts were determined using both automatic and manual rain gauges. Erosion and runoff were recorded from each catchment and sub-catchments during 2001 both manually using staff gauges and automatically using automatic water level recorders. Bed load sediments (BL), i.e., the sediments trapped in the weirs, were collected and weighed after each main rainfall event.

Mean catchment area was 40.1 ha (min. 0.9 ha, max. 290 ha). The annual precipitation amount (P) ranged from 938 to 3840 mm; the precipitation ratio (Pr), i.e., the ratio between the minimum monthly precipitation (Pn) and the maximum monthly precipitation (Px), ranged from 0.03 to 0.31; and the slope gradient (S) from 7.7° to 31°. Land use variables included the areal percentages of annual crops (C), crops associated with conservation practices (Cp), fallows or pastures (Fa), and forests (Fo). Teak and eucalyptus tree plantations, and orchards were placed in a single category (O). Mean runoff coefficient (R) was 22% (ranging from 0.4 to 48%); mean BL was 3 t ha^{-1} (0.01–20 t ha^{-1}). Mean suspended load sediments (SL) was 1.76 t ha^{-1} (0.04–6.37 t ha^{-1}) and mean sediment concentration (SC) was 1.63 g L^{-1} (0.33–3.50 g L^{-1}).

Annual runoff coefficient was predicted (R^2=0.73) using a stepwise regression model combining the impact of Px, S, and C. Similarly, SL was predicted (R^2=0.75) by C and Pr; C seemed to have the main influence on BL (R^2=0.41). No significant relation was found between runoff coefficient or sediment yield parameters and the catchment area. Also, there was no relation between runoff and sediment yield and Fo or Cp. This may be due to the absence of these two types of land use in some of the tested catchments. These results clearly illustrate the impact of annual crops on runoff and sediment yield under sloping land conditions.

Water availability, water quality, and sediment delivery have become a vital issue for food security, human health, and environment. In particular, most concerns stem from the rapid changes in land use patterns caused by demographic, economic, political, and/or cultural transitions (e.g., Ingram et al. 1996).

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Inappropriate land use is one of the major causes of decreasing water supply, and accelerated soil erosion and nutrient loss, particularly in areas of recent land cover changes such as tropical regions. The conversion of tropical rainforests to pastures or cultivated land commonly results in a reduction of surface soil porosity. Increased erosion removes the top soil where the major part of organic matter and nutrients are present. In addition to a decreased on-site productivity, these processes lead to off-site consequences including flooding, decrease of groundwater recharge, pollution by nutrients, heavy metals, and pesticides, siltation, and eutrophication of reservoirs (IGBP 1995).

Despite the crucial need for a sound assessment of these processes, available data remained scarce and was based on a single process observed at a specific scale (e.g., soil loss from erosion plots). In the sloping lands of Southeast Asia, land use changes are very rapid due to strong demographic, economic, and politic drivers. In many locations, the pristine forest has been cleared for slash and burn cultivation or for more intensified systems based on the use of pesticides, fertilizers, and machinery. At the onset of the rainy season, the tilled soil left bare tends to crust and generates runoff, which favors gully erosion. Conversely, appropriate land use can lead to soil and water conservation.

To tackle these issues, the Management of Soil Erosion Consortium (MSEC) initiated a research project in six countries of Asia with the support of the Asian Development Bank (ADB). It aims at developing, adapting, and disseminating appropriate tools and methodologies to reduce on-site and off-site effects of erosion on land and water resources (Maglinao and Penning de Vries 2003). Each participating country has selected a catchment of about 100 ha and delineated four to five sub-catchments within the catchment. These catchments are adequately equipped to monitor runoff and sediment yield and are representative of the prevailing biophysical and socioeconomic conditions. The objectives of this study are: (i) to assess runoff and sediment yield annual budget from the data collected in 2001 in 5 of these catchments and 21 sub-catchments; (ii) to assess the impact of land use, climate, topography on runoff, bed load sediments (BL) and suspended load sediments (SL) annual budgets; and (iii) to predict annual runoff coefficient and sediment yield using a statistical model.

Data Acquisition

Land use was assessed from detailed field surveys. Land use types included: forest (Fo), annual crops (C), and fallows or pastures (Fa). Crops associated with conservation practices (Cp) were mainly coffee and agroforestry techniques with annual crops. Teak and eucalyptus tree plantations, and orchards were placed in a single category (O). Topographic features of catchments were derived from Digital Elevation Model (DEM) with a 10-m mesh. In most cases, DEMs have been constructed at 10-m resolution by interpolation from digitized contours with a 5-m interval of 1:50,000 topographic map. Some accurate DEMs also have been established by interpolation from field spot heights using theodolithe (e.g., Laos). Spline Interpolations were performed using the interpolation tool of Arc-View software. Catchments were then automatically delineated from DEMs and weirs location within UTM system using BASIN3 (EPA 2000). Automatic delineation of catchments was used to avoid inaccuracies associated with expert judgment. The BASIN3 delineation tool allows a manual delineation of sub-catchment boundaries and uses the multiple flow direction algorithm of Quinn et al. (1991). After removal of the sinkholes from the DEM map grid, a flow direction was automatically estimated to determine a stream network using a threshold area of 0.5 ha. Topographic characteristics as slope angle were estimated from DEMs of each catchment using Arc-View software.

Runoff and sediment yield were monitored from the 26 catchments (5 main catchments and 21 sub-catchments) in five countries (Indonesia, Laos, Philippines, Thailand, Vietnam) throughout the rainy season of 2001. The area of the catchments and sub-catchments ranged from 0.9 to 290 ha (Table 1). The detailed description of the biophysical and socioeconomic conditions in these catchments are given in the individual country reports. Manual rain gauges with a daily time step and automatic weather stations with a 6-minute data acquisition were installed in each main catchment. Weather and water-level data were downloaded every week.

Table 1. Main topographic and land use factors of the 5 catchments and 26 sub-catchments in Southeast Asia[1].

Sub-catchment	Study name	Surf (ha)	S (°)	C (%)	Fa (%)	Cp (%)	O (%)	Fo (%)
Laos								
S0	L0	1.2	25.0	0.0	69.0	0.0	31.0	0.0
S1	L1	19.6	29.0	9.2	76.0	0.0	0.8	14.0
S2	L2	32.8	27.0	1.7	19.7	0.0	7.0	11.6
S3	L3	51.4	25.0	18.6	61.2	0.0	9.5	10.2
S4	L4	60.2	28.0	2.3	52.7	0.0	9.9	35.1
S5	L5	63.0	17.0	0.0	55.7	0.0	31.0	13.4
Vietnam								
W1	V0	4.6	28.0	80.0	0.0	20.0	0.0	0.0
W2	V1	9.4	29.0	0.0	5.0	95.0	0.0	0.0
W3	V2	6.2	27.0	0.0	35.0	65.0	0.0	0.0
W4	V3	11.7	31.0	0.0	60.0	40.0	0.0	0.0
MW	V4	59.5	25.0	28.0	22.0	20.0	30.0	0.0
Indonesia								
Babon	Ib	290.0	10.0	0.0	0.0	0.0	100.0	0.0
Sill	Is	150.0	8.0	10.0	0.0	90.0	0.0	0.0
Tegalan	It	3.2	14.0	50.0	0.0	0.0	50.0	0.0
Rambutan	Ir	2.0	12.0	0.0	0.0	0.0	100.0	0.0
Kalisidi	Ik	38.5	8.0	0.0	0.0	0.0	100.0	0.0
Philippines								
Main	P0	84.5	14.0	23.7	45.0	16.8	0.0	15.4
MC1	P1	24.9	14.0	10.0	60.2	12.1	0.0	16.1
MC2	P2	17.8	14.0	47.8	39.3	5.6	0.0	11.2
MC3	P3	7.9	14.0	15.2	76.0	12.7	0.0	12.7
MC4	P4	0.9	25.0	42.6	31.9	0.0	0.0	21.3
Thailand								
W1	T1	7.5	14.1	30.0	0.0	30.0	30.0	0.0
W2	T2	7.8	11.6	80.0	0.0	0.0	1.0	10.0
W3	T3	2.2	12.7	3.0	2.0	2.0	92.0	0.0
W4	T4	7.5	14.6	60.0	0.0	15.0	15.0	10.0
Flume	Tf	79.5	11.4	70.0	5.0	12.0	8.0	5.0

1. Surf is the catchment area; S is the slope angle; areal percentage is denoted as C for annual crops, Fa for fallows or pastures, Cp for crops with conservation practices, O for orchards, and Fo for forest.

Runoff and erosion data were collected at the outlet of each catchment where hydrologic stations have been constructed and instrumented. Erosion and runoff in each catchment were recorded throughout 2001 both manually using staff gauges and automatically using the automatic water level recorders. The location of these structures and equipment were reported using a geographic positioning system (GPS). Water level in the weirs was automatically recorded at a time step lower than 10 minutes. Water samples were collected during the main rainfall event to assess the sediment concentration. The time interval for water sampling differed among sites. Samples were collected at time intervals from 2 minutes to 1 hour depending on water discharge peaks. Sediment concentration has been assessed in Indonesia, Laos, and Thailand catchments only. Bed load sediments, i.e., the sediments trapped in the weirs were collected and weighed after each main rainfall event or once at the end of the rainy season. Runoff and sediment yield data were computed over 2001 to obtain yearly means. Runoff was derived from water depth after calibration curves were established in the field. Mean annual suspended sediment concentration was combined with water fluxes data to assess the annual suspended load, using data interpolation between the sampling periods.

Statistical Analysis and Modeling

The relation between environmental factors and runoff coefficient (R), BL, and SL was first investigated using correlation coefficient. Variance analysis was done between runoff and sediment yield budget as dependent variables and environmental factors as independent variables. These environmental factors included the annual precipitation amount (P), the precipitation ratio (Pr) between the minimum monthly precipitation (Pn) and the maximum monthly precipitation (Px), the slope gradient (S), the catchment area (Surf), and the areal percentage of each land use type. Statistical analysis was carried out with the Statistica® package for use on a personal computer (StatSoft 1995). The statistical significance of results was evaluated using the *P*-level, considering values that yield 0.05 (*) and 0.01 (***) as statistically significant and highly significant, respectively.

Forward stepwise regression analyses were used to predict runoff and sediment yield budgets using environmental factors as predictors. Regression analyses were performed using the Statistica® package. Only parameters with statistical significance at the 0.01 level were considered for computing predictive equations and reporting results. Depending on the available data, these analyses have been conducted for a varying number of catchments and sub-catchments, i.e., n=16, 21, and 11 for R, BL, and SL, respectively.

Stepwise Regsression Analysis

Statistics of environmental variables and sediment variables are presented in Tables 2, 3, and 4. Runoff and sediment yield were not significantly related to Surf. Runoff coefficient was highly correlated to O (R = –0.87) and slope angle S (R = 0.56). BL was significantly correlated to C (R = 0.83) while SL was mainly related to C (R = 0.76) and Pr (R = 0.61).

The results of the stepwise regression analysis are given in Table 5. The relationships between the observed and predicted mean annual runoff and between the observed and predicted mean annual sediment load are presented (Figs. 1 and 2). Deviations from the regression line are very low for runoff values lower than 15%. For higher runoff values, spot scattering slightly increased, deviations being lower than 30% of runoff value. Less than half of the variance of BD is explained by C ($R^2 = 0.41$). The regression model for SL included Pr and C. It explained a high proportion of the variance of SL ($R^2 = 0.75$), with an equal distribution of the regression errors.

It is interesting to note that the model deviation errors could be ascribed to country conditions, suggesting some site specificity. For instance, the Philippine catchments were systematically situated under the regression line for BL lower than 10 t ha^{-1}, the highest loads being highly underestimated (Fig. 3). BL of Vietnam catchments were underestimated for low erosion rates and over estimated for high values. This regression model seems to best predict BL for Indonesian and Laotian catchments.

Discussion

Under analogous circumstances, runoff coefficient and sediment yield usually decrease when the catchment area increases. Despite values ranging from 0.9 to 290 ha, such relation could not be established here, presumably because of the overriding influence of land use. As observed also in West Africa, the runoff coefficient increases due to a stronger development of surface crusts even when annual rainfall decreases (Valentin 1996). The areal percentages of fallow, forest, or crops associated with conservation practices did not statistically influence runoff production or sediment yield, probably because their effects were counterbalanced by other factors as slope angle for runoff and the areal percentage of annual crop for sediment yield. Contrary to what have been observed on micro-plots in the Thai catchment, runoff at the catchment scale increases with mean slope angle. The two observations are consistent because the water flux

Table 2. Main statistics for environmental factors[1].

Description	Surf (ha)	P (mm)	Pm (mm)	Pr (%)	S (°)	C (%)	Fa (%)	Cp (%)	O (%)	Fo (%)
Mean	40.15	2019	466	16	18.8	22.4	27.5	16.8	24.0	7.2
Minimum	0.94	1385	275	3	8.0	0.0	0.0	0.0	0.0	0.0
Maximum	290.00	3840	672	31	31.0	80.0	76.0	95.0	100.0	35.1
SD	62.08	938	151	9	7.7	26.8	28.4	27.1	34.8	8.9

1. Surf is the catchment area; P is the annual precipitation amount; Pm is the maximum monthly precipitation; Pr is the ratio between the minimum monthly precipitation (Pn) and Pm; S is the slope angle; the areal percentages are denoted as C for annual crops, Fa for fallows or pastures, Cp for crops with conservation practices, O for orchards, and Fo for forest.

Table 3. Main statistics for runoff and sediment yield variables[1].

Description	R (%)	BL (t ha^{-1})	SL (t ha^{-1})	SC (g L^{-1})
Mean	22.3	3.01	1.76	1.63
Minimum	0.4	0.01	0.04	0.33
Maximum	48.0	20.02	6.37	3.50
SD	17.8	4.92	1.99	1.04

1. R = runoff coefficient; BL = bed load sediments; SL = suspended load sediments; and SC = sediment concentration.

Table 4. Correlation coefficients between environmental factors, runoff, and sediment yield variables[1].

Description	Surf (ha)	P (mm)	Pm (mm)	Pr (%)	S (°)	C (%)	Fa (%)	Cp (%)	O (%)	Fo (%)
R	0.04	–0.95*	–0.91*	0.95*	0.55*	0.25	0.53	0.21	–0.87*	0.39
BL	–0.29	–0.16	0.01	0.22	–0.37	0.83*	–0.4	–0.07	–0.27	0.04
SL	–0.08	–0.54	–0.3	0.61*	–0.28	0.76*	–0.37	0.43	–0.47	0.21
SC	0.33	0.35	0.2	–0.39	0.23	–0.04	0.18	–0.45	–0.05	0.21

1. Surf is the catchment area; P is the annual precipitation amount; Pm is the maximum monthly precipitation; Pr is the ratio between the minimum monthly precipitation (Pn) and Pm; S is the slope angle; the areal percentages are denoted as C for annual crops, Fa for fallows or pastures, Cp for crops with conservation practices, O for orchards, and Fo for forest.
* = Significant at $P = 0.05$.

Table 5. Regression analysis between runoff coefficient, sediment yield factors, and the most relevant environmental factors.

Regression equations	No. of catchments	R^2
Runoff coefficient (%)		
$R_{est} = 24.1 – 0.48\ Px + 0.42\ S + 0.42\ C$	16	0.73
Bed load sediment (t ha^{-1})		
$BL_{est} = 0.28 + 0.648\ C$	21	0.41
Suspended load sediment (t ha^{-1})		
$SL_{est} = –0.79 + 0.638\ C + 0.503\ Pr$	11	0.75

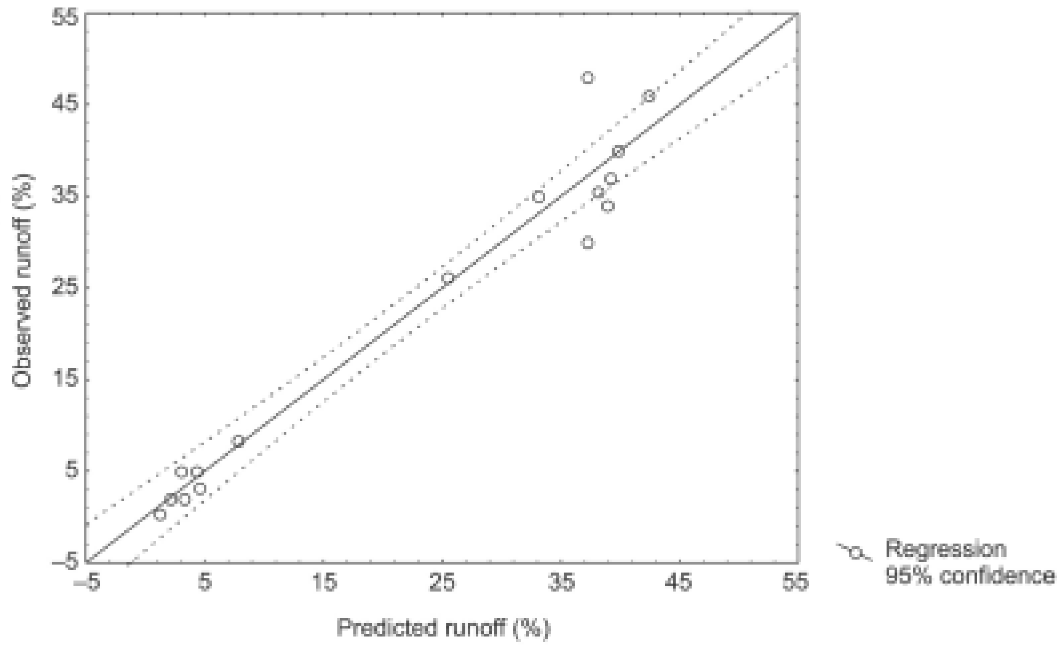

Figure 1. Observed mean annual runoff as a function of predicted runoff for a data set of 16 catchments in Southeast Asia.
(Note: Y=X and 95% confidence lines are presented.)

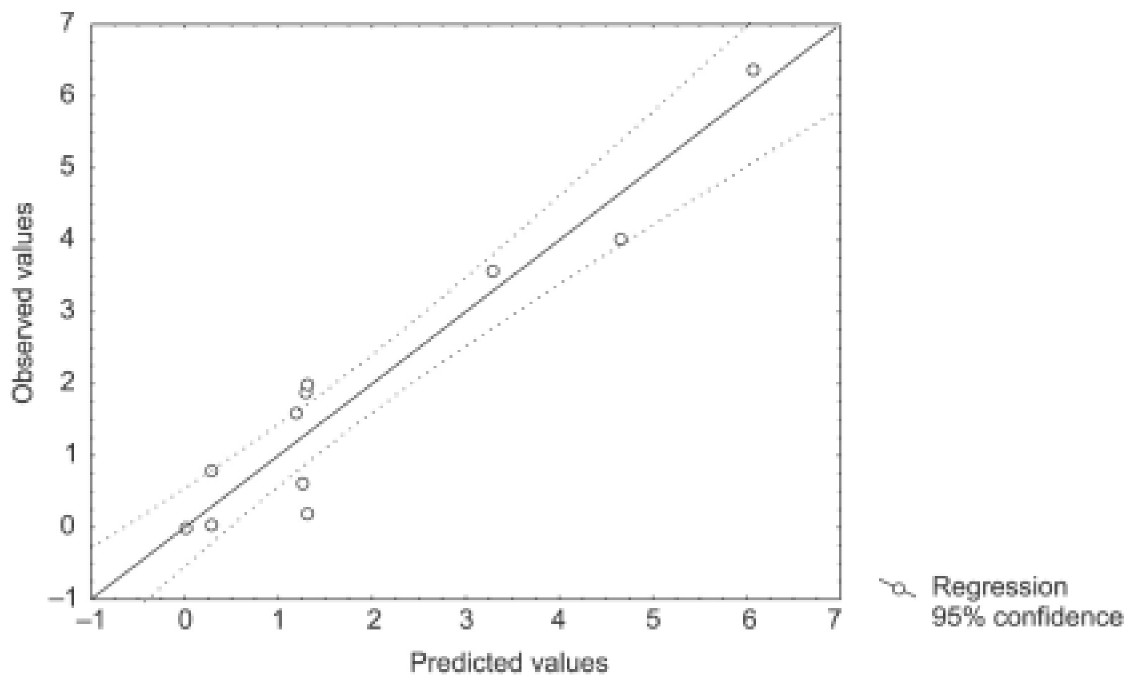

Figure 2. Observed mean annual suspended sediment load as a function of predicted suspended sediment load for a data set of 11 catchments in Southeast Asia.
(Note: Y=X and 95% confidence lines are presented.)

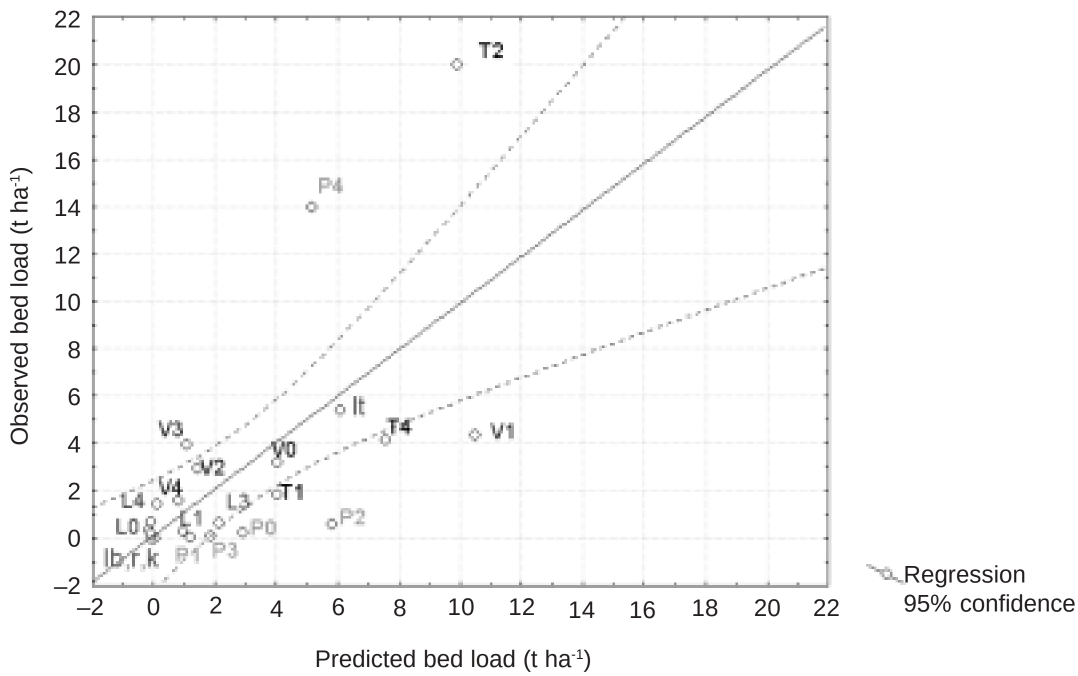

Figure 3. Observed mean annual bed load as a function of predicted bed load for a data set of 21 catchments in Southeast Asia.

[Note: Y=X and 95% confidence lines are presented. Relation between estimated values and catchment named after country: Indonesia (It, Ib, Ir, Ik), Laos (L0 L1, L3, L4), Philippines (P0 to P4), Thailand (T1, T2, T4), and Vietnam (V0 to V4).]

recorded from a steep slope catchment can result from the combination not only of surface runoff water but also of water that has been infiltrated in the hillslope and ex-filtrated in the bottom as suggested by preliminary isotopic assessment in Laos.

The deviation errors from the model for bed load, which are specific to each country, can reflect the impact of other factors such as surface stoniness, soil resistance to shear stress, and mean depth of soil. Thinner soil with low soil water storage may affect sediment losses (Burt 2001). Under these sloping land conditions, the percentage of annual crops, not associated with conservation practices, appears as the main factor controlling sediment yield, both in terms of suspended load and bed load, irrespective of the size of the catchment. These results indicate that annual crop proportion seems to be the key parameter for bed load and suspended load production. More surprisingly, no significant relation was found between runoff coefficient or sediment yield variables and the areal percentages of land occupied by forest or crops associated with conservation practices. This may be due to auto-correlation among the various land use types. This study should be conducted over a longer period to validate and refine these preliminary statistical analyses and to test the influence of other land use types on runoff and sediment yield from the same catchments.

Conclusions

This study leads to three main conclusions:

- The MSEC network of catchments and sub-catchments provides an invaluable tool to test the impact of land use changes on runoff production and sediment yield on various biophysical and socioeconomic conditions.
- The annual runoff coefficient increases due to surface layer crusting even with decreasing annual rainfall and increasing slope angle. Thus more attention should be paid to water conservation in the drier catchments with very steep slopes (e.g., Laos) than in wetter countries with gentler slopes (e.g., Indonesia).
- The areal percentage of the catchment cultivated with annual crops is the best predictor of sediment yield.

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Land Use Characteristics and Hydrologic Behavior of Different Catchments in Asia

M G Villano[1] and R O Ilao[2]

Abstract

Development and management of natural resources is crucial for increasing and sustaining the system productivity and maintaining ecological balance. There is lack of information in most of the less developed countries to know the effect of land use on hydrological behavior. Such information is useful for formulation and implementation of the appropriate natural resource management policies. The paper presents the hydrological effects of various land uses in some catchments in Asia. This activity is a part of the on-going catchment study of the Management of Soil Erosion Consortium (MSEC)-International Water Management Institute and identifies indicators/criteria such as peak runoff, total runoff, duration of runoff, time of concentration of runoff, sediment load, and groundwater levels to evaluate impact of changes in land uses. A set of recommendations is drawn for collection of reliable hydrologic data for meaningful analysis and practical utility of such data to planners and policy makers.

Quantitative data on the impact of different land uses on the behavior of catchments are indispensable information not only for extension workers to advise farmers on conservation farming techniques, but also for planners and decision-makers to formulate appropriate and implementable policies for sustainable development and management of the natural resources. Such information is also very useful to engineers for the proper design of water control structures for irrigation, flood control, and soil and water conservation. Among others, the more significant environmental impacts of land use and cover type modifications are hydrologic in nature. Specifically, these include variation in runoff, soil erosion, and sediment transport, and groundwater quantities. In most of the less-developed countries, however, there is practically a dearth of factual data on the effects of land use on the hydrologic behavior of a catchment. Indeed, the on-going catchment study of the Management of Soil Erosion Consortium (MSEC)-International Water Management Institute (IWMI) is a move towards addressing such data gaps.

The objectives of this paper are to: (i) identify criteria and indicators for evaluating the relationships of land use characteristics and hydrologic responses in a catchment level; (ii) present MSEC methodology of hydrologic field data monitoring and preliminary analysis of available results; and (iii) make relevant recommendations.

The Hydrologic Cycle

The hydrologic cycle or water cycle may be visualized as starting with the upward movement of water in the form of vapor (caused by radiation from the sun) from bodies of water (e.g., ocean, lakes, reservoirs, and rivers) and moist soil by evaporation and from vegetation by transpiration (Fig. 1). Such vapor is transported by air mass, forms clouds, and may fall on the land surface vegetation and into the bodies of water including the ocean as precipitation. Precipitation reaching land surfaces is disposed off in different ways. Some infiltrate below the ground and others move down the land slopes as surface runoff or overland flow. As surface runoff moves over the land surface, some of it may still infiltrate below the ground and the rest may reach depressions, gullies, streams, and rivers and finally leads to the lake or

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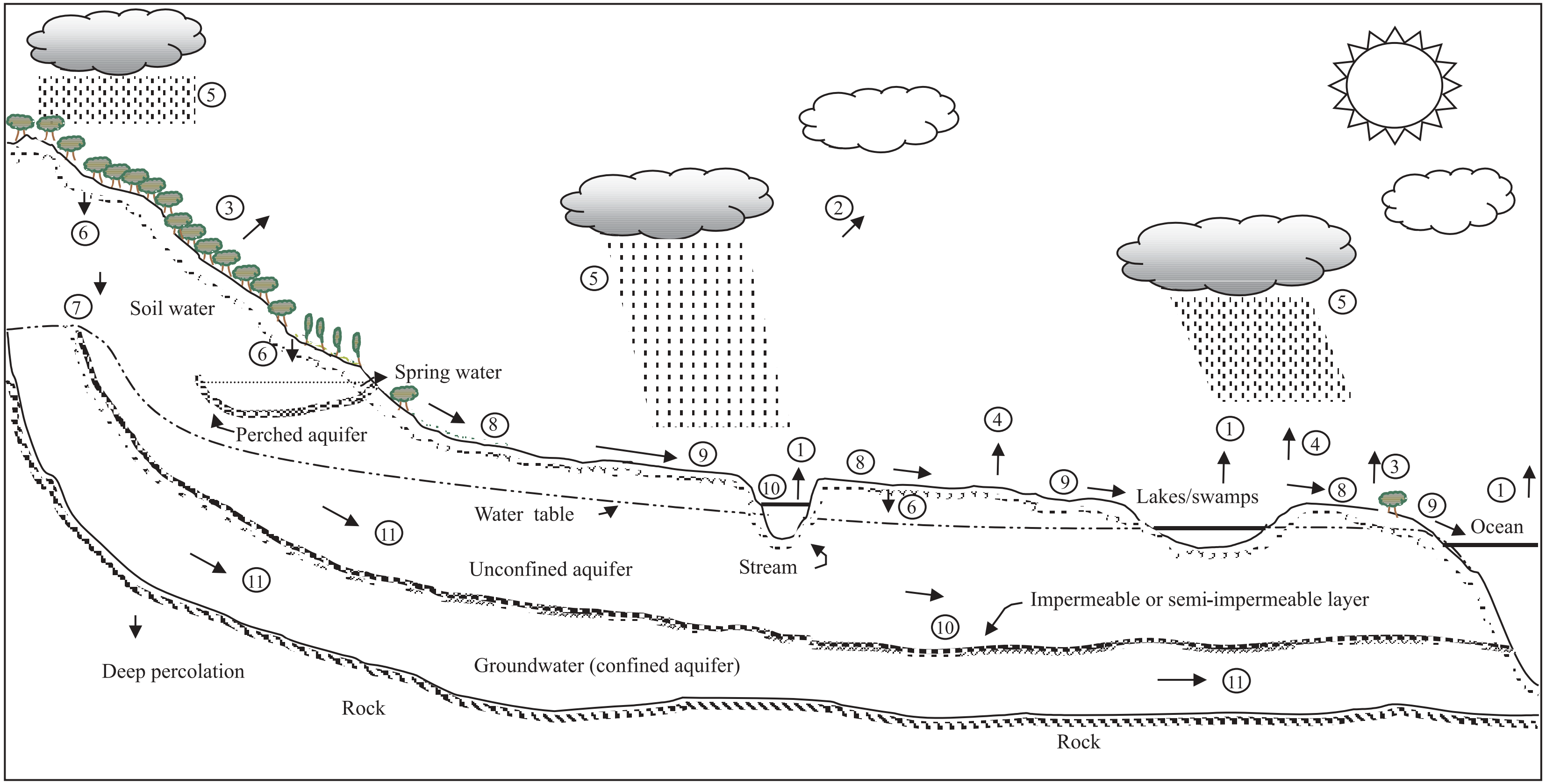


Hydrologic processes
1 = Evaporation from water surfaces (oceans, lakes, rivers, dams, canals)
2 = Raindrop evaporation
3 = Transpiration from plants
4 = Evaporation from moist soil
5 = Precipitation/Rainfall
6 = Infiltration through soil surface
7 = Percolation
8 = Surface runoff/Stream flow
9 = Soil erosion and sediment
10 = Stream flow
11 = Groundwater flow

Figure 1. The hydrologie cycle.

ocean. Surface runoff added to the stream flow is referred to as direct runoff.

The portion of precipitation that infiltrates below ground surface enhances the soil water. If the infiltrating water encounters an impermeable soil layer, it may seep laterally and will return to the surface at some location away from the point of entry. This component of runoff is known variously as interflow, storm seepage, or quick-return flow. As more fraction of precipitation infiltrates below the ground surface, the soil water further increases and reaches the maximum water retention capacity of the soil. Beyond this capacity, succeeding infiltration water may percolate down the soil profile and into the groundwater (aquifers). This could increase the unconfined aquifer's water level or piezometric water level of confined aquifers. Some of this move as groundwater flow towards the stream as its base flow. Confined aquifer is the main source of free-flowing well. A perched aquifer is a layer of semi-permeable soil formation above the normal water table. It could intercept and store infiltrating water and with favorable conditions it may release water out to the mountain sides as spring water. Such water could contribute to the base flow of a stream.

Hydrologic Effects of Land Use and Cover Type Modifications

As presented by David (1984), typical land uses may be categorized as forest land, grassland, arable land, and urban and industrial lands. In a given catchment, the change of existing land use to another or the conversion of a significant portion of it to other land uses may result in positive or negative effects. For example, conversion of a significant forest area to arable land could accelerate soil erosion leading to decreased crop productivity level, increased sediment material downstream, and decreased fresh water supply availability. On the other hand, the introduction of soil conservation measures (e.g., contour cultivation, hedgerows, terracing, and check-dams) in available lands may control soil erosion and runoff, and increase dependable water supply.

Effects of land uses on infiltration and percolation

It is through infiltration and percolation that groundwater in aquifers is recharged leading to sustained freshwater supply and enhanced environment in general. Of the above mentioned land uses, forest cover has the greatest effect on enhancing the infiltration and percolation rates of the soil. The increase in infiltration is mainly due to the addition of high organic matter of decayed litter that falls on the ground surface while the improvement in percolation rates of the soil profile is affected by the decayed deep-penetrating tree roots and burrowing earthworms. While well-managed grassland also improves surface soil infiltration rates, the relatively shallower roots could hardly improve the percolation rates of lower soil profile. Generally, infiltration and percolation rates of arable lands are relatively low, especially if no adequate soil and water conservation is practiced.

Effects of land uses on runoff

Storm runoff hydrograph

Total runoff measured in a stream is the sum of surface runoff (or direct runoff), interflow, and base flow (or groundwater flow). The most dramatic impacts of land use and cover type are on the variation with time of these stream flow components in a storm hydrograph (Fig. 2). Specifically, the relevant hydrograph components affected by land use are the peak flow, direct runoff volume, and base flow. For good soil and water conservation, direct runoff should be less but base flow should be high.

The magnitude of surface runoff is highly dependent on the infiltration and percolation rates of the soil. The effects of different land uses or cover types on surface runoff are related to their effects on infiltration and percolation rates. Generally, forest land will yield the least surface runoff volume and peak flow, followed by grassland, arable land, and urban and industrial lands in increasing order. In terms of runoff coefficient values (the fraction of precipitation that reaches the stream as surface or direct runoff), estimated runoff-producing potentials of vegetation and land use common in the Philippine watersheds are given in Table 1. Other sample values are given in Tables 2 and 3.

Forest land with dense trees effectively restrict fast movement of surface water resulting in longer time to peak than arable lands without soil conservation measures. Arable land with hedgerows, terraces, check-dams, and other conservation structures, however, may exhibit longer time to peak than grasslands or urban and industrial lands. There is a limit to the amount of precipitation that could be allowed to infiltrate and percolate below ground surface. Thus, extended downpours with intensity very much greater than the infiltration rate of soil occurring in forest lands, could still result into very destructive flash floods downstream.

Annual runoff hydrograph

Annual hydrograph shows the variation of daily, weekly, or decadal mean flows over a year. Based on the annual hydrographs, streams may be classified into three classes as: (i) perennial, (ii) intermittent, and (iii) ephemeral (Subramanya 1984) (Fig. 3).

A perennial stream always carries some flows. There is considerable base flow (or groundwater flow) throughout the year as the water table is above the stream bed (an effluent stream) even during the dry season. Normally, the catchment or recharge area of this stream is of good cover such as primary forest or well managed grasslands.

An intermittent stream has limited contribution from groundwater. The stream may be effluent during wet season, but becomes influent during the dry season. Depending on the catchment's geological nature, such a stream may become perennial under favorable land use and ground cover which could significantly enhance annual recharge of the groundwater.

A stream which does not have any base flow contribution is referred to as ephemeral. Its annual hydrograph (Fig. 3) shows series of short-duration spikes marking flash flows in response to storms. It becomes dry soon after the end of the storm flow. This stream may become intermittent or even perennial with improved land use and ground cover if the soil and geological characteristics would allow significant subsurface water recharge and fair to good groundwater flow.

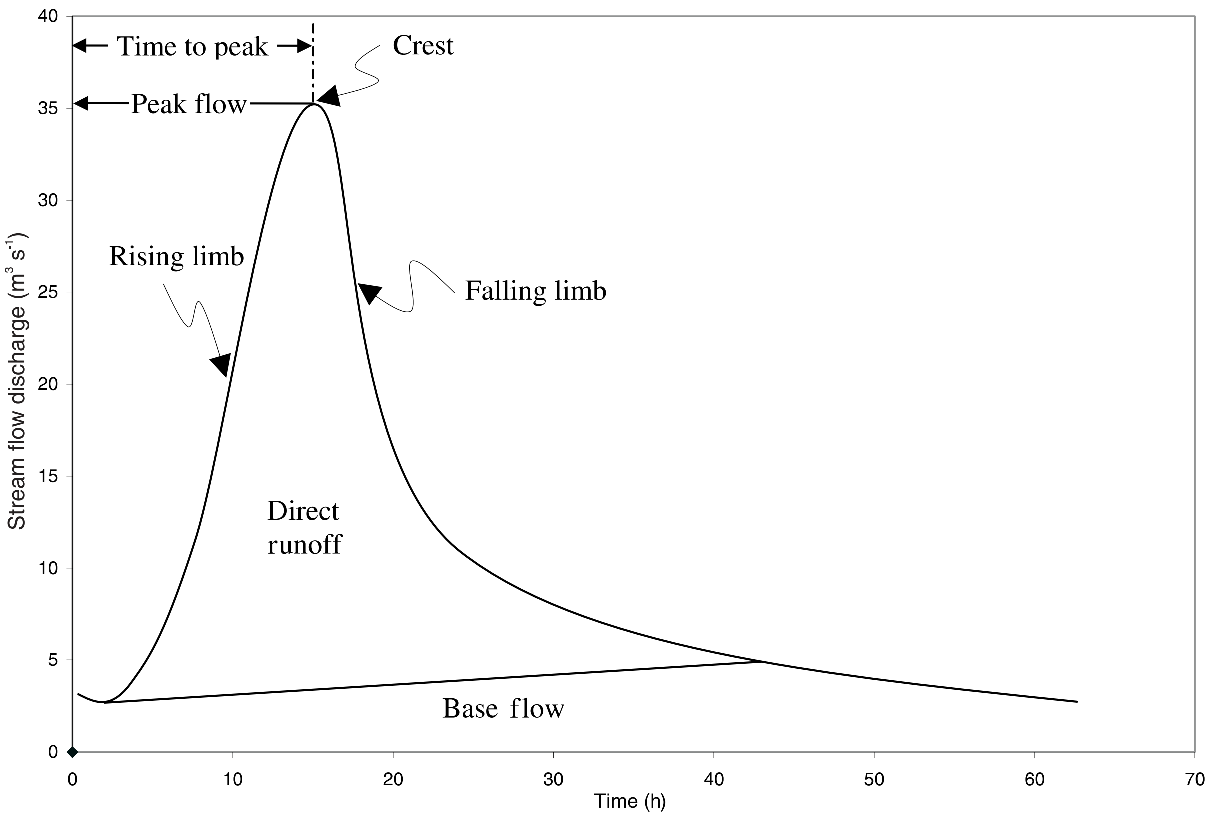


Figure 2. Components of a storm hydrograph.

Table 1. Estimated crop cover coefficient (C) values for the common cover conditions of Philippine watersheds.

Cover	C value	C value (%)
Bare soil	1.0	100
Primary forest (with dense undergrowth)	0.001	0.1
Second growth forest with good undergrowth and high mulch cover	0.003	0.3
Second growth forest with paths of shrubs and plantation crops of 5 years or more	0.006	0.6
Industrial tree plantation (ITP)		
Benguet pine with high mulch cover	0.007	0.7
Mahogany, *narra*, 3–8 years with good cover crop	0.01–0.05	1–5
Mahogany, *narra*, 8 years or more with good undergrowth	0.01–0.05	1–5
Yemane, 8 years or more	0.08	8
Mixed stand of ITP plant species, 8 years or more	0.07	7
Agroforestry tree species		
Cashew, mango, and jackfruit, less than 3 years, without intercrop and with ring weeding	0.25	25
Cashew, mango, and jackfruit, 3 to 5 years without intercrop, without ring weeding	0.15	15
Cashew, mango, and jackfruit with intercrop or native grass undercover	0.08	8
Mixed stand of agroforestry species, 5 years of more with good cover	0.08	8
Coconut with tree intercrops	0.05–0.10	5–10
Coconut with annual crops as intercrop	0.10–0.30	10–30
Ipil-ipil, good stand, first year with native grass intercrop	0.20	20
Ipil-ipil, good stand, 2 years or more with high mulch cover	0.10	10
Ipil-ipil for leaf meal or charcoal	0.30	30
Grasslands		
Imperata or Themeda grasslands, well established and undisturbed, with shrub	0.007	0.7
Imperata or Themeda grasslands, slightly grazed, with patches of shrub	0.15	15
Shrubs with patches of open, disturbed grasslands	0.15	15
Well-managed rangeland, slightly grazed cover of slow development, first year	0.30–0.80	30–80
Well-managed rangeland cover of fast development, first year, ungrazed	0.05–0.10	5–10

continued

Table 1. *continued.*

Cover	C value	C value (%)
Well-managed rangeland, slightly grazed cover of slow development, 2 years or more	0.01–0.10	1–10
Well-managed rangeland cover of fast development, ungrazed, 2 years or more	0.01–0.05	1–5
Grassland, moderately grazed, burned occasionally	0.20–0.40	20–40
Overgrazed grasslands, burned regularly	0.40–0.90	40–90
Annual cash crops		
Maize, sorghum	0.30–0.60	30–60
Rice	0.10–0.20	10–20
Groundnut, mung bean, soybean	0.30–0.50	30–50
Cotton, tobacco	0.40–0.60	40–60
Pineapple	0.20–0.50	20–50
Banana	0.10–0.30	10–30
Diversified crops	0.20–0.40	20–40
New Kaingin areas, diversified crops	0.30	30
Old Kaingin areas, diversified crops	0.80	80
Others		
Built-up rural areas, with home gardens	0.20	20
Riverwash	0.50	50

Source: David (1988).

Table 2. Sediment and surface water yields[1].

Land use or cover type	Average annual rainfall (mm)	Average annual runoff (mm)	Runoff coefficient (%)	Annual sediment yield (t ha^{-1})	
				Range	Mean
Open land					
Cultivated	1321	406	31	8.11–106.40	53.75
Pasture (one unit)	1295	381	29	2.94–5.02	3.98
Forest land			14		0.32
Abandoned fields	1295	178	10	0.02–1.33	0.25
Depleted hardwoods	1295	127	2	0.05–0.79	0.05
Pine plantations	1372	25	18	0.00–0.20	0.05
Mature pine-hardwoods[2]	1295	229		0.02–0.10	
Gullies[3]	1346	-	-	208.31–986.69	449.72

1. Data are means of 9 values, 3 replications of each cover for the 3 years, 1959–61 except pine-hardwoods (1960–61).
2. These watersheds are on hydrologically shallow soils.
3. Average annual and sediment outflow from 7 gullies for the 5 years, 1956–60.

Source: Ursic and Dendy (1965).

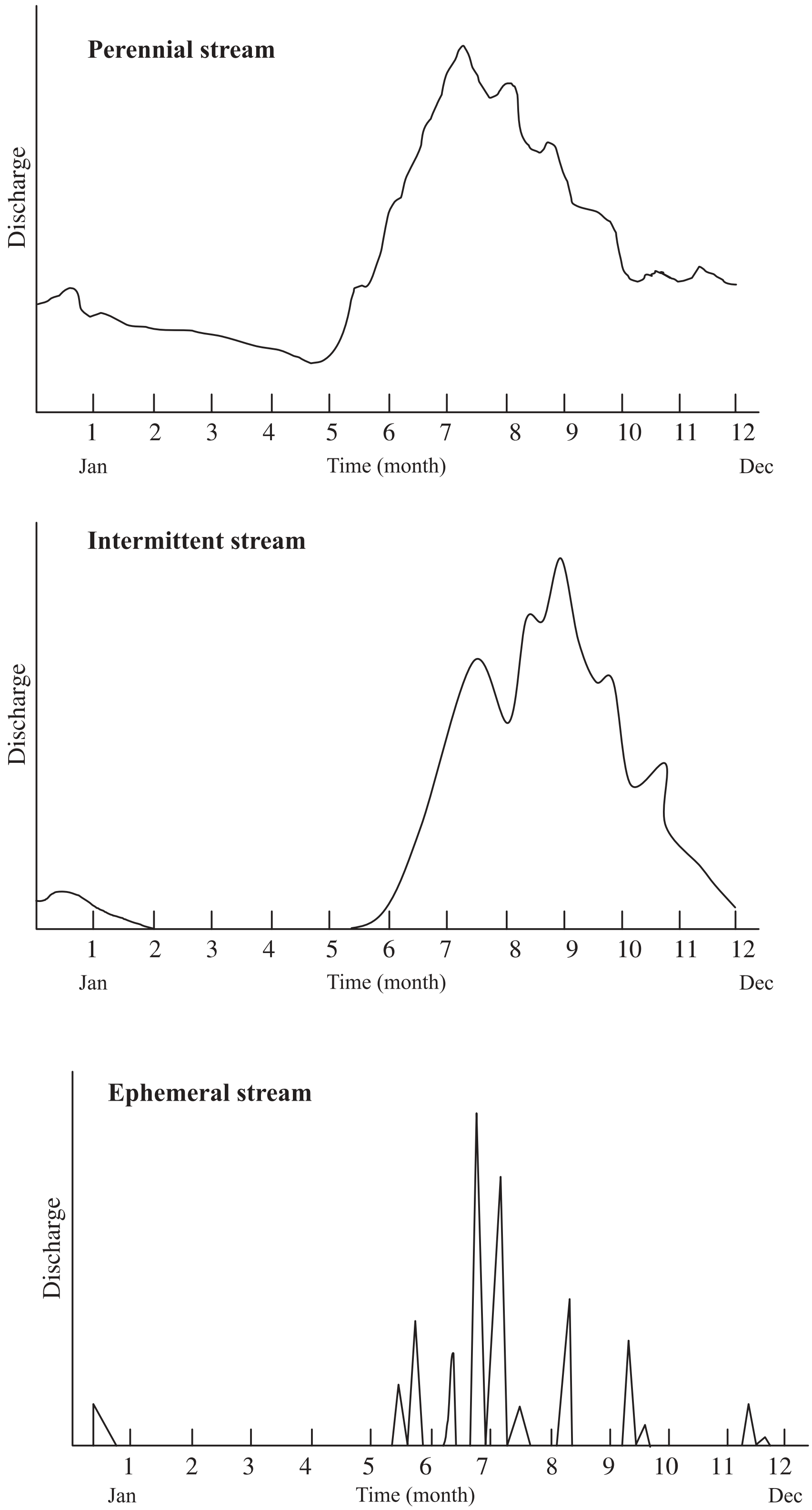


Figure 3. Annual runoff hydrographs.
(Source: Subramanya 1984)

Table 3. Barlow's runoff coefficient K_b in different catchments (for use in Uttar Pradesh, India).

Class	Description of catchment	K_b[1] (%)		
		Season 1	Season 2	Season 3
A	Flat, cultivated, and absorbent soils	7	10	15
B	Flat, partly cultivated, stiff soils	12	15	18
C	Average catchment	16	20	32
D	Hills and plains with little cultivation	28	35	60
E	Very hilly, steep, and hardly any cultivation	36	45	81

1. Season 1: Light rain, no heavy downpour; Season 2: Average or varying rainfall, no continuous downpour; and Season 3: Continuous downpour.

Source: Subramanya (1984).

Effects of land uses on soil erosion and sediment transport

Soil erosion by water may be defined as the detachment and transport of soil from the land surface by rainfall and runoff energy (wind erosion is less significant than water erosion in Asian countries). The subsequent transport of detached particles downstream through channels or streams is referred to as sediment transport. Sediment discharge, sediment load, and sediment yield refer to the amount of sediment delivered downstream per unit area per unit time by the catchment through its channels or stream network. The magnitude of soil erosion is dependent on the interactive effects of climate, soil characteristics, geology, topography, surface cover, and land use. For a given catchment of known soil types, geology, and topography, however, the rate of soil erosion may be expected to vary with the interaction of precipitation with land use and cover type.

Different ground cover types and land uses vary in the degree of protecting the soil against the detaching and transporting power of raindrops and surface runoff. Thus, lands fully covered with forest trees and grasses are ably shielded against raindrop erosion while arable lands with bare areas are vulnerable to it. As the kinetic energy or erosive power of surface runoff is also dependent on its mass, land use or cover type which enhances infiltration and percolation and tends to yield lesser runoff; hence, less soil erosion.

The effect of land use is on the production of sediment material through erosion and its efficacy in intercepting or trapping such sediment material. The arable lands are expected to yield more sediment materials compared to forest and grasslands.

Criteria and Indicators for Evaluating Hydrologic Impacts of Land Use and Cover Type Modification

The more significant hydrologic impacts of land use and cover type that need quantification are runoff, groundwater recharge, soil erosion, and sediment transport. For a particular catchment of known soil type, geology, and topography, the variations in these hydrologic processes are mainly dependent on the interactions of other hydrologic processes, namely, precipitation, infiltration, and percolation.

The best way of characterizing land use effect on runoff behavior is to quantify the more relevant components of storm hydrographs of a catchment. Of specific interest are the peak runoff, time to peak, direct runoff volume, and base flow volume increment. The first three are more relevant to their impacts on flood hazards, soil erosion, and sediment transport (Table 4). Base flow is the available stream flow during non-rainy days. Another indicator of the runoff-producing effect of land use is the runoff coefficient (ratio of direct runoff to precipitation) of the catchment. Indicators of the effects of land use on groundwater recharge may include measurement of changes in spring water discharge, depth of static water table of unconfined aquifers and depth of static piezometric water level in confined aquifers. Annual stream hydrographs could also indicate possible long-term changes in groundwater storage.

On a catchment level, the effects of the different combinations of land uses and cover types on soil erosion and sediment transport may be assessed by measuring the sediment yield of the stream flow.

Table 4. Criteria and indicators for evaluating hydrologic effects of land use and cover type.

Major hydrologic criteria	Major impacts onenvironment	Some quantifiable hydrologic indicators
Runoff	Flood water hazards downstream	Storm hydrograph peak flow; storm hydrograph time to peak.
	Water source for dams/reservoirs	Storm hydrograph direct runoff; downstream flood damages; runoff coefficient.
	Available stream water during dry days	Storm hydrograph base flow; annual stream flow hydrograph.
Groundwater recharge/flow	Fresh water resources availability and sustainability	Change in soil water storage; change in spring water discharge from perched aquifers; change in depth of static water table of unconfined aquifer; change in depth of static piezometric water level in confined aquifer; storm hydrograph base flow; annual stream flow hydrograph.
Soil erosion and sediment transport	Potential downstream sedimentation problems	Stream flow sediment load/ yield; sediment delivery ratio.

However, the total stream sediment load measured at the gauging station could also include eroded soils from gullies, stream banks, and landslides. If such added sediments are significant in magnitude, appropriate corrections on the total sediment yield may have to be done before computing the soil erosion rate (sheet and rill or interrill).

MSEC Methodology of Hydrologic Data Monitoring

Hydrologic data collection and measurement

The hydrologic data being monitored are listed in each of the MSEC catchments in Table 5. Figure 4 shows a typical instrumentation layout. Regular field monitoring of the possible change in the land uses and cover types is being done in each catchment. Specific farm activities are also noted including soil and water conservation measures being practiced.

Data analysis approaches

Analysis and interpretation of field data may be done in two ways. One is to find effects of land use modifications on selected hydrologic criteria of a given catchment of known soil, geologic formation, and topographic characteristics. It may take considerable time before statistically significant change on some hydrologic indicators could be observed. It may, for instance, take several years before a newly-started reforestation project could effect significant change on a storm hydrograph component such as peak flow, time to peak, and base flow. The factorial analysis of runoff and sediment yield from 5 catchments and 21 sub-catchments of Southeast Asia conducted by Phommassack et al. (2003) is of this type.

Another way is to determine the significance of land use and other catchment characteristics such as soil infiltration rate, land slope, and rainfall intensity on the variations of hydrologic criteria (such as runoff coefficient, peak runoff, base flow, and sediment

Table 5. Hydrologic data and measuring instruments in MSEC catchments.

Hydrologic data	Measuring instrument per catchment
Precipitation	
Total daily rainfall	5–8 manual rain gauges.
Rainfall intensity	1 automatic mini-weather station with automatic rainfall recorder.
Runoff/Stream flow	Compound sharp-crested weir (contracted rectangular weir with V-notch). Water level is being measured by a staff gauge and an automatic water level recorder.
Sediment load/yield	
Bed load	Approach channel of the weir serves as bed load sediment tank or interceptor. Such trapped sediments are considered bed load. After every sediment-producing storm rainfall, water is drained from the tank and then the bulk sediment volume is measured. A sample is taken out and oven-dried in the laboratory to get the dry mass density. This density multiplied by the bulk volume is the total sediment dry mass for the storm.
Suspended load	Initially, no sampler was used. Manual scooping was done with can sampler or series of sampling cans at different levels in the weir approach channel. ICRISAT-design automatic pumping type samplers were delivered to most catchments during the last quarter of 2001 but not all were installed.

yield). Based on about a year of field observations from MSEC catchments, such analysis tend to indicate that areal percentage of annual crops seem to have the main influence on bed load sediment.

The following analysis is focused on analysis using available preliminary observations. While the limited data may not demonstrate significant relationships between land use and selected hydrologic indicators within a catchment, this presentation mainly intends to demonstrate sample procedures in analyzing some of the identified hydrologic indicators and possibly establish base data from which to compare future observations in the same catchment.

Initial Results

Initial hydrologic data of three MSEC-participating countries in Asia are given in Table 6.

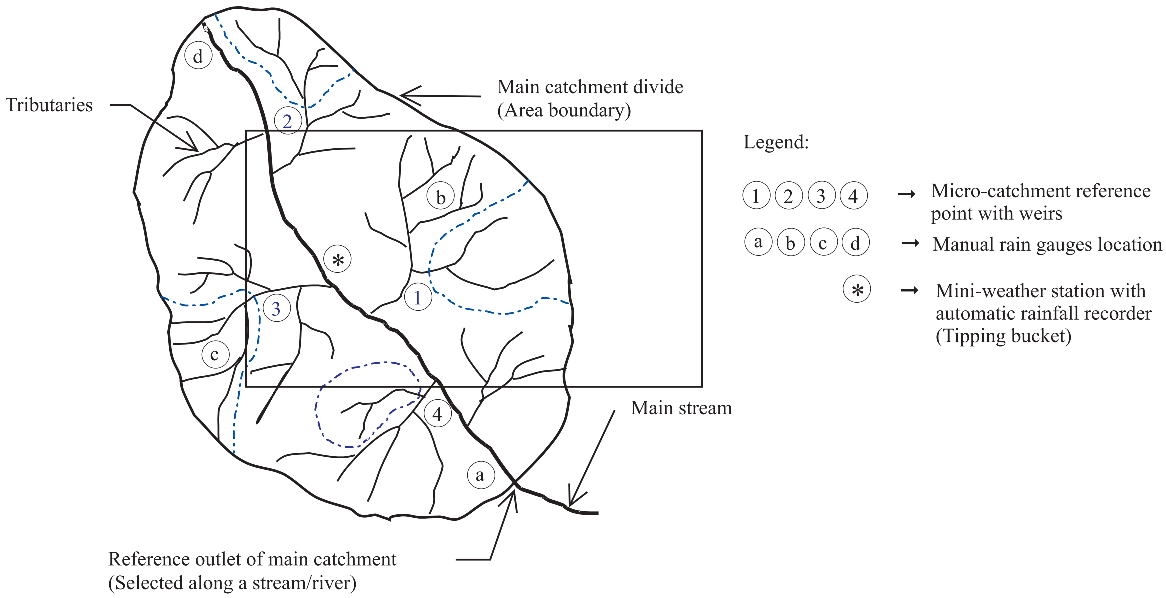
Initial values of runoff coefficients

As discussed earlier, runoff coefficient is an indicator of the surface runoff-producing characteristics of the catchment. The smaller the value of runoff coefficient, the better. More fraction of the rainfall infiltrates below the ground surface thus adding to the soil water storage and even to the water table through percolation.

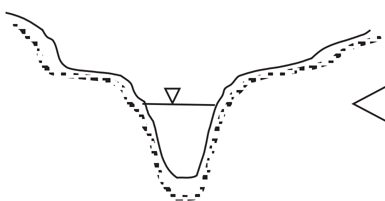
Storm runoff coefficients range from 0.01 to 18.7% for main catchments and from 0.01 to 0.05% for micro-catchments (Table 6). For monthly runoff coefficients, the values range from 0.55 to 10.20% for main catchments and from 0.01 to 18.89% for micro-catchments. These values are within the ranges of estimated C values for similar vegetation or land uses presented in Table 1. Serving as base data, their variations with time and land use change are to be observed in succeeding years.

Initial values of storm hydrograph behavior

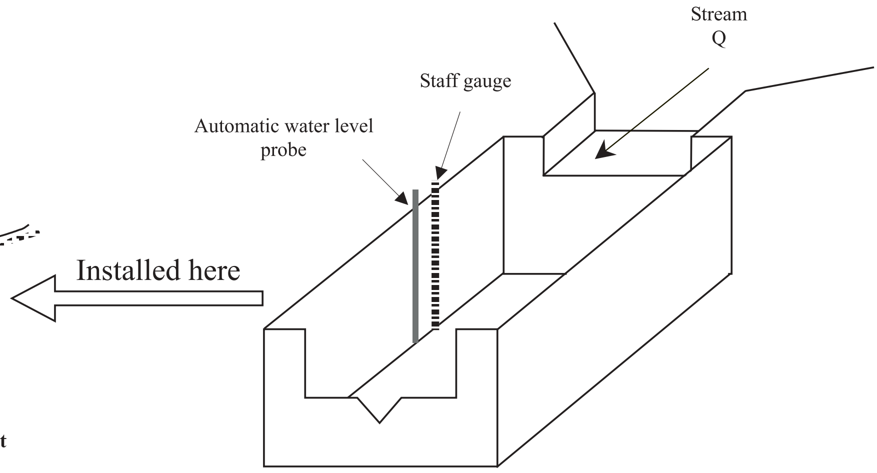
Only one catchment (Mapawa catchment) has available data for storm hydrograph analysis. Three sample storms were selected from 2000 and four from 2001. The hydrograph of a selected storm is shown in Figure 5 while the magnitudes of relevant hydrograph components of the seven sample storms are given in Table 7. These data will serve as baseline information for comparing hydrograph behavior of storms in the future as appropriate conservation farming



Plan view of catchment showing instrumentation location



Stream cross-section at reference outlet (where runoff or stream flow and sediment load/yield are being measured)



Typical compound weir (sharp-crested and contracted rectangular weir with sharp-crested V-notch) for measuring stream flow and sediment load (installed at reference outlets)

Figure 4. Typical MSEC catchment hydrologic instrumentation for monitoring rainfall, stream flow, and sediment load.

Table 6. Summary of initial hydrologic data in three MSEC-participating countries in Asia, 2000–01[1].

Hydrologic indicators	Dong Cao (Vietnam) (Main)	Mapawa (Philippines)				Babon (Indonesia)		
		Main	MC 1	MC 2	MC 3	Rambutan MC	Tegalan MC	Kalisidi MC
Runoff coefficient (%)								
Storm runoff coefficient	0.01–0.80 (Av. 0.224) (30 storms)	0.30–18.7 (Av. 8.6) (47 storms)				0.01 (1 storm)	0.04 (1 storm)	0.05 (1 storm)
Monthly runoff coefficient	0.55–3.13 (Av. 2.57)	1.12–10.20 (Av. 5.02)	0.65–4.36 Av. 2.48	0.21–11.62 (Av. 7.70)	1.34–6.65 (Av. 3.89)	0.01–1.67 (Av. 0.24)	0.03–18.89 (Av. 2.14)	NA
(No. of months with runoff)	8	12	7	5	4		11	11
Storm hydrograph behavior								
Peak runoff ($m^3 s^{-1}$)	NA	0.186–1.122	NA	NA	NA	NA	NA	NA
Time to peak (min)		10–125 (7 storms)						
Time base (h)		8.17–19.67 (7 storms)						
Sediment load ($t\ ha^{-1}$)								
Bed load	1.037					1.580	16.842	0.564
Suspended load	0.063					0.574	3.714	2.440
Total soil loss	1.100	0.36	0.08	0.56	0.59	2.154	20.556	3.004

1. Main = Main catchment; MC = Micro-catchment; NA = Data not available.

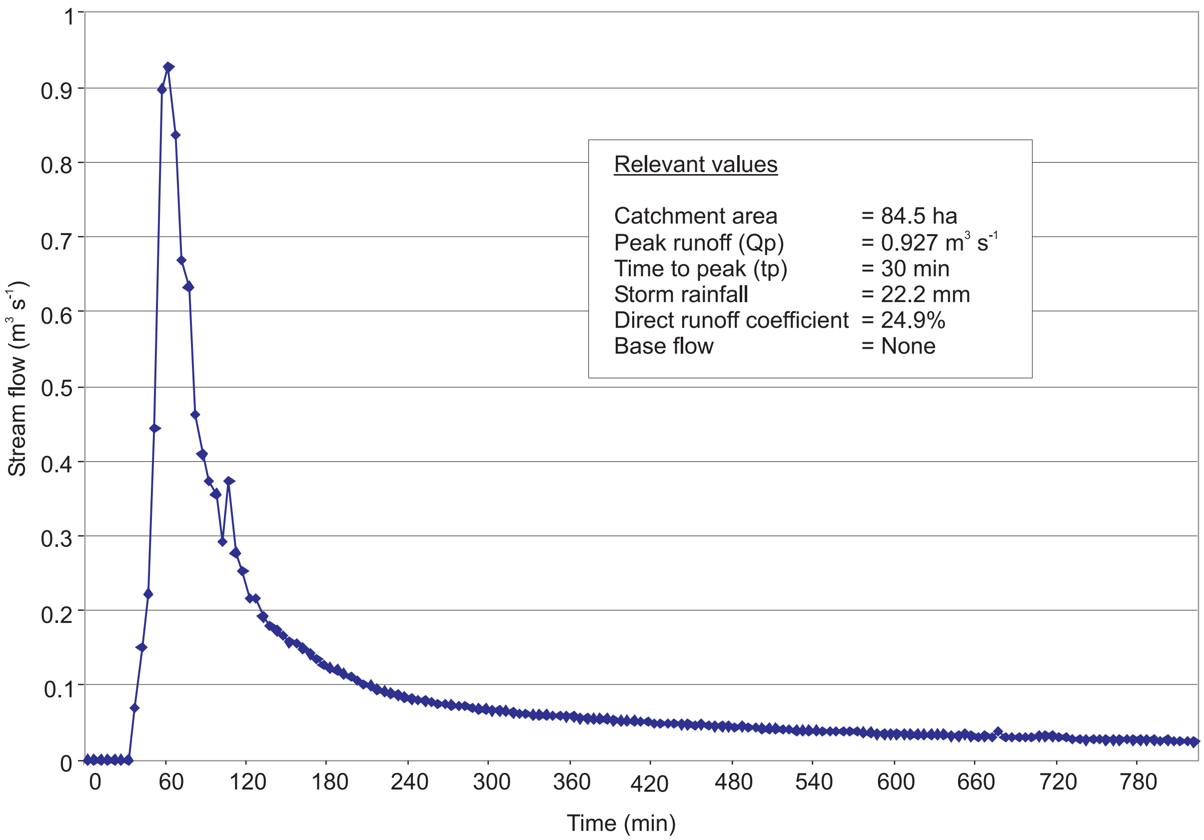


Figure 5. Storm hydrograph on 6–7 October 2001 for Mapawa catchment (main weir), Philippines.

Table 7. Magnitudes of storm hydrograph components for sample storms in Mapawa catchment (main weir) in the Philippines during 2000 and 2001.

Date of occurrence	Rainfall (mm)	Direct runoff m^3	Direct runoff mm	Direct runoff coefficient (%)	Peak runoff (Q_p) ($m^3 s^{-1}$)	Time to peak (t_p) (mm)
2000						
September 24–25					0.55	15
October 5–6					0.917	125
November 5					0.669	10
2001						
September 13–14	33.90	4127.40	4.74	14.0	0.826	35
September 26–27	35.60	2997.00	3.44	9.7	0.186	105
October 4–5	22.00	4563.00	5.24	23.8	1.122	20
October 6–7	22.20	4806.90	5.53	24.9	0.927	30
Total/Average	113.70		18.95	16.7		

technologies start to be widely practiced by farmers within the catchment. At present, no significant soil and water conservation practices are followed in the cultivated areas of the Mapawa catchment.

Initial values of sediment yield

Reported sediment yield from one main catchment and six micro-catchments indicate that bed load ranges from 0.6 to 17.0 t ha^{-1}. Bed load (sediments trapped in the weir approach channel) is about 19.94% of the total sediment load. Total sediment load of the stream, i.e., the total soil loss leaving the catchment ranges from 0.1 to 21 t ha^{-1}. An attempt to relate these soil loss values to the observed land use and field conditions during the periods of sediment load monitoring was presented by Maglinao and Penning de Vries (2003).

Recommendations

The on-going MSEC catchment studies would definitely be of great contribution towards generating information to show that appropriate land uses could sustain the use of our land and water resources and enhance the environment. However, generation of adequate and reliable information would require longer duration of field data observations. For example, increasing the aerial extent of forest cover and conservation farming practices could enhance fresh water supply. But this would require sufficient period to observe significant increases in the base flow of a stream or in the water table of aquifers. There is indeed a need to extend the study to gather sufficient data for a more convincing conclusion and recommendations. Monitoring of hydrologic field data is quite costly. Gathering of enormous but unreliable data should therefore be minimized if not totally avoided. The specific recommendations for improving the reliability of field data are:

- Functionality and accuracy of field instruments should be ascertained. Preparation of a field manual on the proper observation, operation, and maintenance of installed instruments should be considered. It should be simple enough to be easily understood by field observers. If necessary, it may be written in the local dialect of the concerned observer.
- Capability and sustainability of field data observers should be ascertained. More than one capable staff may be needed to minimize data gaps when an observer is sick or resigns.
- Occasional checking/verification of actual field data monitoring to ensure uniformity of procedure and reliability of collected information.
- Use of uniform technical terms and units to avoid confusion and for easy comparison of results with other publications. A glossary of terms and units may have to be agreed upon.
- Delineation of catchment/micro-catchment divides with respect to the actual stream flow gauging stations should be done using topographic map and re-checked in the field. Some catchment areas being reported are not yet fixed.
- Inclusion of other indicators of groundwater recharge specifically the spring water discharge (if there exists some within the catchment area) and water table/piezometric water level variation in all catchments if possible. A common methodology and instrumentation for these indicators is necessary if they are to be monitored.

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Nutrient Loss and On-site Cost of Soil Erosion Under Different Land Use Systems in Southeast Asia

F Agus and Sukristiyonubowo[1]

Abstract

It is generally understood that high slopes, high amount and intensity of rainfall, and intensive cultivation leads to high runoff, soil loss, and nutrient losses. This paper presents the results obtained in nutrient and soil erosion research conducted by the Management of Soil Erosion Consortium (MSEC) project on 19 catchments in Indonesia, Philippines, Laos, and Vietnam. In most of the countries little or no external nutrients are added to upland crops. Though the nitrogen, phosphorus, and potassium losses per unit area due to soil erosion are not high, the annual upland food crop farming system is not very profitable and sustainable because of nutrient losses due to leaching and removal of residues. The replacement cost of nutrient losses is high. The less nutrient exploitative system, addition of external nutrients, and control of erosion are the options to come out of the vicious circle of land degradation, unsustainability, and poverty.

High amount and intensity of rainfall, coupled with steep slopes and intensive cultivation in the uplands of Southeast Asia has led to high runoff and erosion, and in turn high nutrient content in runoff water and transported sediments. Nutrient transport out of the catchment occurs regardless of external nutrient inputs to the system. In Kaligarang watershed of Java, Indonesia, around 20 kg nitrogen (N), 6 kg phosphorus (P), and 9 kg potassium (K) leave annually a 0.9-ha annual food crop-based catchment. Limited fertilizer application is given to the system because of inability of the farmers to purchase fertilizers, insecure tenure, or combination of both (Agus et al. 2001). In this catchment, fertilizer application is prioritized for paddy farming and urea is considered by most farmers as the most important nutrient source. Similar farmers' practices were reported in Dong Cao catchment in Vietnam (Toan et al. 2001). In Indonesia, farmers use about 50 to 75 kg N ha^{-1} yr^{-1} and variable amount of farmyard manure (FYM) for paddy fields. In paddy fields in Vietnam, fertilizer is applied at 72, 25, and 53 kg ha^{-1} yr^{-1} of N, P, and K, respectively, besides 5 to 8 t ha^{-1} yr^{-1} of FYM. In the annual upland system, fertilizer application is rare among the upland poor. Fertilizer application usually goes with other inputs used. For instance, farmers planting cassava, sweet potatoes, and local variety of upland rice are unlikely to apply any fertilizers, but where farmers adopt improved varieties of maize, rice, soybean, etc., fertilizer application becomes a more regular practice. Higher fertilizer application is found in vegetable crop-based farming system.

Despite the low rate of fertilizer application, soil nutrients are lost from the system through various processes such as plant uptake, leaching, denitrification (for N), and nutrient transport with runoff water and transported sediment during erosion. Continuous depletion of soil nutrients leads to decline in soil fertility. By knowing the amount of nutrients lost through erosion, one can plan strategies to rectify degradation and to ensure sustainability of the scarce natural capital.

Nutrient transport through the process of erosion poses a threat to the off-site areas especially if the concentration is high and the off-site areas are used for other key livelihood activities such as drinking water, fisheries, etc. Therefore, the assessment of catchment scale nutrient transport is important as a partial assessment of the total nutrient loss in the system. The more complete method, i.e., nutrient balance analysis, will give a comprehensive assessment but in the first phase of the Management of Soil Erosion Consortium

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(MSEC) research, the assessment is concentrated on the lateral loss through erosion. Some countries in the consortium have planned to conduct a complete nutrient balance study during the second phase of MSEC.

This paper reviews and discusses nutrient loss and the costs of these losses in Indonesia, Philippines, Vietnam, and Laos. MSEC Phase 1 uses the catchment as the scale of analysis because plot-scale research as was common in the past reflects only the soil and nutrient loss out of the plot and ignores the amount of soil and nutrients transported out of the plots. The weakness of the micro-catchment scale measurement, however, is the difficulty of evaluating the processes within each segment of the catchment.

Nutrient Loss and Soil Erosion Research

MSEC research is conducted in 6 countries in Asia, but this paper covers results only from four countries, namely, Indonesia, Philippines, Vietnam, and Laos (the other two countries in the consortium are Thailand and Nepal). In each country, catchment-scale research has been adopted.

The biophysical aspect of research was initiated with the construction of V-notch weirs and sediment traps and, for Indonesia, also Parshall flume in the different catchments. The pairs of sediment traps and V-notch weirs were installed with both Automatic Water Level Recorder (AWLR) (Orphimides or Thalimedes) and manually recorded staff gauges. The sediment traps are used for collecting bed load. ‘Coarse’ soil particles and aggregates (the bed load) eroded from the catchment and collected by the traps were weighed and the water content was determined gravimetrically for every eroding rainfall event. For most countries, nutrient (N, P, K) contents in the bed load samples were determined periodically based on composite samples of a few rainfall events. In addition, nutrients contained in runoff water were also determined although some countries have yet to conduct the measurement. The on-site costs associated with nutrient loss was calculated based on the conversion of elemental nutrients to fertilizer material equivalent and then multiplying the value with the prevailing fertilizer prices.

Progress

Catchment setting

The catchments vary in size from 0.9 to 285 ha. In Indonesia, the study site is located in Ungaran subdistrict, Central Java Province. The catchment is located relatively close to the urban development area. Farming constitutes the second or third source of income by most households. Annual rainfall of 3,800 mm in 2000/01 was above the normal annual average of 2,800 mm and considerably higher than that in the other Southeast Asian countries. Despite the high rainfall, the runoff did not exceed 10% indicating the high infiltration capacity of the Inceptisols at the site. Soil loss from each sub-catchment, except for the annual crop-based sub-catchment, was less than 2 t ha^{-1} yr^{-1}. For the Tegalan sub-catchment, which is dominated by annual upland food crops, soil loss was about 20 t ha^{-1} yr^{-1}. This high soil loss can be attributed to the relatively exposed soil surface to rain drops, little litter cover, intensive tillage, steep slopes, and small catchment size (Table 1) (Agus et al. 2001).

The Philippine catchment is located in Mindanao Island. The rainfall in 2001 was 2,574 mm. The area of the sub-catchments ranged from 0.9 to 85 ha. For the sub-catchments between 8 and 85 ha, soil loss was only up to 1 t ha^{-1} yr^{-1}. Catchment MC4 with a size of 0.9 ha and 40% cultivated or bare land, had an annual soil loss of 52 t ha^{-1}. This may be attributed to the fact that the bare and cultivated areas were relatively close to the sediment trap, otherwise this value seems to be extremely high for catchment scale measurement.

The Dong Cao catchment in Vietnam has an annual rainfall of about 2,000 mm. It represents the typical cultivated mountainous uplands with slopes ranging from 15 to 60%. The altitude varies from 125 to 700 m above sea level. The main crops are cassava, taro, groundnut, rice, maize, and forest plantation such as eucalyptus, *Acacia mangium*, cinnamon, etc. Water from streams at the catchment is used for irrigation of 10 ha of paddy in Dong Cao village. The sub-catchments range from 4.8 to 96 ha, and the annual soil loss ranged from 1.6 to 4.4 t ha^{-1} (Table 1).

The MSEC study site in Laos is located in the Luang Prabang Province. Luang Prabang is

Table 1. Characteristics of MSEC catchment in four countries.

Catchment	Area (ha)	Rainfall (mm)	Runoff coefficient (%)	Soil loss (t ha^{-1} yr^{-1})	Soil order/ Subgroup	Land use/ farming system	Dominant slope (%)	Fertilizer application (per ha)
Indonesia								
Tegalan	1.1	3820	0.05	20	Andic Eutropepts	Cassava, maize	45–47	1500 kg cattle dung
Rambutan	0.9	3820	0.01	1.7	Andic Dystropepts	Rambutan, shrub	22–55	406 kg urea; 420 kg TSP; 658 kg KCl[1]
Kalisidi	20.0	3820	0.09	1.9	Andic Dystropepts	Rambutan	22–55	406 kg urea; 420 kg TSP; 658 kg KCl[1]
Parshal Flume	285.0	3820	0.02	0.04	Typic Tropaquepts	Rice, etc.	0–55	For rice only 100 kg urea
Philippines								
MC1	24.9	2574	2.07	0.1		Falcata, bamboo, grassland (98%), vegetables and root crops (2%)		2 bags (1 bag = 50 kg) chicken dung and 6 bags complete fertilizer 14-14-14
MC2	17.9	2659	6.57	0.5		Forest, grassland (85%), cropland, shrubs (10%)		2 bags chicken dung and 6 bags complete fertilizer 14-14-14
MC3	8.0	2659	3.63	1.0		Grassland (75%), cultivated (15%), settlement (10%)		2 bags chicken dung and 6 bags complete fertilizer 14-14-14
MC4	0.9	2443	-	51.6		Grassland, trees (60%), cultivated and bare land (40%)		2 bags chicken dung and 6 bags complete fertilizer 14-14-14
Whole	84.5	2623	4.44	0.45		Grassland, bamboo, eucalyptus, vegetables and root crops (20%)		2 bags chicken dung and 6 bags complete fertilizer 14-14-14

continued

Table 1. *continued.*

Catchment	Area (ha)	Rainfall (mm)	Runoff coefficient (%)	Soil loss ($t\ ha^{-1}\ yr^{-1}$)	Soil order/ Subgroup	Land use/ farming system	Dominant slope (%)	Fertilizer application (per ha)
Vietnam								
W1	4.8	2035		4.4		Cassava, grass		-
W2	9.4	2035		3.9		Cassava, *Acacia mangium*		-
W3	5.2	2035		2.9		Cassava, taro, *Acacia mangium*		-
W4	12.4	2035		1.6		Cassava, *Acacia mangium*, secondary forest		-
MW	96.0	2035		1.9		Cassava, arrowroot, secondary forest		-
Laos								
S0	1.3	1229		0.01	Ultisols Alfisols	Bush fallow (69%), teak (31%)	25	-
S1	19.6	1229		2.1	Ultisols, Alfisols, Entisols	Bush fallow (76%), forest and teak (14%), annual crops (9%), perennial crops (1%)	29	-
S2	35.7	1229		2.3	Alfisols, Ultisols, Entisols	Bush fallow (80%), forest and teak (15%), annual crops (2%), perennial crops (3%)	27	-
S3	55.9	1229		3.9	Alfisols, Entisols Ultisols	Bush fallow (60%), forest and teak (10%), annual crops (20%), perennial crops (10%)	25	-
S4	65.4	1229		6.4	Alfisols, Ultisols, Entisols	Bush fallow (53%), forest and teak (43%), annual crops (2%) perennial crops (2%)	28	-

1. Fertilizer application for rambutan (*Nephelium lappaceum*) was ceased in 1999 till mid-2001 because of encroachment by villagers. In November 2001 fertilizer application as well as efforts to regenerate some of the trees were resumed.

predominantly mountainous, consisting mostly (99.99%) of hills with steep and very steep slopes (8% to >55%) while the flat and gentle slopes (0 to 2%) represent <1% of the area and lie at the foothills, at the bottom of the valley. Elevation varies from 290 to 2257 m above sea level. The most common soil order is Ultisols and found on the slopes ranging from 8% to 50%.

The province has a wet-dry monsoon tropical climate. The dry season (November to March) is cold and mostly dry, while the wet season (April to October) is hot and humid. The average annual rainfall is 1403 mm and in 2001 it was 1230 mm. The sub-catchment of 1.3 ha, planted to teak and covered by bush yielded only 0.01 t ha^{-1} yr^{-1} of sediment. Other larger sub-catchments ranging between 20 and 65 ha and cultivated to annual upland crops yielded 2.1 to 6.4 t ha^{-1} yr^{-1} of sediments.

Nutrient loss

Nitrogen

In the 19 catchments and sub-catchments in the four countries, there was relatively high amount of N leaving the catchment (Table 2). High N loss in general was associated with annual upland crop systems. But in Laos, with relatively low rainfall, perennial tree cover and shifting cultivation system, N loss was also high. In Indonesia, over 21 kg ha^{-1} yr^{-1} of N leaves the annual crop-based Tegalan sub-catchment. Nitrogen loss from Kalisidi as high as 9 kg ha^{-1} yr^{-1} was associated with the high erosion due to encroachment of the rambutan plantation by local villagers (Agus et al. 2001). The level of 21 kg ha^{-1} yr^{-1} of N loss from the Tegalan annual upland system is considered very high owing to low addition of nutrients into the system. About 1.5 t ha^{-1} yr^{-1} of cattle manure is added to the sub-catchment and this contributes only about 20 kg N with the assumption that N concentration in FYM is 13 g kg^{-1}. Other N sources include plant residue, N_2 fixation during rotation with leguminous crops and, to a limited extent, N fertilizers. This indicates negative balance of N in the current system. Unless N fertilizer or some techniques of soil and nutrient conservation are applied, the Tegalan system will not be sustainable.

In Philippines, the MC4 sub-catchment that includes 40% of cultivated and bare lands yielded as high as 144 kg ha^{-1} yr^{-1} of N. The estimate of N loss in this case was based on the organic matter content of the eroded sediment. Nitrogen content in the organic matter was assumed as high as 5% (Duque et al. 2001). Fertilizer application in the MC4 sub-catchment included 2 bags of chicken dung and 6 bags of 14-14-14 (i.e., approximately 300 kg of NPK fertilizer per year). With 14% N content, this amount translates to 42 kg N addition per crop per year. Two bags (approximately 100 kg) of chicken dung can contribute only about 2 kg N and N from fertilizer and chicken dung put together is equivalent to about 44 kg and is far below the N loss of 144 kg ha^{-1} yr^{-1} indicating substantial N deficit as the current process continues. The extremely high soil N loss could easily be verified by long-term crop yield and soil total N data. Duque et al. (2001) presented soil organic matter level of 32 g kg^{-1}, which in most soils in the tropics could be considered as moderate level. Should the actual soil and N losses stay at the level as shown in Tables 1 and 2, there will be significant decline in crop yield and soil test levels.

In Vietnam, like in the Philippines and Indonesia, high N loss of 9 to 11 kg ha^{-1} yr^{-1} in W1, W2, and W3 sub-catchments (Table 2) is associated with cassava planting (Table 1). As mentioned by Toan et al. (2001), fertilizer and manure are used mainly for paddy fields, but almost no fertilizer is used for the upland system. Nitrogen loss of around 10 kg ha^{-1} yr^{-1} plus the amount of N that is taken out from the catchment with harvest, and other loss through leaching indicates declining soil fertility in the Vietnamese sub-catchments. In sub-catchments W4 and MW, N loss was relatively low (3.5 to 4 kg ha^{-1} yr^{-1}) and this may be associated with the presence of secondary forest in parts of the catchments and with their large size.

Despite relatively low annual rainfall (1,230 mm) during the year and the relatively large size (20–65 ha) of sub-catchments S1, S2, S3, and S4 in Laos, relatively high amount (5–16 kg ha^{-1} yr^{-1}) of N loss occurred. Furthermore, the dominant (about 80%) land use in the study area was rotating cultivated land (shifting cultivation) which is characterized by low external nutrient inputs. Despite the existence of teak plantation near the trap of catchment S4, the average N loss was 16 kg ha^{-1} yr^{-1} and this again raises concern on the sustainability of the system. Nitrogen loss from catchment S0 was negligible (0.03 kg ha^{-1} yr^{-1}). With

Table 2. Nutrient loss through erosion and on-site cost at MSEC catchments of different countries[1].

Catctment	Nutrient loss ($kg^{-1} ha^{-1} yr^{-1}$)			On-site cost ($US\$ ha^{-1} yr^{-1}$)
	N	P	K	
Indonesia				
Tegalan	21.53	5.82	9.02	20.54
Rambutan	0.89	0.89	1.11	2.00
Kalisidi	9.24	0.21	5.97	8.01
Parshal Flume	0.60	0.00	2.10	1.46
Philippines				
MC1	0.50	0.003	0.50	0.30
MC2	2.30	0.0003	0.05	1.03
MC3	4.80	0.004	0.19	2.28
MC4	144.20	0.079	6.09	67.86
Whole	1.30	0.0008	0.15	0.67
Vietnam				
W1	10.79	4.81	4.26	11.99
W2	10.83	4.97	2.46	10.20
W3	8.73	3.99	2.68	10.83
W4	4.03	2.25	1.38	4.41
MW	3.55	1.94	2.58	3.96
Laos				
S0	0.03	0.00	0.00	0.01
S1	4.74	0.89	0.82	3.53
S2	5.12	0.93	0.79	3.72
S3	12.51	1.91	0.76	7.93
S4	16.27	2.73	0.98	10.56

1. In Indonesia and Laos, nutrient concentration was determined from both the bed load and runoff water samples, while in Philippines and Vietnam it was based on only the bed load.

the small sub-catchment size, this trend is contrary to that of the other three countries.

Phosphorus and potassium

Data in Table 2 show that P loss in general was related with N loss. In the Philippines, however, despite high soil and N losses in catchment MC4, P loss was almost undetectable. Extractable P content in the Philippines soil was 3 to 13 mg kg^{-1}. For Indonesia, Vietnam, and Laos, P loss, albeit low in absolute value is considered significant as almost no external P was added to these catchments. For annual crop-based farming, P is especially high in the seed which is the part of harvest almost completely removed from the system. This P off-take indicates unsustainability of the current systems.

Potassium is subject to lateral transport along with soil mass transport in exchangeable form and/or along with runoff water during and following storms. Thus, K loss through erosion was almost parallel with soil and N losses in the four countries. Potassium is rarely applied by farmers in the upland farming systems, but crop residue recycling under minimum input agricultural systems could reduce the need for K and calcium (Ca) fertilization by 50%, P by 30%, N and magnesium (Mg) by 90% depending on the kinds of successive plants in the rotation (Wade et al. 1988). Thus the promotion of crop residue recycling technique should be intensified.

Nutrient loss and gap to sustainability

In general soil fertility declined because of significant nutrient loss through erosion even if very limited or no external nutrients were added by the upland resource-poor farmers in the studied catchments. In the flat area on Oxisols and Ultisols of Sitiung, Sumatra, Indonesia after more than five years of soil fertility management research, Wade et al. (1988) came up with nutrient management recommendation for continuous farming systems (Table 3). Capability of local farmers to purchase inputs was far below the recommended level.

In Laos, where shifting cultivation is mainly practiced, depending on the length of fallow period, the system may be able to rejuvenate. But when the system intensifies, there will be progressive need for external inputs. In Indonesia, Vietnam, and Philippines where farmers practice continuous farming system, the low external nutrient inputs as given in Table 1 may progressively fail to support the current system in the near future.

The options will be to control erosion significantly, add external nutrients, and/or modify the current systems to less exploitative ones such as agroforestry or agro-silvo-pastoral system. The current agricultural system may have been in a vicious cycle of poverty and land degradation. The challenge ahead will be to eradicate poverty and at the same time come up with more soil conserving farming practices.

On-site cost of soil erosion

With the level of nutrient losses as discussed earlier, the replacement cost of nutrients that should be borne by farmers based on fertilizer prices could be as high as US$ 20 in Indonesia. In the Philippines, it could go as high as US$ 68. This, as has been mentioned in former sections, only takes into account the loss through erosion, but not the loss through leaching, off-take with harvest, and other biochemical processes. The problem is more complicated for annual upland food crop farming systems because, as in Indonesia, the replacement cost for nutrient was the

Table 3. Initial rate and annual maintenance rate (in parentheses) of nutrient inputs needed to satisfy nutrient requirements of six main food crops grown in clayey Oxisols and Ultisols in Sitiung upland, Sumatra, Indonesia.

Input	Rice	Soybean	Maize	Groundnut	Mung bean	Cowpea
Lime ($Mg\ CaCO_3\ ha^{-1}$)[1]	0.5–1.5	4–5	3–5	3–5	5	1–3
N ($kg\ N\ ha^{-1}$)	45 (45)	0 (0)	135 (135)	0 (0)	0 (0)	0 (0)
P ($kg\ P\ ha^{-1}$)	20 (20)	80 (20)	80 (20)	80 (20)	80 (20)	80 (20)
K ($kg\ K\ ha^{-1}$)[2]	60	40	60	60	80	60
Mg ($kg\ Mg\ ha^{-1}$)[3]	8	24	32	8	nd[4]	nd
S ($kg\ S\ ha^{-1}$)	0	0	0	0	0	0

1. Use equation LR = 1.5 [(Al – (RAS × ECEC / 100)] for initial and maintenance rate, where LR is lime requirement in $Mg\ ha^{-1}$ of the $CaCO_3$ equivalent, Al is aluminum concentration in $cmol_c\ kg^{-1}$, and ECEC (effective cation exchange capacity) is the sum of exchangeable Ca, Mg, and K plus KCl extractable Al in $cmol_c\ kg^{-1}$. RAS values of maize, groundnut, rice, soybean, cowpea, and mung bean are 29, 28, 70, 15, 55, and 5%, respectively.
2. These are initial and maintenance rates if crop residue is removed. Return of crop residues would permit these rates to be reduced by 50%. Reference point for initial rate is when the soil is degraded, such as after bulldozing land clearing or after several years of severe erosion.
3. Unless dolomitic lime is utilized, maintenance rates are not given.
4. nd = Not determined.

Source: Adapted from Wade et al. (1988).

Table 4. Average yield of major crops planted within MSEC catchment in the Philippines.

Crop	Yield (kg ha^{-1})	Average price (US$ kg^{-1})	Value (US$ ha^{-1})
Potato	4700	0.33	1566.67
Sweet pea	1220	1.00	1220.00
Baguio beans	2500	0.18	444.44
Cabbage	3500	0.27	933.33
Wongbok	3200	0.22	711.11
Maize (no fertilizer)	233	0.14	33.66
Maize (with fertilizer)	767	0.14	110.79

Source: Adapted from Duque et al. (2001).

highest and the system happened to be the least profitable. When family time for farming is taken into account, the annual upland farmers suffer loss of about US$ 51 annually or a benefit-cost ratio of –0.29. If they replace the lost nutrients they may get better crop yields, but the ability to spend extra US$ 20 besides US$ 51 loss is questionable. In many cases, however, farmers do not consider their own labor time and they feel secure if they can get food from farming.

For the Philippines, revenues generated from several field crops is presented in Table 4. Maize gives the lowest return compared with vegetable crops. Fertilized and unfertilized maize gives US$ 34 and US$ 111 returns, respectively. With various on-farm expenses, it is very unlikely that the farmers can afford to invest for the nutrient replacement which is as high as US$ 68 (Table 4).

Conclusions and Suggestions

- Except in Laos, nutrient loss per unit area was lower as the catchment size increases.
- High nutrient loss through erosion is also likely to happen when the farming system base is annual upland crops.
- Annual upland food crops based system is in general the least profitable and it is the system that is highly vulnerable to erosion and thus demanding high replacement cost of nutrient loss.
- Long-term crop yield and spatially distributed soil test data should be included as an integral part of this nutrient loss study and there is a need for a unified research methodology in the MSEC project to enable better cross country analysis.

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Soil Erosion and Farm Productivity Under Different Land Uses

T D Toan[1], F Agus[2], C M Duque[3], and A Chanthavongsa[4]

Abstract

Land use is an important factor of soil erosion. The paper presents initial evaluation of soil erosion and nutrient losses under different land uses, farm productivity, and income for various annual crops on arable lands in four participating countries namely Indonesia, Laos, Philippines, and Vietnam for the Management of Soil Erosion Consortium project. Initial results indicated that the soil loss was highest under annual crops followed by perennial crops, grasslands, bush land, and forests. The yields of annual crops are low and because of intensive cropping and reduced fallow period on arable land the yields have declined over a period. Based on the results it is concluded that there is a need for implementation of soil and water conservation measures to conserve natural resources and increase the potential of system productivity.

Soil erosion is commonly observed in sloping lands especially in the tropical zones of Southeast Asia. Farming and other economic activities on sloping lands have become environmentally unsustainable causing deleterious on-site and off-site effects. In 1998, the Management of Soil Erosion Consortium (MSEC) initiated a project aimed at developing and promoting sustainable and socially acceptable community-based land management options through a participatory and interdisciplinary approach in six countries in Asia with support from the Asian Development Bank (ADB). This paper presents an initial evaluation of soil erosion, land use, and farm productivity in four participating countries, namely Indonesia, Laos, Philippines, and Vietnam. It discusses the land management options for sustainable adoption in developing agriculture and forestry on sloping lands.

Approach and Methodology

Site selection and characterization

MSEC uses an integrated, interdisciplinary, participatory, and community-based approach in research involving all land users and stakeholders on a catchment scale. Representative catchments were selected by using carefully defined criteria and methodological guidelines developed for the purpose. More detailed characterization was done to establish the baseline information about the sites. Within the catchments, several micro-catchments representing various land uses were further identified and delineated to conduct more detailed soil erosion and hydrological studies.

Hydrological and soil erosion monitoring

Hydrological monitoring stations equipped with automatic water level recorders, manual staff gauges, sediment traps, automatic weather stations, and manual rain gauges were installed. Data collection and analysis followed guidelines set up by the members of the consortium. In addition to the biophysical data, monitoring of the socioeconomic parameters was also undertaken.

Land management options

On the basis of the information gathered and consultations with farmers, the best-bet options were identified and introduced in the catchments.

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2. Center for Soils and Agroclimate Research (CSAR), Bogor, Indonesia.
3. Central Mindanao University (CMU), Musuan, Bukidnon, Philippines.
4. Soil Survey and Land Classification Center (SSLCC), Vientiane, Laos.

Considering the inputs of the farmers, any intervention would be better adopted and sustained. But the intervention should address both soil conservation and farm productivity.

Results and Discussion

Catchment profiles

The experimental catchments selected in Indonesia, Laos, Philippines, and Vietnam ranged from 71 to 139 ha with four smaller micro-catchments representing different land uses delineated within. The catchments have slopes ranging from 12 to 80% and average annual rainfall ranging from 1,080 to 2,500 mm. In the catchments in Indonesia, Laos, and Vietnam, water flows in the creeks throughout the year, while in the catchment in the Philippines, water flows only during the rainy season. The catchments are dominated by annual cash crops with some patches of perennials and are cultivated primarily by ethnic minorities. In general, the model catchments represent a resource management domain with biophysical and socioeconomic characteristics common in the marginal sloping uplands.

Soil erosion and sediment yield

Soil loss in the different micro-catchments in Houay Pano catchment in Laos is presented in Table 1. The soil loss under land use with high bush fallow and forest (Weir 1) was lowest (0.5 t ha^{-1}), while in the micro-catchment with more annual crops, the amount of soil loss was 1 t ha^{-1}. In Mapawa catchment in Bukidnon, Philippines, about 80% of the area is under forest and grassland in Weir 1, Weir 2, and Weir 3. The amount of soil loss ranged from 0.1 to 0.6 t ha^{-1} (Table 2). In Weir 4, which is mostly cultivated, the soil loss was 14 t ha^{-1}. Soil loss under different land uses at Dong Cao catchment is shown in Table 3. Soil loss was high in Weir 1, Weir 2, and Weir 3 and ranged from 3 to 5 t ha^{-1}. More than 50% of the area of these sub-catchments are cultivated to annual crops such as cassava, taro, and forest trees and the soil cover was very poor.

Cost of nutrient loss

In Indonesia, the lowest on-site cost of nutrient loss was US$ 0.46 ha^{-1} yr^{-1} in Rambutan sub-catchment followed by US$ 1.38 ha^{-1} yr^{-1} in Babon catchment. The on-site cost was US$ 3.74 ha^{-1} yr^{-1} and US$ 2.84 ha^{-1} yr^{-1} in Tegalan and Kalisidi sub-catchments respectively. In the Mapawa catchment in the Philippines the highest on-site cost (680 PhP ha^{-1} yr^{-1}) was in Weir 4, where more than 40% of the area is cultivated. In Dong Cao catchment in Vietnam the lowest cost was in the main weir at US$ 3.95 ha^{-1} yr^{-1}.

Crop yield and income

In the Babon catchment in Indonesia, the benefit-cost ratio of paddy farming, tegalan, and rambutan were

Table 1. Soil loss under land use in the micro-catchments in Houay Pano catchment, Luang Prabang, Laos during May to September 2001.

Micro-catchment	Area (%)	Average slope (°)	Land use	Soil loss (t ha^{-1})
Weir 1	29.3	29	76% bush fallow, 14% forest, 9% annual crops, 1% perennial crops	0.5
Weir 2	19.8	27	80% bush fallow, 15% forest, 2% annual crops, 3% perennial crops	-
Weir 3	27.7	25	60% bush fallow, 10% forest, 20% annual crops, 10% perennial crops	1.0
Weir 4	13.1	28	53% bush fallow, 43% forest, 2% annual crops, 2% perennial crops	1.9
Weir 5	2.5	17	56% bush fallow, 44% forest	2.0

Table 2. Soil loss under land use in the micro-catchments in Mapawa catchment, Bukidnon, Philippines during January to August 2001.

Micro-catchment	Area[1] (ha)	Average slope (°)	Land use	Soil loss (t ha^{-1})
Weir 1	24.93 (19.5)	-[2]	2% vegetable and root crops, 98% falcata, bamboo, eucalyptus, grassland	0.444
Weir 2	17.88 (21.2)	-	20% vegetable, root crops, 80% grassland, bamboo, eucalyptus, falcata, settlement	0.608
Weir 3	7.96 (9.4)	-	10% settlement, 15% cultivated, 75% grassland	0.132
Weir 4	0.94 (1.1)	-	40% cultivated (14% of cultivated area is left bare), 60% grassland, trees	14.326
Main Weir	84.5 (100)	-	20% vegetable and root crops, 80% grassland, bamboo, falcata, settlement	0.261

1. Figures in parentheses are percentages.
2. Slope in micro-catchment not recorded.

Table 3. Soil loss under land use in the different micro-catchments from January to October 2001 in Dong Cao catchment, Hoa Binh, Vietnam.

Micro-catchment	Area[1] (ha)	Average slope (°)	Land use	Soil loss (t ha^{-1})
Weir 1	4.77 (5.0)	28	67% cassava, 33% natural grass	5.59
Weir 2	9.45 (9.8)	26	24% cassava + *Acacia mangium*, 59% cassava + taro, 17% natural grass	4.43
Weir 3	5.19 (5.4)	20	52% cassava + *Acacia mangium*, 48% cassava + taro + *Acacia mangium*	3.49
Weir 4	12.36 (12.9)	29	26% cassava + *Acacia mangium*, 0.8% cassava, 74% natural grass	1.82
Main Weir	64.23 (66.9)	19	22% cassava + *Acacia mangium*, 1.14% arrow root, 41% cassava, 2.86% *Vemicia montana*, 4.86% eucalyptus, 4.09% natural grass	2.80

1. Figures in parentheses are percentages.

0.91, –0.29, and 0.73 respectively. Rambutan yields fruits only seasonally and due to lack of postharvest processing equipment, the fruit prices become unacceptably low during the peak season. Paddy farming is economically most profitable.

In the catchment in Laos, farmers practice rice-based cropping system. Crops like maize, cucumber, vegetables, root crops, and chili are common intercrops wit`h upland rice. Sometimes they are also grown in adjacent plots or in separate fields. They can

Table 4. Average yields of major crops planted within MSEC catchment in the Philippines.

Crop	Average yield ($kg\ ha^{-1}$)	Average price (Ph. peso kg^{-1})	Value (Ph. peso ha^{-1})
Potato	4700	15.00	70,500.00
Sweet pea	1220	45.00	54,900.00
Baguio beans	2500	8.00	20,000.00
Cabbage	3500	12.00	36,000.00
Wongbok	3200	10.00	32,000.00
Maize (without fertilizer)	233	6.50	1514.50
Maize (with fertilizer)	767	6.50	4,985.50

Table 5. Average yield of major crops planted within the Dong Cao catchment in Vietnam during 2000–02.

Crop	Average yield ($kg\ ha^{-1}$)	Average price (Ph. peso kg^{-1})	Value (Ph. peso ha^{-1})
Cassava	16,600	383	6,363,760
Arrow root	1,350	525	708,750
Taro	1,200	1,267	1,520,400

also be grown as intercrops with banana. Most upland rice farmers practice 2–3 years bush fallow rotation with one year of rice on the same land. The average yield of upland rice in this area is 1.2 t ha^{-1}, while maize and job's tears yield an average 1.3 t ha^{-1} and 1.4 t ha^{-1}, respectively. Farmers reported that because of more intensive cropping and reduced fallow period, crop yields have declined 2–3 times compared to the crop yields 20 years ago.

In the MSEC catchment in the Philippines, unfertilized native maize produced only an average grain yield of 233 kg ha^{-1} in one crop, while fertilized maize yielded about 767 kg ha^{-1} (Table 4). The average production of potato is 4700 kg ha^{-1} per crop. Leafy vegetables such as cabbage and wongbok are also grown. In Dong Cao catchment in Vietnam, the main crop is cassava. Arrow root and taro are grown as intercrops with cassava. These crops increased land cover density, reduced soil erosion, and increased farmers' incomes (Table 5).

Conclusion

Farming activities in the MSEC catchment enhances soil erosion. Data on soil loss obtained from the weirs of the four countries indicated that the amount of soil loss mostly depends on land use and land management. There is a great need for adoption of soil and water conservation measures to reduce soil erosion and increase crop yields. The farmers realize this and most of them have indicated their interest to adopt integrated measures like contour hedgerow farming, and farming systems for crop cover in the rainy season. The amount and size of sediment originating from the catchment largely depended on land cover and management systems and catchment size. Intensive soil tillage and minimal surface cover for annual crops in the catchment made it relatively susceptible not only to bed load transport but also to suspended sediment transport. The relation between soil erosion and crop yields cannot be formulated because not enough data have been collected in the catchments studied.

Economic Incentives and the Adoption of Soil Conservation Practices

E Biltonen[1]

Abstract

Soil conservation measures are an important component of farmer participatory and multi-disciplinary catchment management approach for the management of soil erosion and for improving the agricultural system's productivity. The degree of adoption of soil conservation measures by farmers varies with the economic incentives offered by competing alterations. These alternatives are influenced by socioeconomic factors, resources, cost-benefit analysis of technologies, time horizon of benefits, discount rate, value of farm labor, farmers' perceptions, land tenure, and sustainability of the measures.

This paper presents an analysis of the research conducted on catchments in Indonesia, Laos, Philippines, and Vietnam by the Management of Soil Erosion Consortium project. The average household income, average expenditure, net farm income, income from cropping, and estimated on-site erosion cost were collected for all catchments. The study indicates that successful implementation of soil conservation measures must have significant on-site impact on production and benefits of a practice must substantially outweigh the cost. The measures should offer increased and sustainable benefits with minimal fluctuation. The farmer's perception on soil erosion as a problem is important. Incentives for adoption of soil conservation practices should be devised so as to increase the likelihood that a farmer voluntarily adopts the measures and decrease the chance of conflict between policy makers and farmers.

The Management of Soil Erosion Consortium (MSEC) is one of four consortia within the Soil, Water, and Nutrient Management (SWNM) program of the Consultative Group on International Agricultural Research. The primary objective of the consortium is the development of community-based land management practices from a catchment perspective. The research approach has been designed to follow a participatory, multi-disciplinary, and catchment-based approach. Over the last several years, MSEC has conducted research on various soil conservation practices in a number of settings and soil conservation options have been identified and verified through MSEC's work. The next phase of efforts in realizing the objective of MSEC involves the dissemination of the accrued knowledge and the adoption of recommended soil conservation options.

The next phase of MSEC work extends the research findings beyond the examination of biophysical feasibility to socioeconomic feasibility. Besides productivity impacts, conditions such as society, knowledge, market access, and household demographics influence what a household perceives to be in its best interest and, therefore, its production decisions (Enters 1998). Of great importance for the adoption of soil conservation practices is the proper provision of incentives. Economists believe strongly in the idea of incentives as motivators of human behavior (Young 1996). Incentives send signals to people regarding the impact that a certain activity will have on their well-being. These are especially important in weighing the trade-offs between competing alternatives.

This paper investigates the role that economic incentives may play at the household level in the adoption of soil conservation practices as determined by MSEC research. The paper then examines research conducted in the four MSEC-participating countries: Indonesia, Laos, Philippines, and Vietnam.

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Economic Incentives

An incentive is "something that encourages or motivates somebody to do something" (Source: Encarta World English Dictionary, Microsoft Corporation, 1999). The encouragement is provided by the condition of whether the thing will add to or detract from one's well-being. This paper considers incentives as both natural and imposed by institutional processes. In economics, an analysis of existing and potential incentives is usually conducted in the well-known form of cost-benefit analysis. An important characteristic of cost-benefit analysis is the assumption that all costs and benefits (incentives and disincentives) can be quantified as if they were traded in a market place. Traditional cost-benefit analysis runs into problems when the costs and benefits are derived from non-market items.

Economists normally assume that a person acts to maximize their utility or net benefits. However, if a person is living near or below a subsistence level, then their objective may not be maximization of net benefits, but maximization of the probability of surviving (Miracle 1968). This difference has implications for the incentives necessary for the private farmers to adopt soil conservation measures.

A Modern Approach to Soil Conservation

The traditional approach for the economic analysis of soil degradation is to concentrate on either nutrient loss or soil erosion in isolation with the aim of finding a structural solution to the problem. The land husbandry view aims to maintain the productivity of soil by getting individual farmers to adopt good practices (FAO 2001). The difference is in the concentration on land use practices rather than structures as the solution to erosion problems. The land husbandry approach differs from the traditional approach in that it perceives the farmer as a knowledgeable actor who is constrained by circumstance.

Concerning a household's decision making, a current approach is that the household makes its decisions based on a given set of attributes including socioeconomic factors, resources, and technologies (FAO 2001). The decisions are influenced by the incentives existing within the specific context of credit availability, land tenure status, and information and data available to the farmer. These factors are impacted by external shocks and policies, which feed into a household's perceptions (Fig. 1).

The farmer's perceptions concern the resource base available for productive activities and the benefits and costs involved with a productive activity. It is then the farmer's own decisions about production practices that ultimately have an impact on the natural environment. A change in the incentives can be used to signal to the farmer that existing resource use needs to be changed as their relative attractiveness declines. This is achieved when a farmer weighs the incentives and disincentives of various options. This general evaluation process has been formalized in cost-benefit analysis.

The Cost-Benefit Analysis of Soil Erosion

Cost-benefit analysis is a common sense implementation of economic theory. It has generally been applied to larger projects; however, it can be applied to any investment activity of any size. Cost-benefit analysis provides a tool to aid decision makers in making informed decisions based on a consistent and logical framework of analysis. This framework evaluates the discounted stream of future net benefits arising from various options.

A crucial element is determining from whose point of view the results of a cost-benefit analysis will be utilized. For example, a poor upland farmer will probably not consider the costs that soil erosion from his land may impose on an industry several hundred kilometers downstream. However, a national level decision maker should consider this cost. Similarly, a farmer would probably not willingly go along with a soil conservation measure that held positive benefits for the country, but caused a net loss to the farmer. When analyzing incentives, it is vitally important to conduct the analyses from the point of view of those affected.

For the individual farmer, soil conservation will increase net benefits from productive activities. However, impact of soil erosion on productivity is complex. As a result, complex models have been developed to analyze the benefits and costs. In developing countries, however, the data is often not available or a working knowledge of the model is lacking. This has created a tradeoff for the analyst regarding data availability and model complexity. As a result, these models have been limited in their usefulness because of their complexity.

Alternatives

Cost-benefit analysis seeks to value and rank alternatives. Therefore, the range of impacts of soil erosion will need to be identified. A proper analysis of alternative soil conservation measures will draw a comparison between situations with the practice and

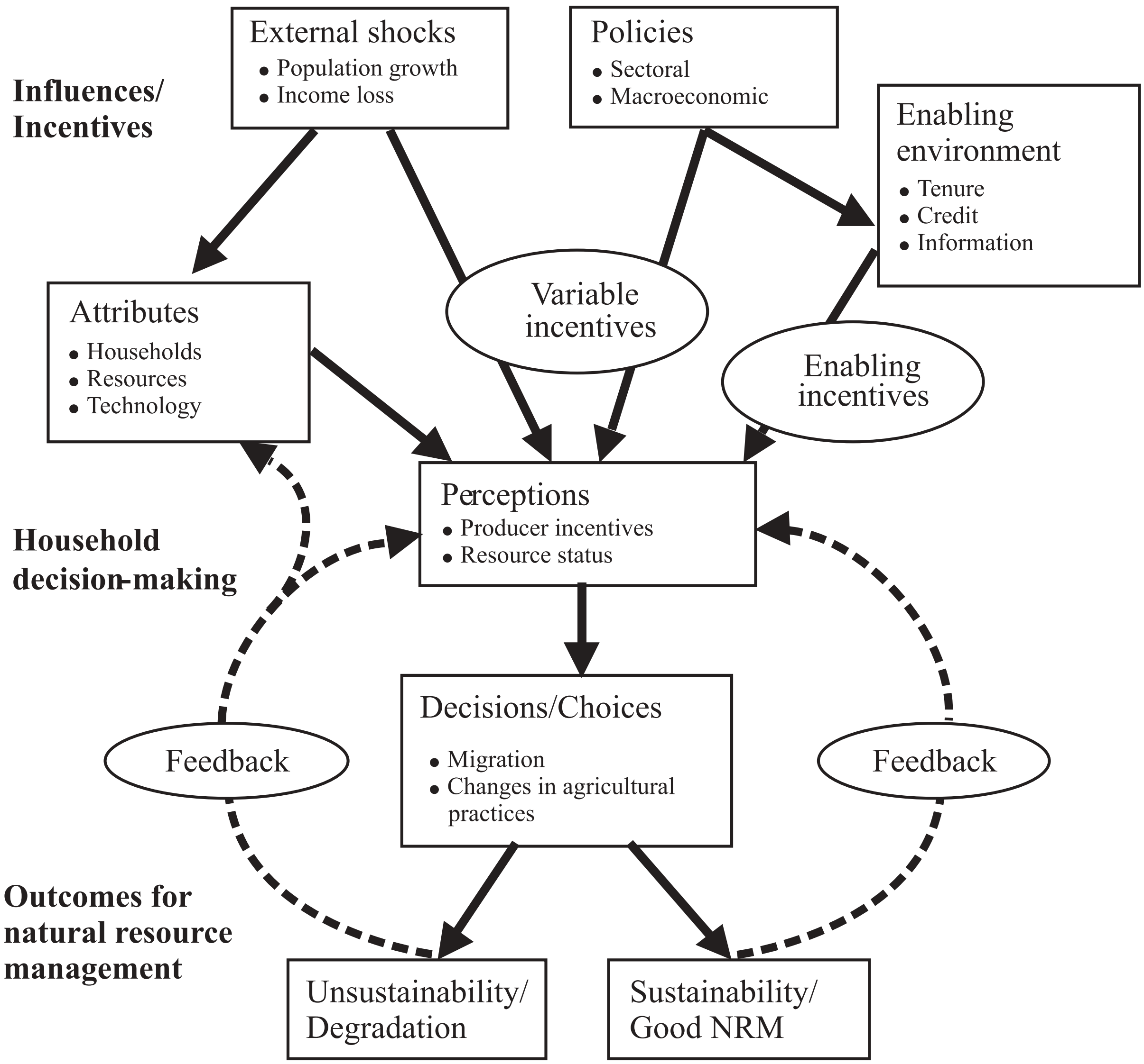

Figure 1. The role of incentives in farmer decisions on soil productivity.

without. This approach will give a clear indication of what would happen with adoption of the soil conservation practice compared to what will happen if the soil conservation practice is not adopted.

Time horizon

The time horizon is also important to cost-benefit analysis. Proper time horizon should be equal to the expected life of the conservation measure. If it is to be an indefinitely sustained practice then it is permissible to use a time horizon of 50 years as the effect of even a low discount rate will reduce net benefits to negligible levels after 50 years.

Enters (1998) has warned against simply assuming only a short-term planning horizon in poor farmer decision making. Instead, the nature of a farmer's needs should be assessed. For instance, having enough food to eat would be a short-term need, while having a child educated could be considered a long-term need. The implication is that an analysis of incentives will need to consider the impact that the incentive will have on the target group's needs.

Discount rate

Understanding the discount rate is crucial to analyze incentives for the private investor. The discount rate reflects the relative attractiveness of immediate consumption versus consumption postponed until a future time. Determining the appropriate discount rate is a much debated issue in the field of economics. In simple terms, the discount rate is the premium one must receive to be induced to forego immediate consumption.

It is generally assumed that the more desperate people become, the higher their discount rates will be. The higher a farmer's discount rate the lower is the present value of the damage done by future soil erosion. Therefore, the benefits arising from the adoption of soil conservation measures should be high.

As standard practice, the Asian Development Bank (ADB) uses a discount rate of 10 to 12% as a criterion for judging a given project (ADB 1997). However, the precise calculation of specific discount rates is varied and contentious. Consequently, some researchers recommend using a range of discount rates due to the difficulties in determining the "correct" discount rate. A decision maker with a firm grasp of the concept of the discount rate can make a better informed decision.

Value of labor

Another factor for any valuation method is the value of a farmer's own labor. This is the opportunity cost of using his time to undertake the productive activity or soil conservation measure. There are two elements to this value. There is that part of labor that is used for manual labor, which is usually equated with the unskilled labor wage rate. An often overlooked aspect is the farmer's management labor. This labor component involves the utilization of a farmer's skill in choosing crops, overseeing production, choosing when to harvest, etc. Management skills are normally more highly valued than manual labor skills. Enters (1998) has pointed out that the labor cost associated with various soil conservation measures is often the biggest obstacle to their adoption.

Evaluation criteria

Evaluation criteria typically involve the net present value, internal rate of return, and benefit-cost ratio. These criteria have advantages and disadvantages (ADB 1997). The net present value is the discounted net benefits summed over a given time horizon. This value should be greater than zero for an option to be considered. The internal rate of return is the rate of return a given alternative will yield considering the discounted stream of costs and benefits. It should be greater than some benchmark rate in order to be considered. The benefit-cost ratio is the ratio of benefits over costs. If this ratio is greater than 1, then benefits outweigh costs and the alternative can be considered acceptable.

Valuation Techniques

The two techniques for valuation of soil erosion that have been commonly used in the literature are: (1) replacement cost method; and (2) change in productivity method (Enters 1998). The replacement cost approach (which was utilized in several of the case studies) takes the value of soil erosion to be the equivalent cost of replacing the lost nutrients. This estimated cost not only includes the cost of inorganic fertilizers, but also transportation and labor required to replace the lost nutrients. Weaknesses with this approach include the fact that estimated replacement quantities may have little or nothing to do with production requirements. Furthermore, as erosion continues the estimated annual costs will demonstrate the perverse trend of declining. An additional difficulty with the replacement cost approach is that farmers may not understand the concept very well (Enters 1998).

The change in productivity approach measures the cost of soil erosion as the decline in the value of soil-dependent productive activities. This approach has an easily understood logic, particularly in analyzing farmer responses. A key problem with this approach lies in isolating the impact that soil erosion has on changes in production. The farming practice causing soil erosion needs to be compared with a soil conserving productive practice, which means that changes in the cost structure also need to be accounted for in the analysis. The change in productivity approach has the most intuitive appeal for encouraging farmer participation.

Sustainability of Soil Conservation Measures

Another important area of concern is the sustainability of a soil conservation measure. Essentially, a soil conservation measure will need to be funded in order to be maintained. This can be in the form of farmer's own contribution, subsidies, credit provision, farmer's volunteered labor, or some combination of these. Ideally, the enabling environment is such that farmers are willing to undertake the conservation practice with no additional input from the government. If subsidies are required as initial startup funding, then either the government must adopt a long-term commitment to provide the subsidies (and related compliance monitoring) or devise a procedure for phasing out the subsidies.

Case Studies

This section examines the research conducted in Indonesia, Laos, Philippines, and Vietnam so that an analysis can be made regarding possible incentives. Information is obtained from progress reports for the four countries.

Indonesia

The Government of Indonesia is quite conscious of the fact that farmer profits will largely determine the sustainability of any soil conservation program. The MSEC site in Indonesia is the Kaligarang catchment in Java. The population growth in Indonesia will increase food demand by 30% by 2025 (Agus and Sukristiyonubowo 2000). Efforts by the government to increase food production are being hampered by continued soil erosion that diminishes the capacity to grow adequate food supplies. Currently, farmers have been unwilling to adopt soil conservation measures citing the lack of any short-term enhancement of profits. Furthermore, the temporary nature of externally provided incentives has limited the successful adoption of soil conservation measures on a sustainable basis (Huszar and Pasaribu 1994, Agus and Sukristiyonubowo 2001).

Average farm income from both on- and off-farm sources was reported as US$ 373 (2,980,400 Rp). Farm plot sizes are small (0.05 to 0.25 ha) with a single farmer often farming multiple plots. While most farmers hold the perception that soil fertility is low, they also lack the ability to buy adequate amounts of fertilizers. Off-farm employment is undertaken by approximately one-third of the village members in addition to farming activities. Low farm income is attributed to small farm size, low soil fertility, low value crop cultivation, and low input technology implementation. Currently, farming accounts for less than half of a family's annual income, but farming is still perceived as an important activity for ensuring food security and as a source of income (Agus and Sukristiyonubowo 2000).

Some farmers have responded to market incentives for the crops they have chosen to grow. Experience in the study site demonstrates those farmers are willing to switch to alternative technologies that they perceive are appropriate. The choice of a best-bet option was based on the understanding that a farmer's adoption of a conservation measure will be determined by the measure's contribution to a household's income. The annual replacement cost of lost nutrients was estimated at US$ 3.74 ha^{-1} (Agus and Sukristiyonubowo 2001). This amount is equal to about 1.5% of the average annual total income. However, the per-household cost of soil erosion will be smaller if farm size is less than 1 ha.

A benefit-cost ratio was reported for three different production activities: paddy, annual upland crops, and rambutan plantation. The ratios represented the profitability of three crop options and were computed as profit over expenditure. Profitability is concerned with the size of the profit relative to the utilized resources value. The presented ratios indicated that paddy would produce a relatively higher profit for the required expenditures than the other two crops. However, a rambutan plantation, while requiring higher expenditure, would produce a greater profit. For analysis of incentives, the cost requirements for each crop and the land constraints facing a farmer are relevant. In this case, if land size is a constraint then choosing the crop that generates the greatest profit would be the objective, even though its profitability is lower than paddy.

Laos

Forests in the northern and central regions of Laos have suffered severe encroachment by farmers. Forested area has been reduced in these areas to only 30% of total area. The mountainous topography of Laos exacerbates the effect of deforestation on soil erosion rates. These rates were estimated at 30 to 150 t ha^{-1} yr^{-1} (Soil Survey and Land Classification Center 2001). Soil erosion has been positively identified as a constraint to the sustainable development of agriculture on steep sloping land areas.

The MSEC study area in Laos is the Houay Pano catchment located in Luang Prabang Province. The area has a population density of 23 persons km^{-2} and an annual growth rate of 2.3%. In the study catchment, approximately 97% of the population is engaged in farming as the primary source of income and livelihood and the average household is made up of 6.2 persons. Within the MSEC study watershed, shifting agriculture accounts for 80% of the classified land use. Furthermore, the problems of land quality and weeds have tended to worsen as farming is intensified. Thus, the labor requirements for weed control have increased. Additionally, the increased pressure on land have reduced the soil fertility resulting in lower yields.

Protection measures were initiated under the 1994 Land and Forest Allocation Scheme. Land use allocations were determined based both on production and protection of the soil. However, land remains the property of the state. Land is leased to households for farming on a long-term basis with the average landholding being 3 ha in the MSEC site.

Farmers in the study area earn about 70% of their income from farming activities. However, most of the agricultural production is kept for home consumption. Most of the inputs for agricultural activities are retained from the previous harvest or from an extension worker. The average annual income from on-farm sources in the study area was US$ 207 (1,572,000 kip). However, 61% of the households earned less than US$ 132 (1,000,000 kip) per year from farming activities indicating a degree of income inequality within the catchment. Sixty-three percent of farmers surveyed invested less than US$ 4 (30,000 kip) in agriculture. No estimates of the cost of soil erosion were given.

Philippines

Food and fiber production by subsistence farmers in the Philippines is increasingly threatened by soil erosion. The topography and rainfall patterns exacerbate the soil erosion problems on sloping lands, which are compounded by cultivation practices. The study site chosen for the MSEC research is the Mapawa catchment located near Lantapan, Bukidnon. Farming is the major occupation in the catchment area. Most of the land in the catchment area is classified as private.

Farmers in the catchment area practice maize monoculture (42%) as well as mixed cropping (38%). Only 50% of surveyed farmers use fertilizer with 30% applying complete fertilizer alone and 20% applying complete fertilizer and chicken dung. The farmers are primarily landowners with a small fraction farming as tenants. Among the farmers, 32% have adopted some sort of soil conservation practice. The rest have not adopted a soil conservation practice, primarily citing the high labor cost involved with establishment. This may be due to the fact that soil erosion is not perceived as a serious problem by the farmers (Caprina and Duque 2000).

The Philippine study site conducted both on- and off-site analyses of the cost of soil erosion. On-site costs were estimated using the replacement cost method, while off-site costs were estimated as the proportion of dredging costs of an irrigation scheme that could be attributed to sedimentation from the MSEC study catchment. The on-site cost of soil erosion in the study site was estimated at US$ 0.20 to 0.52 ha^{-1}. No income data was reported for comparison.

Vietnam

In Vietnam soil erosion has occurred on 13 million ha of land, which represents 40% of the total land area (Toan and Phien 2001). The MSEC study site is Dong Cao catchment located in Ha Tay Province in Northern Vietnam. Water exiting the catchment is used to irrigate 10 ha of paddy. Access to the site requires the use of a 4-wheel vehicle. Current soil nutrient conditions in the catchment are poor, highlighting the need for soil conservation measures especially for improving soil quality.

All farmers in the study site are full-time. Typical upland farming patterns involve no fertilizer with intercropped rotation or fallow periods. Paddy cropping involves only low rates of fertilizer application. Cassava is the main crop and is usually grown as monoculture or in rotation with taro. In 2001, the farmers adjusted their cropping patterns to allow for both higher food production and higher cover density to protect against rainy season erosion. Off-farm income was an insignificant source of income. The average cultivated area was 2.14 ha, of which 1.5 ha area is upland and 0.29 ha is paddy land. This total area was divided into seven separate plots. Due to several plots, farmers generally did not apply fertilizers. Reported yields were low in comparison to the Red River Delta (except for the Chinese rice variety Q5 which yielded 6.5 t ha^{-1}). The average net income for households in the Dong Cao catchment was about US$ 139 (VND 2,100,000).

Soil erosion costs were estimated using the replacement cost method. The cost estimates in the sub-catchments ranged from US$ 4 to 12 ha^{-1} depending upon nutrient loss. For the whole catchment, the per-hectare cost was estimated at US$ 4 because most of the soil erosion remained within the catchment. This represents a cost equal to 2.8% of the average annual income, although the cost is not incurred in financial terms.

Lessons Learned

There are many lessons to be drawn from the work already done in the MSEC study sites. These lessons give a good indication of the current status within the catchments and guidance in the implementation of an enabling incentive system. These lessons also give guidance as to where further work could be conducted.

There appears to be wide recognition and promotion of the idea that soil conservation measures, if they are to be sustainably adopted, must hold appeal to the individual farmers. Successful implementation of soil conservation options must have significant on-site impact on production. Soil conservation must hold short-term benefits, as well as long-term benefits for the farmers. Thus, the benefits of a practice adopted must outweigh the costs for the farmer.

In all four studies summarized here, it has been demonstrated that for most people within the watershed, farming is the primary occupation and source of income. In Indonesia off-farm activities in the catchment hold greater opportunity for increased incomes. Thus incentives that impact the financial structure of farming operations can have serious implications for household incomes.

The Philippine study reported that 38% of farmers had already adopted a soil conservation practice before the MSEC study began. It would be interesting to know which crops the farmers adopted, what are their sources of income, and what their personal reasons are for adopting the soil conservation measures. This could make for an interesting case study on natural versus state-provided incentives.

Indications of incomes in the study areas were presented, although some manipulations were necessary to get income values in comparable forms (Table 1). The presented values try to represent income for average farms in the study catchments and are not normalized on a per-hectare basis. Additionally, expenditures and net income values do not benefit from detailed crop budgets or household expenditure surveys in all cases. The savings rate is probably not very high. Thus, it may not be practical or socially acceptable to apply “Polluter pays” fines on the upland farmers. This is further demonstrated by the data in Table 2 which compares estimated replacement costs of soil erosion for the four countries to total household income. Table 3 compares the estimated costs of soil erosion to income from cropping activities. In both

Table 1. Income comparison of four case studies.

Country	Catchment	Average household income (US$)	Average expenditure[1] (US$)	Net farm income (US$)	Income from cropping (US$)	Percentage of total income earned from cropping
Indonesia	Babon	373	358	15	183	49
Laos	Houay Pano	296	13	282	207	70
Philippines	Mapawa[2]	29	0	29	29	100
	Mapawa[3]	726	196	530	726	100
Vietnam	Dong Cao	774	628	147	458	59

1. The value for Laos includes only farm expenditure and that for Philippines includes only fertilizer expenditure.
2. Maize monoculture without fertilizer.
3. Potato/maize mixed cropping assuming 0.5-ha farm plot.

Table 2. Total household income and estimated cost of soil erosion.

Country	Catchment	Average household income (US$)	Estimated on-site erosion cost (US$ ha^{-1})	On-site erosion cost as percentage of household income[1]
Indonesia	Babon	373	0.46–3.74	0–1
Laos	Houay Pano	296	–	–
Philippines	Mapawa[2]	29	0.05–52.28	0–90
	Mapawa[3]	726		0–4
Vietnam	Dong Cao	774	3.96–11.99	1–3

1. Cost adjusted to assumed farm size.
2. Maize monoculture without fertilizer.
3. Potato/maize mixed cropping assuming 0.5-ha farm plot.

cases, it can be seen that the cost of soil erosion is a small fraction of income, either total or from cropping. The exception is the high cost of erosion in the Mapawa catchment MC4. Compared to the high cost of labor for erosion control measures, the cost of erosion is relatively small. It would seem unlikely that farmers will be interested in controlling erosion based on cost alone.

Analysis of data from Indonesia indicate that a benefit-cost ratio of 1 is required for benefits to at least equal costs. Only paddy and rambutan plantation but not upland crop options satisfy the minimum requirement of a benefit-cost ratio of 1 (Table 4); paddy yields a higher benefit-cost ratio. The benefit-cost ratio in this case is a revenue-to-cost ratio, which gives an indication of relative profitability. Rambutan plantation, however, yields a larger profit than paddy. This is indicated by the higher net present value. Therefore, if land is a constraint and sufficient capital is available, a rambutan plantation would be the preferred option.

A proper cost-benefit analysis would need to consider alternatives based on with- and without-conservation measure scenarios. A 20-year time horizon was assumed for conducting a quick analysis. The ADB-recommended 12% discount rate was utilized. It was assumed that without soil conservation, yields would decline by 3% a year. Adoption of soil conservation measures would reduce the yield decline to 1% per year but add 5% to annual

Table 3. Cropping, income, and estimated cost of soil erosion.

Country	Catchment	Income from cropping (US$)	Estimated on-site erosion cost (US$ ha^{-1})	On-site erosion cost as a percentage of income from cropping[1]
Indonesia	Babon	183	0.46–3.74	0–2
Laos	Houay Pano	207	–	–
Philippines	Mapawa[2]	29	0.05–52.28	0–90
	Mapawa[3]	726		0–4
Vietnam	Dong Cao	458	3.96–11.99	2–6

1. Cost adjusted to assumed farm size.
2. Maize monoculture without fertilizer.
3. Potato/maize mixed cropping assuming 0.5-ha farm plot.

Table 4. Cost-benefit analysis of three options for soil conservation.

Crop	Cost US$)	Revenue (US$)	Profit (US$)	Benefit-cost ratio	Net present value[1] (US$)
Paddy	150	286	137	1.91	1236
Annual upland crops	177	125	–51	0.71	–463
Rambutan plantation	250	433	183	1.73	1653

1. Discount rate equal to 12%.

costs (Obviously, these assumptions are developed for demonstration purposes only and results should not be considered reliable). Results of the informal analysis are presented in Table 5. Both the benefit-cost ratio and the net present value are higher for the soil conserving option. This indicates that it is preferable to adopt soil conservation measures according to economic criteria. Positive net benefits from soil conservation would not occur until the third year after adoption. A poor farmer may find this wait unacceptable (indicating a higher discount rate) and prefer not to adopt the conservation measure.

Conclusions and Recommendations

This paper has outlined some of the concepts on economic incentives and linked them with four case studies conducted under the MSEC program. It has been shown that estimated costs of soil erosion by themselves will probably be insufficient to motivate farmers to adopt conservation measures. Instead, it will be necessary for farmers to understand the long-term impacts and adopt the perception that controlling these impacts are in their best interest. The Philippines offers an interesting opportunity to study a situation where some farmers have adopted soil conservation measures, while others have hesitated out of concern for the high labor cost. The voluntary adoption is perhaps linked to what appears to be a higher dependence on cropping activities and a more desperate income situation. Identification of the reasons behind this behavior and quantification of the determinants would help in planning the use of incentives.

Regarding incentives, it is useful to keep in mind that ultimately it is the farmer who adopts the soil conservation measures. If the farmer does not view soil erosion as a problem, then they will not be concerned with protecting against it. The farmer can be a valuable asset in planning and implementing soil conservation measures. Gaining a farmer's input can help scientists and policy makers determine whether a

Table 5. Demonstration of cost-benefit analysis results for paddy option.

Description	Benefit-cost ratio	Net present value (US$)
Soil erosive practice	1.41	765
Soil conserving practice	1.64	957
Incremental benefit of soil conservation		192

lack of adoption is due to lack of knowledge about soil erosion or lack of concern for damages. A lack of knowledge about the damage of soil erosion and the benefits of conservation can be rectified through the use of extension agents and training programs. However, if the farmer is knowledgeable and does not perceive erosion as a serious problem then other means will need to be determined in order to foster adoption.

It is necessary to determine the degree to which farm production is used for income generation or home consumption. The more dependent a household is on farm production for home consumption or income generation the more vulnerable the farmer will be to fluctuations in production. It would be useful to demonstrate to the farmer the reduced vulnerability to production fluctuations or declining trends that soil conservation offers.

Farmers are also concerned with costs of production. It will be important to determine the cost structure of production. If the cost (including labor) is high relative to production and income values, then it is less likely a farmer will voluntarily adopt the soil conservation measures. Farmers are also concerned with benefits, normally in the form of higher production values and income. However, the reduction in risk/vulnerability to production declines is also an important factor to be considered. Any conservation measure must be able to clearly demonstrate significant benefits and low relative costs.

Cost-benefit analysis, when properly applied, can aid in demonstrating the net benefits of a particular soil conservation option. Cost-benefit analysis considers the projected changes in crop productivity, price, costs of soil conservation, and labor requirements over time. In comparisons between existing and experimental farm plots (yield gap analysis), it will be crucial to determine the cost of labor (especially management) to derive an accurate idea of the true incremental benefit.

Policy makers interested in seeing the adoption of soil conservation measures must strive to provide an enabling environment. The sustainability of any conservation measure will rely on the commitment of the farmer, scientists, and the policy makers. It may be useful to use farmer participation not only to provide input, but also to provide output. Also, the farmers should be allowed to choose the options that appeal to them.

Finally, in examining incentives and whether to implement new ones or take advantage of natural ones, the analyst should think from the perspective of the farmer. That is, given the existing state of the farm household income generating activities, what set of conditions are needed to encourage adoption of soil conservation measures? The importance of farmers' perceptions cannot be emphasized strongly enough. In this way, incentives can be devised that appeal to the farmer leading to a higher chance of voluntary adoption of soil conservation measures and less chance of conflicts between policy makers and farmers. Successful incentives must be oriented toward the problems of farmers.

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Consortium Approach in Soil Management Research: IWMI's Experience in Southeast Asia

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Abstract

Land and water degradation problems are major constraints in improving living conditions of people in marginal and sloping uplands of Asia. Past research and development efforts have not been successful to solve these problems. A new approach of networking involving all the stakeholders was tried by IBSRAM with the financial assistance from the Asian Development Bank (ADB) and Swiss Agency for Development Cooperation. This project namely ASIALAND Network to manage sloping lands was started in 1988 and continued up to 2001. Based on the success of their project a new approach called Management of Soil Erosion Consortium (MSEC) started in 1996 and ADB funded it in 1998 for 4 years. In these two approaches all stakeholders like researchers of NARES, international agricultural research centers, advanced research institutions, farmers, and NGOs worked in a participatory manner with a common goal and shared information among the stakeholders. The details of organization, working, and achievements are covered in this paper.

Past research and development efforts have not been able to provide sustainable solution to land and water degradation problems, and soil erosion has remained a major constraint in improving the living conditions of the people in the marginal and sloping uplands in Asia. While sustainable land and water management is primarily the activity and responsibility of the farmers and other major users of the land, it also requires support from research and development agencies and organizations working at various levels. To be efficiently conducted, programs on soil management require a good knowledge of soils and their environment, of the farmers and their practices, as well as of the latest developments in research on the subject. Individual efforts in soil management are time consuming and costly. The use of existing knowledge, the sharing of new findings by national and international institutions working on the same subject, and the coordination of these efforts are believed to be the most cost-effective ways to tackle this problem.

Under this scenario, the International Board for Soil Research and Management (IBSRAM), since its inception, had employed the networking strategy in the implementation of its activities on soil management research. The regional networks had involved the national agricultural research and extension systems (NARES) in parts of Africa, Asia, and the South Pacific, addressing soil management problems in Vertisols, sloping lands, and acid soils. This mechanism has been continued by the International Water Management Institute (IWMI), which took over IBSRAM's programs when it ceased to exist, and an IWMI regional office for Southeast Asia (IWMI-SEA) was established in Bangkok, Thailand on 2 April 2001.

This paper highlights the experiences of IWMI in employing the networking and consortium approach in the implementation of its research programs on the management of sloping lands in Asia. It is based on lessons learned from the activities of the ASIALAND Network on the Management of Sloping Lands and the Management of Soil Erosion Consortium (MSEC).

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Organization of the Network and Consortium

Networking hopes to help the different partners, especially the NARES cooperators to conduct the investigations (by designing methodologies, disseminating information, and coordinating programs) necessary for the practical validation of improved soil management and land use practices (IBSRAM 1985). The organization of the regional network program consists basically of three main bodies (Fig. 1). The cooperators initiate and undertake the soil management program through: (i) simple participation in the different program activities, mainly by sharing information; (ii) active participation both by having an accepted program and by participating in all the various program activities; (iii) basic participation by having an approved program, some basic research related to the objectives of the network, and also participation in all the program activities; and (iv) support participation by the international and other research agencies by undertaking some part of the basic research related to the objectives of the network, either alone or in conjunction with other cooperators.

IWMI, through a Coordinator and backed by the network steering committee (NSC), catalyzes, coordinates, and assists the NARES partners in conducting their activities. It provides assistance in the preparation and in the presentation of projects to donor agencies. The Coordinator serves as the link between the different partners and IWMI. Also, the coordinator helps strengthen the national cooperators' program by regular visits and consultations and by backstopping the network or consortium activities. This was the mechanism followed by the ASIALAND Network on the Management of Sloping Lands, which is one of the earlier networks established. Considering the lessons learned from the earlier regional network projects, particularly the ASIALAND network on sloping lands, and other studies on soil erosion, MSEC was organized to implement soil erosion management research. The major difference from the ASIALAND network is that it works on the catchment level of study.

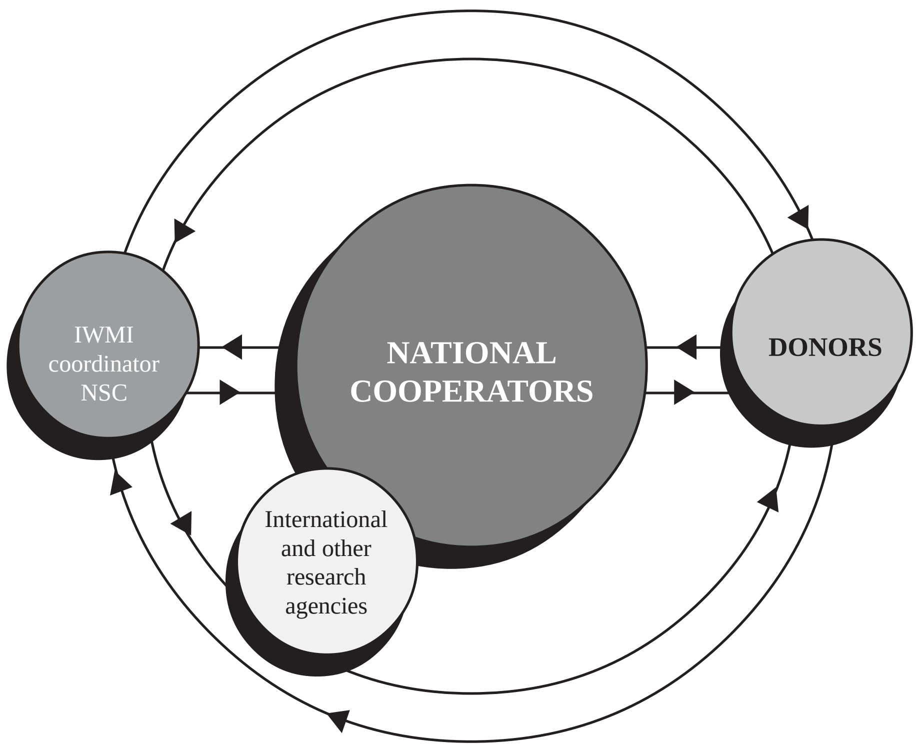

Figure 1. The organization of the regional network program.

The consortium employed an organizational model that engages scientists and research institutions to tackle a common goal. The model allows participation of those who can contribute, exploits synergies, and is mutually beneficial. Research planning is undertaken through consultation among concerned NARES, international agricultural research centers (IARCs), non-governmental organizations (NGOs), and farmers. A facilitator, a steering committee, and an annual assembly are essential to ensure the effective operation of the consortium. NARES play the central role in the consortia and in participatory research, but with a broad responsibility for underpinning applied and strategic research. Another major attraction of the consortium model is the capacity to draw the interest of advanced research institutes (ARIs), which can contribute significantly through strategic and basic research. In turn, the consortium provides a carefully considered development context for their more strategic interests. The whole idea of the program is to take a bottom up approach in research planning with iterative discussions between farmers, NARES, IARCs, and ARIs in the definition and implementation of the research process. In both instances, the donors play a crucial role. They provide funds for program coordination and in most part, support the activities of the individual country participants.

Implementing the Network and Consortium Programs

The ASIALAND network

The ASIALAND network was established in 1988 with initial funding from the Asian Development Bank (ADB) and continued with the support from the Swiss Agency for Development Cooperation (SDC). Presently, the participating countries include China, Indonesia, Laos, Malaysia, Philippines, Thailand, and Vietnam. Its main objective is to assist the national agricultural research systems (NARS) in conducting research and related activities that promote sustainable land management on sloping lands in Asia. The specific objectives are to:

- Assist NARS in validating or testing improved soil management technologies;
- Facilitate the exchange of research information on soil management among agricultural scientists in the region through meetings, workshops, and publications;
- Strengthen the research capacity of the NARS participating in the network; and
- Evaluate and select cost-effective and farmer-acceptable options for a more sustainable agricultural production in sloping lands.

The network realizes that technology transfer should be demand-driven, and these needs should come from the farmers themselves. Researchers can act as facilitators for farmer-clients to identify their needs (Sajjapongse and Maglinao 1998). To address its objectives, the network has chosen a stepwise approach in identifying appropriate soil conservation technologies and extending them to the farmers. It is envisaged that implementation should be carried out step by step in phases. In Phases 1 and 2, the project focused mainly on research. Various improved technologies were developed and validated under farmers' conditions. These technologies include alley cropping, grass strip barriers, hillside ditch, agroforestry, strip cropping, legume cover crop, and crop residue management.

In Phase 3, a different approach was introduced to take into account the farmers' socioeconomic context. Instead of researchers doing experiments in farmers' fields, researchers acted as facilitators. In addition, extension services started to be involved. Technologies were chosen by the farmer and tested against their common practices in their fields. In Phase 4, the most promising technologies were disseminated, and pilot conservation farming villages were established. Phase 5 of the project started in September 2001 and is aimed at enhancing wider adoption through a more intensive and extensive extension campaign. At the end of this phase, it is expected that at the national level, a larger network of institutions would be created. Furthermore, the network itself will be strengthened to pave the way for sustaining their activities even after the international leadership ceases.

The MSEC project

The MSEC was established to address the inadequate understanding of the socioeconomic and policy factors underlying land degradation and improvement. The fragmented research on soil, water, and nutrient management with little coordination at the national, regional, and international levels has also resulted in very insignificant impact of soil management technologies. MSEC is one of the four consortia established through the Soil, Water, and Nutrient Management (SWNM) initiative of the Consultative Group on International Agricultural Research (CGIAR). The participating countries in the current project are India, Indonesia, Laos, Nepal, Philippines, Thailand, and Vietnam.

Consultations among various stakeholders in the establishment of the consortium started in 1996 and support for the operation of the project in the participating countries began in late 1998 with funds provided by ADB. The objectives of the consortium are to:

- Develop sustainable and acceptable community-based land management systems that are suitable for the entire catchment;
- Quantify and evaluate the biophysical, environmental, and socioeconomic effects of soil erosion, both on- and off-site;
- Generate reliable information and prepare scientifically-based guidelines for the improvement of catchment management policies; and
- Enhance NARES capacity in research on integrated catchment management and soil erosion control.

Project implementation follows an interdisciplinary, participatory, and community-based approach. This ensures that all stakeholder groups in the landscape affected by soil erosion, including farmers and policy makers, benefit from the knowledge generated, recognize the scope and severity of the problem, and make appropriate decisions about investments and land use policy in the sloping land areas. It started with the selection of representative catchments in participating countries by an interdisciplinary team using carefully defined criteria and methodological guidelines (IBSRAM 1997). Visits and dialogues with local institutions, scientists, and farmers were facilitated by the NARES.

After finally selecting the model catchments, more detailed characterization was done to establish the baseline information about the sites. Different tools and techniques for conducting both biophysical and socioeconomic surveys were employed (Maglinao et al. 2001). Several microcatchments representing various land uses were further identified and delineated to conduct more detailed soil erosion and hydrological studies. Hydrological monitoring stations equipped with automatic water level recorders, manual staff gauges, sediment traps, automatic weather instrumentation, and manual rain gauges were installed. Data collection, monitoring, and analysis followed the agreed upon protocol.

To provide guidelines for and direction of the implementation of the consortium activities, the consortium Steering Committee was formed. Within the countries, collaboration among relevant partners has likewise evolved (Table 1). The organization of these teams from different institutions and disciplines is expected to enhance the participatory, interdisciplinary, and inter-institutional mechanism that the consortium is implementing. Generally, this arrangement is committed through formal agreements signed between and among institutions. Further strengthening the institutional linkages and sharing of information among the consortium partners is the conduct of the consortium annual assembly. This provides the opportunity to discuss issues concerning the implementation of the approach. The first four years of the project will be completed in August 2002 and a follow-up phase has been prepared. The consortium is envisioned to function for at least 10–12 years.

Project Experiences

The experience of the ASIALAND network and the MSEC project in Southeast Asia could be valuable lessons that may be considered in future projects that intend to do similar research and extension approaches. The following sections highlight these experiences in relation to project design, project implementation, and project outputs. Some insights on the participatory and consortium approach are also given.

Project design

Research and development work on land management and ultimate extension and adoption of their results normally require a longer time frame. The ASIALAND network project has been carried out in phases for more than 12 years. This has caused

Table 1. Consortium partners and potential research activities in the MSEC collaborating countries.

Country	National partners	International institutions	Proposed research activities
India	CRIDA, BAIF, IISS, JNKKV	IRD, ICRISAT	Agronomy; farming systems
Indonesia	CSAR, BAPEDA, BPTP, CSES	CIRAD, IRD	Agronomy; hydrological studies; institutional arrangements
Laos	SSLCC	IRD, ICRAF, NORAGRIC	Hydrological studies; nutrient dynamics
Nepal	NARC	ICIMOD, University of Bayreuth, IRD, IFPRI	Farming systems; nutrient dynamics; hydrological studies; institutional aspects
Philippines	PCARRD, CMU, BSWM DA, DENR, SANREM, UPLB, local government	ICRAF, IRD, SEARCA, ACIAR	Hydrological studies; institutional arrangements; policy studies; off-site impact; farmers' adoption; modeling
Thailand	RFD, DLD	ICRISAT, IRD, AIT, University of Bayreuth	Farming systems; off-site impact; nutrient dynamics and pollutants; hydrological studies; remote sensing
Vietnam	NISF, NEU, VASI	ICRISAT, CIRAD, IRD, IFPRI, IRRI	Farming systems; hydrological studies; institutional arrangements

anxiety to the cooperators every time the current phase was about to end. As such, there were outputs that should have been delivered very much earlier had there been assurance of a much longer-term continuity. The network was not planned to be a long-term project right from the beginning (Santoso et al. 2000). Therefore, from phase to phase, all the collaborating countries with the leadership of the network coordinator have to prepare new proposals for the succeeding phases. Fortunately, SDC has recognized the accomplishments of the project and continued to provide support for a longer period.

In the case of MSEC, a long-term program has been developed although funding is only assured for limited duration. In any case, both projects were developed and designed considering the increasing awareness of the effects of soil erosion and land degradation on agricultural productivity and the environment and the advances in research on the subject. The objectives were identified based on the common observation that adoption of land management technologies is generally insignificant. The objectives have been set to address the important issues as perceived by the major stakeholders and the design process was carried out with their active involvement. Because of the involvement of a broad range of stakeholders, the project design process has taken no less than two years from conceptualization and consultations to the start of implementation.

As the project looks both at research and research methodology, further refinement of the design itself is also carried out. In the ASIALAND network, this was done in the preparation of the succeeding phases. In MSEC, the design intended to integrate biophysical and socioeconomic aspects, but it was observed that in the early stages, there was a very strong focus on the biophysical aspects and therefore further discussion on how the socioeconomic and institutional research could be addressed was recommended. This consideration becomes very important when looking at the off-site impacts of soil erosion and the ultimate adoption of the recommended options.

Project implementation

In the case of MSEC, the consultations and meetings with various stakeholders have taken much time, and the start of full-scale implementation of the project was greatly delayed. A memorandum of understanding (MOU) with the NARES was still needed to formalize the implementation of the project in the participating countries. Attracting donors to provide funds for the project was likewise a slow process. For the ASIALAND network, the participation of major stakeholders proceeded with the development of the proposals by phases. In the earlier phases, mainly researchers were involved. In the later stages, the farmers and extension workers played an active role.

Both projects have steering committees to provide direction and guidance for the operation of the network or consortium. However, there is still concern on the effectiveness of such committees in providing the expected inputs. The committees meet only once or twice a year. The members of the committee are usually the national coordinators who themselves are busy with their regular responsibility in their respective institutions. Several suggestions have been forwarded to strengthen these committees. For MSEC, a smaller cluster or task force has been created to look into the more specific issues of research, capacity building, and information dissemination. Another suggestion was to have just one committee for the two projects, but there were a number of concerns that still have to be clarified.

Monitoring and evaluation is usually done through field visits, annual reviews, and reports. Both ASIALAND and MSEC conduct annual review and planning meetings to review the progress and plan for the following year. These meetings also serve as the venue to share experiences and discuss problems of implementation.

Communication between IWMI and the NARES and among the NARES themselves has much more to be desired. Exchange of information and monitoring is very critical in this kind of research, which implements new methodologies and involves a number of partners. Thus, communication between and among partners needs to be further strengthened. Transaction cost was initially very significant. The existence of the network and the consortium as a long-term collaborative arrangement can be ascertained heavily by the full commitment of all partners, particularly the NARES.

The leadership role of the network or consortium coordinator is quite crucial. Even without a network, researchers can work together and help one another. However, such bilateral and direct cooperation rarely takes place. By working in a network mode, the national coordinators and other researchers related with the project were benefited through exchange of ideas and support from the network coordinator. Joint authorship and cross-country analysis of results can be facilitated by the network coordinator.

Project outputs

Alternative technology and its adoption

Results of technology validation in the ASIALAND network showed that some of the technologies tested were effective in reducing runoff and soil erosion and in maintaining good growth and yields of crops. The alley cropping system, which was a major feature in the improved conservation farming, has been considered an effective conservation measure and an important option for sustainable land management in all member countries. However, there were varying degrees of acceptance of the system. Understandably, farmers would select certain technologies that they perceive to be most appropriate to their socioeconomic conditions. Suthipradit and Boonchee (1998) indicated that reluctance to adopt improved technologies could be due to high cost, high labor requirement, and no immediate return or benefits. From the experience of the network, Maglinao and Phommassack (1998) and Sajjapongse and Maglinao (1998) suggested to consider a number of issues to achieve sustainable adoption by farmers. These include more involvement and participation of the farmers in the project, provision of short- and long-term benefits, properly implemented provision of subsidy, and long-term and constant follow-up by extension.

Monitoring of soil erosion in MSEC catchments showed that it is affected by land use, farm activities, and catchment size (Maglinao et al. 2002, Maglinao and Penning de Vries 2003). More intensively cultivated areas produced more erosion than those planted to perennials or left idle with grasses. Erosion was also higher when high amount of rainfall occurs when the soil had little cover (at planting time). Runoff and erosion start when the soil becomes saturated and infiltration is low. On a per-hectare basis, calculated soil loss is higher in smaller sub-catchments probably because of the short distance traveled by the moving sediments and less deposition occurring along the way. In general, the land management options identified with the farmers are variants of the hedgerow cropping technology. While the farmers expressed interest to apply these technologies, they mentioned some constraints like inadequate labor for establishment and land tenure concerns. Recommendation of land management options for a particular area also depends on catchment size. The role of the farmers in deciding the options that will be introduced is crucial.

These observations will be also useful in identifying erosion "hot spots" where application of soil conservation measures should be prioritized. Also, these will be important in the development and application of the methodology for extrapolation or scaling up of potential interventions for sustainable upland development. As the interventions introduced in the catchment will surely affect other sectors downstream, recognition of their concerns becomes necessary.

Capacity building

During the long tenure of the ASIALAND network, it has accumulated voluminous data, information, and experiences. The network has contributed to various personal and professional changes in the different partners involved both at the national and the international levels. For example, several staff of the NARES have been promoted to lead important divisions or departments. Directly or indirectly, this has benefited and strengthened the network. Many of the promoted staff were able to provide greater support to the network (Santoso et al. 2000).

Information materials and publication

For the annual meeting, each country prepares an annual report. This has been a good practice to report the network's achievements. They are published in proceedings, which can be used as reference by researchers, extension workers, or other agricultural officials from member and non-member countries. The report is also for the project and the donor. The proceedings, however, generally contain only country reports and no network analysis of the data is done. As a research network with research sites spread widely across different agroecosystems in Asia, the network has exceptional opportunities to do and produce analyses across sites. It is only recently that this activity is being pushed through. Analyses across countries can actually strengthen the research network.

The ASIALAND network has tremendous opportunities to also produce technical papers or scientific publications in national and international scientific journals. This remains a great challenge for all members involved in the network. Similar activities are also done by the MSEC project. The technical sessions during the annual meetings have considered the presentation of cross-country analysis, but annual reports are still submitted. MSEC also maintains a web page, which is now redesigned to fit into the IWMI site. In addition, it has started to operate a list server called SLMNet.

Tools, guidelines, and methodologies

The ASIALAND network produced the decision support system for sustainable land management (DSS-SLM) for evaluating sustainable land management for sloping lands. A second version was developed by MSEC to understand the interaction among erosion, nutrient depletion, and conservation practices. However, a prognosis module is still needed to make it more user friendly (Santoso et al. 2000).

The soil and land database (SALAD) was also developed to store and retrieve the data from the ASIALAND project. Training of partners was done to orient them on the use of the program. MSEC's emphasis on both research and research methodology produced tools and guidelines to support decision making and improved implementation of its research activities. One such output is an earlier publication which provides the guidelines for model catchment selection for MSEC. The site selection was based on criteria agreed upon by the consortium partners.

The minimum data sets for biophysical and socioeconomic site characterization was prepared and employed. Protocols on the biophysical data collection, analysis, storage, and retrieval have been discussed during the country visits of IWMI staff. The existing methodologies for the economic assessment of soil erosion and nutrient depletion and on-farm trials have been adapted and applied in the MSEC sites. A soil erosion and hydrology model was developed to predict the consequences of land use changes, technology interventions, and other factors on soil erosion. This will be helpful in deciding development initiatives that have to be introduced in a particular area.

The consortium approach

The network and consortium arrangement has been a good approach to organize many activities covering a large geographical area. It provides avenues for exchange of experiences between and among partners. Through this mechanism, a broader collaboration base is established and inputs to project planning, implementation, and evaluation are viewed at a wider perspective. Researchers and extension workers under the ASIALAND network have speeded up the transfer of research results through methodologies developed by combining experiences from different countries. The network also broadens the view of researchers and enhances researchers' experiences by visiting other centers in the network (Santoso et al. 2000).

The experience of MSEC may not still be sufficient to make any conclusion on the approach that it employs. However, it has in itself added a new dimension to soil erosion management, with the potential to enhance the adoption and sustainability of introduced interventions. In a self-appraisal conducted by the project, benefits from the approach are already evident. These include increased awareness of decision makers and research leaders, increased cooperation across disciplines and institutions, choice of more relevant research topics, and applications of findings across sites (Maglinao and Penning de Vries 1999).

While there are some positive aspects that can be derived from the consortium arrangement, it is also worth noting that there are other concerns that must be looked at. For instance, consultations among partners to come up to an agreement has proved to be a slow and time consuming process. With a number of people and sectors involved, communication becomes critical. Likewise, different partners have different levels of resources and capacity. Thus, strategies to address these concerns should be strongly considered. Commitment of the partners to fulfill their obligations to the project is crucial. Leadership appears to play a major role. In essence, the approach should be combined with other approaches and this will depend on the conditions where and when the project is implemented.

Conclusion and Recommendation

The consortium approach to the implementation of soil erosion management research has resulted in some benefits. These include increased awareness of decision makers and research leaders on the impacts of resource degradation, increased cooperation across disciplines, choice of more relevant topics, and application of findings across sties.

IWMI's experiences in employing the approach in soil erosion management research on sloping lands in Asia have provided some challenging tasks still ahead. Looking at a wider perspective, the approach can be modified to suit the requirements for an integrated land and water management research planning and implementation.

With stronger and continuing partnerships among stakeholders, particularly the farmers, it is believed that the network and consortium arrangement will bear its fruits in the longer term. IWMI will continue to employ this approach and the promising outputs will further be validated at different scales of application and expanded to a much wider area for greater impact.

Acknowledgment

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A Consortium Approach for Sustainable Management of Natural Resources in Watershed

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Abstract

The natural resource management in the dry regions imposes challenging pressure on the fragile ecosystems, as they are the source of livelihoods of people whose key occupation is agriculture. ICRISAT's earlier experiences indicated that in the past, watershed management emphasized soil and water conservation measures. Lack of holistic approach to natural resource management in conventional watersheds has led to the emergence of a new integrated watershed management model. Important components of this new model are farmer-participatory approach, use of new science tools, knowledge-flow from on-station to on-farm watersheds, holistic systems approach with integrated genetic and natural resource management (IGNRM) strategy providing site specific solutions, a consortium of institutions for technical backstopping, continuous monitoring and evaluation by the stakeholders, community and women empowerment, and environmental protection. The main features of the consortium approach are technical backstopping by the consortium of multi-institutions, linking strategic and developmental research on farmers' fields, reducing the lag for transferring results from research fields to farmers' fields, empowering the development workers and farmers to manage natural resources sustainably, and harnessing the strengths of the partners to make a win-win situation for all the partners. The consortium strategy has facilitated the exchange of knowledge and technologies amongst the consortium partners, reduced land degradation, and improved rural livelihoods through increased incomes.

The natural resources in the semi-arid tropics (SAT) are the "life line" of rural livelihoods, the key occupation being agriculture. These dry eco-regions are predominantly rainfed, marginal, and fragile, and prone to severe land degradation. Unpredictable weather, limited and erratic rainfall with long intervals of dry spells, and intense rainfall causing runoff and severe soil erosion characterize these dry regions. The overexploitation and reduced recharge of groundwater, along with low rainwater use efficiency is another serious threat to scarce water resources in the dry regions. Low levels of soil organic matter, accompanied by high rates of organic matter degradation aggravated by low literacy and poverty are the major causes of low productivity and depleting natural resource base in the dry regions. The challenge, therefore, is to develop sustainable and environment-friendly options to manage natural resources in this fragile ecosystem to increase the productivity and incomes of millions of poor farmers who are dependent on the natural resources for their survival. The way forward to address this gigantic task is by sustainable management of natural resources in a manageable land unit, which is a watershed.

A watershed is a logical, natural planning unit for sustainable resource management. Integrated watershed management is the rational utilization of all the natural resources for optimum production to fulfill the present need with minimal degradation of natural resources such as land, water, and environment.

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ICRISAT's Experiences

Scientists of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) have learned the following lessons over years working with watershed technologies in partnership with national agricultural research systems (NARS) (Wani et al. 2002a) for possible reasons of low adoption of watershed technology package.

- Efficient technical options to manage natural resources for sustaining systems are needed.
- Key processes and institutional lessons such as mere on-farm demonstration of technologies by the scientists do not guarantee adoption by the farmers.
- Contractual mode of farmers' participation adopted during Vertisol technology evaluation did not present the expected results. There is a need to have higher degree of farmers' participation through consultative to cooperative mode from planning stage up to evaluation stage.
- Appropriate technology application domains for region specific constraints need to be identified, e.g., broad-bed and furrow (BBF) for all Vertisols.
- Developmental watershed projects implemented by non-governmental organizations (NGOs) lacked technical support; thus technical backstopping is essential. Any single organization cannot provide answers to all the problems in a watershed. Thus, a consortium of organizations is needed for technical backstopping.
- Process of partnership selection for each watershed has to be undertaken carefully. A generalized formula-based selection does not guarantee success. For example, not all NGO-implemented watersheds adopted participatory approach and were successful.
- Technical change is intimately bound with broader institutional context of the watershed and the role of institutions and different players varies from location to location.
- Individual farmers should realize tangible economic profits from the watersheds; only then they would come forward to participate in community-based activities in the watershed.
- Most farmers considered watershed programs as source of employment in the project for soil and water conservation measures and not as programs which could generate long-term employment or increase incomes of most of the small farmers individually.
- Holistic systems approach through convergence of different activities is needed and it should result in improved livelihood options and not merely soil and water conservation in the watershed.
- Technological packages as such are not adopted and farmers adopted specific components that they found beneficial.
- Capacity building for all the stakeholders is critical.
- Women and youth groups play an important role in decision making in the families.
- Sustainability although desired is rarely visible after project duration is over. Exit strategies are not planned in almost all the projects.

The watershed programs were undertaken for managing natural resources and improving agricultural productivity thereby improving the rural livelihoods. However, the expected benefits from these investments were not realized mainly due to lack of people's participation, lack of scientific inputs, compartmentalized approach with maximum emphasis on construction of rainwater harvesting structures (many of which are of poor quality), lack of tangible economic benefits to individuals, involvement of contractors for executing works, and non-involvement of landless families and marginal landholders (Farrington and Lobo 1997, Kerr et al. 2000, Wani et al. 2002a, 2002b).

New Integrated Watershed Management Model for Efficient Management of Natural Resources

A new model for efficient management of natural resources in the SAT has emerged from the lessons learned from long-term watershed-based research by ICRISAT and NARS partners (Wani et al. 2002a). The important components of the farmer participatory integrated watershed management model are:

- Farmer participatory approach through cooperation model and not through contractual model with stakeholders' involvement at all the levels right from inception (planning and implementation) to managing the process and sharing the benefits in the watersheds.

- Use of new science tools such as remote sensing, geographic information system (GIS), digital terrain modeling, and crop simulation modeling for monitoring and management of watersheds.
- Link on-station and on-farm watersheds and facilitate the 'knowledge flow' of the successes of on-station watersheds at ICRISAT to on-farm watersheds, and to use feedback to guide further research in on-station watersheds.
- A holistic systems' approach with integrated genetic and natural resource management (IGNRM) strategy as a new paradigm.
- A consortium comprising several 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.
- A holistic approach to improve livelihoods of people and not merely conservation of soil and water.
- Cost-effective technology approach such as low-cost soil and water conservation structures.
- Amalgamation of traditional knowledge and newly developed technologies.
- Minimize free supply of inputs for undertaking evaluation of technologies. Farmers are encouraged to evaluate new technologies themselves without financial subsidies.
- Emphasis on individual farmer-based conservation measures for increasing productivity of individual farms along with community-based soil and water conservation measures.
- Continuous monitoring and evaluation by the stakeholders.
- Empowerment of community individuals and strengthening of village institutions for managing watersheds with emphasis on women empowerment.
- Environmental protection.

Consortium model for developing and managing watersheds

The concept of consortium is an integral part of the new integrated watershed management model. The consortium model is a participatory watershed system with a multi-disciplinary and multi-institutional approach to technically support a process involving people who aim to create a self-supporting system for sustainability (Fig. 1.). The approach is built on the principle of harnessing the strengths of the consortium partners for the benefit of all the stakeholders including the farmers. The main features of the approach are:

- Technical backstopping by the consortium of multi-institutions.
- Links strategic and developmental research on farmers' fields.
- Cuts down the lag for transferring the results from research fields to farmers' fields.
- Empowers the development workers and farmers to manage natural resources sustainably.
- Harnesses the synergies of the strengths of the partners to make a win-win situation for all the partners.

The model is a holistic systems approach and it demands collective efforts of all the stakeholders to address the complex problems in watersheds. The approach is also a knowledge-driven management system, which operates in a watershed as a unit for efficient management of natural resources.

Process components and execution strategy

- Participatory and bottom-up approach to identify the problem, possible solutions, and approaches.
- Holistic systems approach and use of new science tools for managing and monitoring the watersheds to sustain/increase productivity, and improve livelihoods.
- Site-specific solutions through refinement of existing options.
- Consortium approach to address complex problems through technical backstopping. The consortium partners include farmers, NGOs, government organizations, advanced research institutions, extension agencies, private entrepreneurs, and farmers' training centers (FTCs), who share the broad goal of improving rural livelihoods in the watershed and not restricted sectoral goals such as water and soil conservation.
- Emphasis on empowerment of stakeholders to enable them to take decisions, implement the programs, and manage the processes.
- Continuous monitoring and mid-course refinement of technologies to meet the local needs.

Adarsha Watershed Consortium

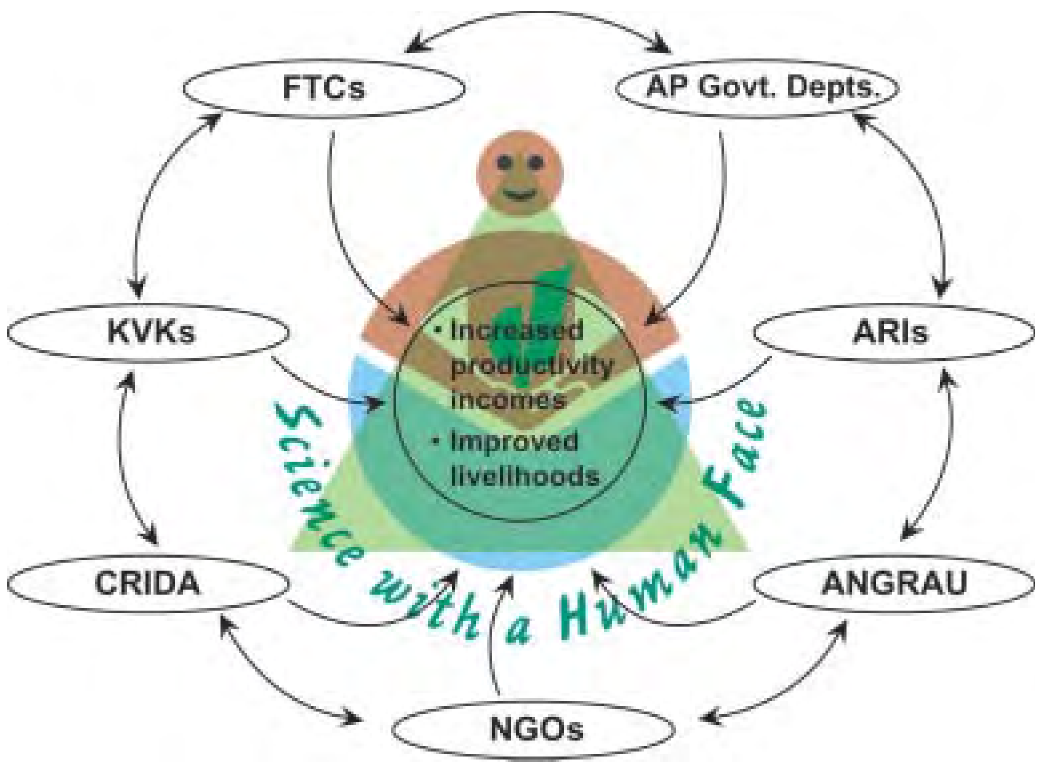

Figure 1. Consortium model for watershed management.
(Note: AP Govt. Depts. = Andhra Pradesh Government Departments; FTCs = farmers' training centers; KVKs = Krishi Vigyan Kendras; CRIDA = Central Reserch Institute for Dryland Agriculture; NGOs = non-governmental organizations; ANGRAU = Acharya NG Ranga Agricultural University; ARIs = advanced research institutions.)

Scaling-up of the watershed approach

To scale-up the benefits of integrated watershed management observed in operational-scale watersheds at research station to the real world on-farm watersheds, the approach followed is in a participatory mode in Asia under ICRISAT's project "Improving Management of Natural Resources for Sustainable Rainfed Agriculture", funded by the Asian Development Bank (ADB). All the on-farm technology evaluation trials are conducted on benchmark watershed sites in partnership with farmers. The on-farm watersheds vary from 30 ha to 10,000 ha with varying agro-ecological potential. Currently, we are evaluating the model of technical backstopping the on-farm watersheds, which are planned, developed, and monitored in partnership with NARS, NGOs, and farmers, using new science tools. Five on-farm watersheds in India, Thailand, and Vietnam are in operation. The model followed adopts a multidisciplinary and multi-institutional consortium approach for technical backstopping the development projects. "Islanding approach" is the strategy for linking strategic research done in micro-watersheds within a community watershed with applied on-farm research for development to provide effective mechanisms to more effectively transfer technologies for managing natural resources to farmers. Holistic farming systems approach to sustain productivity and to improve land and environment quality is adopted. At the village and community level women have been empowered through group training. Women are usually the critical group involved in decision-making regarding natural resources management. Continuous monitoring and impact assessment is considered an integral part of the program right from the initial stage.

Community Participation – An Essential Element for Successful Watershed Management

Programs of development and management of natural resources have suffered due to inadequate participation of local people. For success of any strategy of natural resource management involvement of local people is important. People and livestock are an integral part of the watershed community and should be given utmost importance. They depend on the watershed for their needs and in turn influence the good or bad events in the watershed. Thus participation of the people is essential for the success of the watershed programs. The detailed analysis of successful watersheds revealed that community participation played a significant role in making the watersheds successful.

In the past, watershed management was synonymous to soil and water conservation. In the new approach, it is more synonymous with people's livelihoods and is used as a vehicle for overall development of rural people through poverty alleviation and sustainable development for the welfare of the people. With the new focus on poverty alleviation and food security through appropriate natural resources management, the people rather than the natural resources become the first focus for watershed management. The degree of peoples' participation in watershed management varies from location to location and is described below:

- Contractual – Contract farmers to provide land and/or services for experiments to be conducted by scientists.
- Consultative – Farmers consult scientists about their problems and solutions but decision is made by the researchers.
- Collaborative – Farmers and scientists collaborate as partners in the research process.
- Collegiate – Farmers conduct the research and researchers provide technical advisory support.

Participatory watershed management aims at farmers' and community involvement in planning and management of natural resources in a watershed for sustainable use. Since farmers and other land users are the main stakeholders in watershed management, they themselves are to take charge of the processes for development of watershed resources. Participation means the act of partaking by farmers in all the stages of watershed programs right from planning, designing various structures, execution, monitoring and evaluation of their performance. Such participation requires that the target farmers voluntarily spend their time and energy for the program and adopt the recommended measures and practices, repair and maintain them in good condition on a sustained basis.

The traditional systems of use of natural resources in the village communities have evolved over a period of centuries. However, the traditional systems that once met the test of sustainability have not been able to respond adequately to modern rates of growth in demand as demanded by current population pressures and rapidly declining quality of land and water resources. To achieve sustainable use of natural resources there is a need to increase farmers' participation in efficient management of natural resources.

Basic principles for effective community participation

Some basic principles which facilitate effective community participation are: compelling vision; strong and shared leadership; shared problem definition and approach; power equity; interdependency and complementarity; mutual accountability; attention to process; communication linkages; explicit decision-making process; trust and commitment; and credit and recognition. The participation process also includes a combination of indigenous and traditional approaches, which may pave the way for long lasting participation. This is critical in case of integrated watershed management.

Promoting community participation

The previous projects had sufficient expertise in implementing soil and water conservation measures and were largely based on technical perspective and involved only land and water management activities. The activities in those projects did not involve people who are actually the important players within the watershed and whose activities have a significant impact. To make the watershed program successful, the primary goal should be the participation of the local community. Project implementation can only be successful if the people participate and contribute adequately to the development program. In an effort to achieve community participation for managing natural resources in the watersheds, ICRISAT is working to build stronger partnerships with state and local agencies, community leaders, and people. These efforts are based on a strong commitment to involve those affected by or responsible for environmental regulation in finding the most effective workable solutions possible. Successful partnerships are critical for understanding participatory watershed management, as several players with varying interests are involved.

Model Application in Project

The project "Improving Management of Natural Resources for Sustainable Rainfed Agriculture" was funded by ADB in 1999 in an effort to improve the natural resource base and to have sustained increase in food production by SAT farmers. The project involves watershed research in three countries (India, Thailand, and Vietnam) at both on-station and on-farm watersheds. The on-farm benchmark watersheds in India, Thailand, and Vietnam are in operation since 1999. This project demonstrated the consortium approach model application in a number of ways by encouraging community participation in watershed management, by empowering the farmers, and also by building stronger working relationships with state and local governments, and NGOs and encouraging voluntary initiatives for improving sustainable use of resources. Five on-farm and three on-station watersheds covering varying agroecological, socioeconomic, and technological situations were selected. A case study of one on-farm watershed, i.e., Adarsha watershed in Kothapally village, Ranga Reddy district in Andhra Pradesh, India is described.

Consortium partners and process

The consortium partners involved in integrated watershed management in Adarsha watershed were:

- ICRISAT – international agricultural research center
- Central Research Institute for Dryland Agriculture (CRIDA) – NARS
- Drought Prone Area Programme (DPAP) – government organization
- M Venkatarangaiya Foundation (MVF) – NGO
- National Remote Sensing Agency (NRSA) – national institute
- Farmers – Kothapally village

In Adarsha watershed, the total irrigable area was very less and no single water harvesting structure for human and animal use was seen in 1998, i.e., at the start of the project. A large area is under rainfed farming in the village. ICRISAT, DPAP, and MVF jointly selected this watershed to evaluate integrated watershed management options for improving rainfed agricultural production through integrated watershed development and thus reduce poverty through increased system productivity. A micro-watershed of 30 ha was selected in partnership with the farmers. The watershed is equipped with hydro-meteorological equipment and is also monitored for inputs, outputs, productivity, incomes, etc., for preparing detailed budgets for water and nutrients at catchment level and also to assess the impact of technical interventions. All the activities in the watershed are planned, executed, and evaluated by the farmers through the watershed committee and watershed association with technical support from ICRISAT. These prime committees form further sub-committees for specific activities such as site identification for check-dams and farm ponds, and for identifying farmers to evaluate the improved options. User groups were formed for development of water harvesting structures. Self-help groups (SHGs) were formed to undertake watershed development activities. A system of social auditing is also an integral part of the integrated watershed development activity. New tools such as remote sensing and crop simulation models were used for planning and monitoring the development activities. Human resource development was considered an important component of the model. Farmers were encouraged to undertake income-generation activities.

Monitoring and impact assessment

Continuous monitoring of several parameters was done in Adarsha watershed as described below:

- Weather: An automatic weather station was installed to continuously monitor the weather parameters.

- Runoff and soil loss: Runoff, soil, and nutrient losses were monitored using automatic water level recorders and sediment samplers.
- Groundwater: To monitor the groundwater levels, open wells in the watershed were geo-referenced and regular monitoring of water levels was done.
- Crop productivities: Productivities were recorded for every crop in each year.
- Nutrient budgeting: Studies on optimum doses of fertilizers were conducted to have balanced nutrient budgets.
- Biological nitrogen fixation (BNF): Quantification of BNF in farmers' fields was done using N difference method and ^{15}N isotope dilution method.
- Satellite monitoring: Changes in cropping intensity, greenery, water bodies, and groundwater levels were monitored. Also, GIS maps indicating soil types, soil depths, and crops grown during rainy and postrainy seasons were prepared.

Community-based soil and water conservation measures such as grassed waterways and gabion structures were constructed in Kothapally. Ninety-seven gully control structures, 60 mini-percolation tanks, 4 water storage structures, and 1 gabion structure for increasing groundwater recharge were completed. Wasteland development was undertaken by contour trenching, planting horticultural and agroforestry plants, and developing grasslands. Along with water harvesting for enhancing water use efficiency, several improved land, crop, pest, and nutrient management options and soil conservation measures were taken up and all of these together made farmers reap rich rewards. Ten SHGs were formed to undertake vermicomposting as a micro-enterprise in the village. Improved cropping systems with high-yielding stress tolerant crop cultivars were introduced in the watershed. Bullock-drawn tropicultor was used for sowing and fertilizer application.

The normalized difference vegetation index (NDVI) images showed that the spatial extent of moderately dense vegetation cover in Kothapally increased from 129 ha in 1996 to 152 ha in 2000. The groundwater level increased. Crop productivities, farmers' incomes, and profits also increased. Farmers were 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 were trained in skilled activities such as HNPV (*Helicoverpa* nuclear polyhedrosis virus) production. Adarsha watershed is a model watershed with significant achievements (Wani et al. 2003).

Emerging Issues

- Scaling-up from benchmark watersheds.
- How to institutionalize consortium.
- Harmonization of existing village institutions and watershed-based institutions.
- Ensuring effective functioning of user groups.
- Common property resources – How to ensure sharing of benefits between user groups and panchayats.
- Equity and gender issues need special attention.
- Efficient and sustainable use of water resources (water use policies, water markets).
- Financial operations and resources for functional viability of associations.
- Linking with markets and enterprises.
- Identification of quantitative indicators for build-up of social capital and processes.

Conclusions

A holistic consortium approach in watersheds enables to have "win-win" situations for sustaining productivity and reducing land degradation which are the main causes of poverty in the rainfed areas of Asia. The current model of watershed research followed at ICRISAT links on-station research to on-farm situation and adopts the consortium approach by technical backstopping. This model seems to have very high potential for bringing favorable changes in drylands of the SAT. On-farm watersheds managed through community participation could sustain productivity of drylands and preserve the quality of the land resources and environment in the SAT. Holistic systems approach through integrated watershed management can result in sustainable management of land resources and in achieving food security in the SAT.

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Improving Rural Livelihoods through Convergence in Watersheds of APRLP

T K Sreedevi[1]

Abstract

The rural livelihoods in the dry agro-regions are dependent on the natural resources. Unpredictable weather, erratic rainfall, poor soil fertility, land degradation, lack of improved varieties, poor knowledge base on improved farm technology, resource-poor farmers, low farm productivity and income levels, and burgeoning problem of rural poverty characterize these dry regions. The challenge therefore is to improve the rural livelihoods and alleviate poverty by increasing the farm productivity and income of rural people. The Andhra Pradesh Rural Livelihoods Programme (APRLP) has adopted watershed as an entry point for efficient management of natural resources for improving rural livelihoods. The APRLP has taken Adarsha watershed as a model, which is a farmer participatory watershed with a multi-disciplinary and multi-institutional approach featured by consortium and convergence mode. It is a system involving people who aim to create a self-supporting system with a vision towards sustainability with increased productivity and profitability of complex farming systems at the farmer level. Convergence in the watersheds has evolved with integrated watershed management model, which apart from integrated genetic and natural resource management strategy has watersheds as an entry point for converging the entire livelihood related activities based on natural resource use. The convergence takes place at different levels facilitating the processes that bring about synergy in all the watershed related activities. Micro-enterprises, equity issues, income generating options for landless and women groups, and micro-finance which in turn bring increased incomes and improve the rural livelihoods in a sustainable way are all features of this holistic approach. The model provides scope for issues related to suitable processes for change in micro-practices, macro-policies, convergence of information and management systems, and socioeconomic, institutional, and policy needs to increase adoption of improved options by the rural people. For sustaining the benefits from watershed management through convergence approach, monitoring and evaluation mechanisms for mid-course corrections and impact assessment are adopted to identify the mechanisms that build the capacity of the community for self-regulation and management.

Natural resource base forms the lifeline for rural livelihoods. Agriculture is the key occupation in rural areas and farming is mainly dependent on rainfall. Amongst the natural resources, land is the most valuable natural resource and fundamental to life, especially to the farming community as it is the primary basis for production (Wani et al. 2002). A close picture of land in the state of Andhra Pradesh, India reveals that 42% of the total land area is degraded. The problem of land degradation is particularly serious where local food production cannot adequately provide survival options to the rural poor. Low agricultural yields and high population pressure have forced small farmers to cultivate fragile marginal lands and clear forests causing soil erosion and thus increasing land degradation.

The rainfed areas with dry agro-ecosystems are characterized by unpredictable weather, and limited and erratic intense rainfall with long intervals of dry spells. Erratic rainfall additionally burdens the rural poor by causing soil erosion, as the torrential downpours are lost as runoff often carrying significant quantities of soil. These rainfed areas have

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higher proportion of poverty as the major socioeconomic and environmental constraints for sustaining increased productivity revolve around water (water is the most critical resource and poses great risk to water productivity in the dry regions). Factors such as low soil fertility, inappropriate soil and water management practices causing land degradation, lack of improved varieties, pest and disease attack, resource-poor farmers, declining land:man ratio, and poor rural communities, who are unable to meet even minimum standards of health and nutrition, add to the burgeoning problem of rural poverty (Wani et al. 2002). The situation calls for reducing poverty through proper management of these limited resources in the dry regions by increasing systems productivity without causing further degradation of natural resource base. Hence, under the existing situation the mission of the Andhra Pradesh Rural Livelihoods Programme (APRLP), Hyderabad, Andhra Pradesh is to help reduce poverty by protecting the fragile environments, promoting inclusiveness through participatory and convergence approach and creating diversified opportunities to the rural poor.

APRLP's Approach

For realizing the goal of sustaining rural livelihoods and effective utilization of existing resources, convergence of activities mode was chosen. The term convergence means a tendency to meet at a point. Adoption of convergence in APRLP is to improve rural livelihoods, which implies that all activities under APRLP should bring in betterment in the rural livelihoods. For maximizing the efforts so as to meet strategic and practical livelihood concerns of the poor, small and marginal farmers, landless people, and women, the convergence system forms the strategy of APRLP. An appropriate unit needs to be worked out for rural livelihood enhancement in the five target districts, through convergence of activities and proper utilization of resources. For efficient management of the existing resources, one has to look for a suitable unit of management so that these resources are managed effectively, collectively, and simultaneously. The APRLP has chosen watershed as a logical unit for efficient management of natural resources thereby sustaining rural livelihoods where focus is on the scope and priorities for development of rural people.

Watershed as an Entry Point

For improving the rural livelihoods, watershed forms a logical unit for efficient management of natural resources thereby sustaining rural livelihoods. A hydrological watershed is a delineated area from which the runoff drains through a particular point in the drainage system. Since soil and vegetation can also be conveniently and efficiently managed in this unit, the watershed is considered the ideal unit for managing the vital resources of soil, water, and vegetation. Watershed management is the integration of technologies within the natural boundaries of a drainage area for optimum development of land, water, and plant resources to meet the basic needs of people and livestock in a sustainable manner.

Integrated Watershed Management Approach

The conventional watershed approach attempts to optimize the use of precipitation through improved soil, water, nutrient, and crop management. In an agricultural watershed approach management of water and land is most important. People and livestock being an integral part of the watershed, traditional watershed programs alone, which are structure driven, cannot offer solutions to improve rural livelihoods. Though watershed serves as an entry point, a paradigm shift is needed from these traditionally structure driven watershed programs. A holistic system's approach is needed to alleviate poverty through increased agricultural productivity by environment-friendly resource management practices.

APRLP believes that watershed, as an entry point, should lead to exploring multiple livelihood interventions. The overall objective of the whole approach being poverty elimination, the new integrated watershed management model fits into the framework as a tool to assist in sustainable rural livelihoods. For the development of rainfed agriculture-based livelihoods, the integrated watershed model conceptually provides an envelope through which many of the steps for sustaining agriculture and agriculture-related activities can be implemented. The task is to intensify complex agricultural production systems while preventing damage to natural resources and biodiversity and to improve the welfare of the farmers.

The new integrated watershed model developed by a consortium led by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) provides technological options for management of runoff water, in situ conservation of rainwater, appropriate nutrient and soil management practices, waterway system, crop production technology, and appropriate farming systems. The current model of watershed management as adopted by ICRISAT watershed team, involves environment-friendly options and use of new science tools along with the concept of consortium approach and emphasis on empowering farmers through capacity building. The new science tools emphasized in the model include geographic information system (GIS), satellite imageries, and crop and climate simulation models employed in understanding the constraints for increasing productivity in the dry agro-ecoregions. The model includes the consortium approach and adopts the concept of convergence in every activity in the watershed (Wani et al. 2002).

APRLP's working mode to improve the rural livelihoods through watershed approach has adopted the Adarsha watershed (in Kothapally, Ranga Reddy district in Andhra Pradesh), as an example which is a more holistic vision that brings the concept of sustainability and eco-regionality and focuses on increased productivity and profitability of complex farming systems at the smallholder level. The integrated watershed approach adopted by the consortium at Adarsha watershed encompasses the new modeling tools and technologies for harvesting and managing natural resources on a watershed scale without undermining the natural resources. Adarsha watershed team led by ICRISAT has clearly demonstrated increased productivity from rainfed systems through integrated watershed approach, which further helped in improving the soil quality and reducing the land degradation. Farmers adopted improved management practices such as sowing on broad-bed and furrows (BBF) landform, *Gliricidia* planting along bunds, integrated nutrient management treatment including inoculation with *Rhizobium* or *Azospirillum* sp, environment-friendly integrated pest management, using improved bullock-drawn tropicultor for sowing and interculture operations, in situ conservation, and harvesting of excess rainwater and storage for use as supplemental irrigation and for increased groundwater recharge.

The Adarsha model is a participatory watershed system with a multi-disciplinary and multi-institutional approach, a process involving people who aim to create a self-supporting system essential for sustainability. The process begins with the management of soil and water, which eventually leads to the development of other resources. Human resource development and large-scale community participation is essential since finally it is the people who have to manage their resources. Access to productive resources, empowering women, building on local knowledge and traditions, and involvement of local farmers or villagers in the local communities in watershed activities contributed to the success story at Adarsha watershed.

APRLP has adopted this path with technical backstopping from research organizations like ICRISAT, Central Research Institute for Dryland Agriculture (CRIDA), and Acharya NG Ranga Agricultural University (ANGRAU) for improving the rural livelihoods in the state. The lessons learned from Adarsha watershed envisages that farmers' participation and involvement is critical in integrated watershed management. Organizing farmers and communities for effective management of resources is complex and needs careful consideration. There is a need to harmonize working between existing institutions such as panchayats and watershed management and users' associations.

Consortium model for developing and managing watersheds

The concept of consortium is an integral part of the new integrated watershed management model. A consortium approach of institutions is adopted for technical backstopping of the watersheds. Expertise from different international, national, and government organizations as well as non-government organizations (NGOs) is utilized to help the farmers on the system under operation. Establishment of an effective and credible consortium mechanism to support the watersheds technically and empowering the stakeholders (mainly the farmers and NGOs) will help to expand the effectiveness of the various watershed initiatives. The activities are:

- Establishing a process for technical backstopping for efficient use of natural resources in the watersheds.
- Addressing the activities of empowering farmers, NGOs, and other stakeholders through training and dissemination of information.
- Establishing an information and communication technology (ICT)-enabled farmer-centered learning system for sharing the knowledge (traditional and improved) and mapping the information flows in the rainfed areas for facilitating the exchange of technologies and information amongst the stakeholders, including scientists and policy makers.

Convergence approach in integrated watershed management

Convergence in the watersheds has evolved with integrated watershed management model, which apart from integrated genetic and natural resource management strategy encompasses several other entities. By adopting a holistic watershed management program, the watershed is used as an entry point for converging all the livelihood related activities based on natural resource use. The approach mode in convergence is to explicitly link watershed development with rural livelihoods and effective poverty eradication and in the process identify policy interventions at micro-, meso-, and macro-levels.

In the new adopted mode, emphasis should be on encouraging the convergence of rural development program at the watershed level. Any project design should encourage a more holistic understanding of the needs and priorities of the poor in integration with policy and institutional structures. An example of convergence for agriculture-related activities in the watershed and its link with other micro-enterprises is shown in Figure 1.

Convergence can take place at different levels. Convergence at the village level requires facilitation of processes that bring about synergy in all the watershed-related activities. Scope for issues related

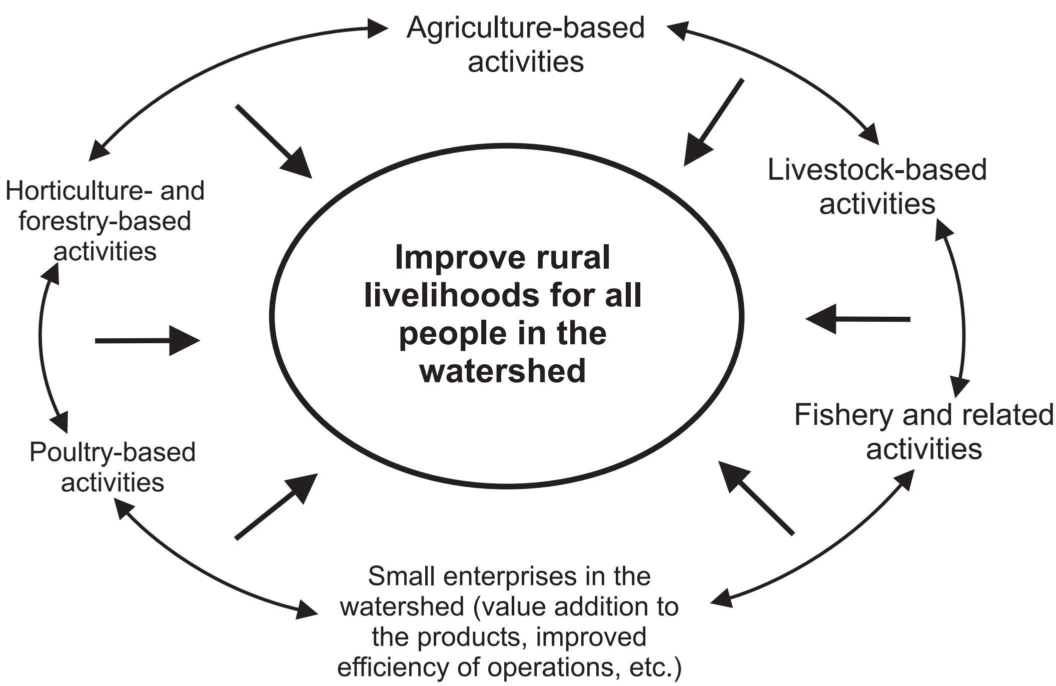

Figure 1. An example of convergence for various activities based on use of natural resources.

to suitable processes for change in micro-practices, macro-policies, convergence, and information and management systems also form part of the APRLP mandate. Socioeconomic, institutional, and policy needs to increase adoption of improved options by the rural people are adapted in the convergence approach.

Adarsha watershed is an excellent example of convergence in the watershed. This model of watershed with technical backstopping is being evaluated by ICRISAT, Drought Prone Area Programme (DPAP) [now District Water Management Agency (DWMA)], CRIDA, and ANGRAU, with the participation and involvement of farmers. The activities in integrated watershed management approach where convergence mode works include:

- Establishing village seed banks through self-help groups.
- Availability of quality seeds to farmers at reasonable rates.
- Processing for value addition (seed material, poultry feed, animal feed, grading and marketability, quality compost preparation).
- Poultry rearing for egg and meat production and local hatching to provide chicks.
- Vermicomposting with cow dung, fodder waste, and weeds provides quality compost locally.

The above activities are income-generating options for landless and women groups, which in turn bring increased incomes and improve the rural livelihoods in a sustainable way through a participatory approach.

Equity issues

The benefits in watershed development generally go to those who own or control the land and water resources in the watershed. However, the landless and marginal farmers' group benefit from the watershed needs to be ensured. The issues of equity for all in the watershed call for innovative approaches; institution and policy guidelines for equitable use of water resource are needed. Along with water use, equity issues concerning sustainable use of common property resources in the watershed also needs to be addressed.

Micro-enterprises

The provision of training and development programs to farming communities in micro-enterprises forms a better way to disable movement to urban areas for seeking employment during off-farm season. Building up on micro-enterprises can be decided on the locally available resources and technical backstopping for training the farmers. Some such technologies include:

- Vermicomposting: Providing training to women farmers can empower women.
- Preparation of bio-fertilizers.
- Livestock-based activities: Improved fodder production to improve livestock productivity, improved genotypes, and animal health.
- Fisheries and related activities: Fish or prawn culture in the water channels where excess rainwater is available. This option can be made available to the landless people in the rural communities.
- Poultry-based activities: Agro-wastes (e.g., from maize cultivation) can be diverted for poultry feed along with other supplemental food. Rearing of improved breed like broilers can increase the returns and improve the livelihood options.
- Horticulture- and forestry-based activities: Teak planting, pomegranate cultivation, and custard apple cultivation along the bunds and marginal lands.

Micro-finance

The rural poor need a market place in which they receive fair prices for their crops and livestock. The APRLP group in partnership with self-help groups and local financial institutions like Grameen Bank aims to develop and link micro-credit and revolving loan programs to resource-poor farmers so that they can purchase basic materials and make farm improvements that increase harvests, improve product quality, and reduce losses.

Monitoring and Evaluation Mechanisms for Mid-course Corrections and Impact Assessment

The major concern of watershed development efforts has been attaining sustainable impacts on poverty and the environment after the end of interventions. For sustaining the benefits of convergence through watershed management approach beyond the project period, it is essential to identify the mechanisms that build the capacity of the community for self-regulation and management. Moreover, special exit strategies, which provide minimal technical and organizational support to the community, are needed to ensure smooth transition.

The need for project monitoring and impact assessment becomes clear as it helps in mid-course corrections. The project strategy being evolutionary and based on the lessons learned during implementation, experiences from the current project would benefit other parallel projects working in the same mode. Also cross-site lessons can be learned and experiences would benefit to improve project implementation. Project monitoring and impact assessment will assist decision makers and policy makers to evaluate the project objectively.

The strategic approach for project monitoring and impact assessment begins with the preparation of inventory baseline data covering socioeconomic, natural resource base, and inputs and outputs for each watershed. This is followed by continuous monitoring and documentation by the project implementing agencies (PIAs) and periodic monitoring by APRLP. The approach also encompasses impact assessment before project completion and process documentation. The key instruments are participatory rapid appraisals, stratified sampling, detailed surveys, objective verifiable indicators (qualitative and quantitative), GIS-based analysis, feedback from the PIAs through regular reports, tour notes by project staff, feedback evaluation from experts/visitors, and impact assessment reports.

For each program activity details of specific strategy, methods, and instruments for monitoring and assessment will be worked out with all the stakeholders. The approach adopted would be a participatory approach involving the stakeholders. There would be greater reliance on quantitative indicators for objective assessment along with qualitative aspects. Further, heavy reliance on information flow and information technology using science-based methods such as GIS, remote sensing, and ICT would be adopted in the process.

Conclusion and Looking Forward

Rural development through sustainable management of land and water resources gives plausible solution for alleviating rural poverty and improving the livelihoods of rural poor. In an effective convergence mode for improving the rural livelihoods in the target districts, with watersheds as the operational units, a holistic integrated systems approach by drawing attention on the past experiences, existing opportunities and skills, and supported partnerships can enable change and improve the livelihoods of rural poor. The well-being of the rural poor depends on fostering their fair and equitable access to productive resources. The rationale behind convergence through watersheds has been that these watersheds help in “cross learning” and drawing wide range of experiences from different sectors. A significant conclusion is that there should be a balance between attending to needs and priorities of rural livelihoods and enhancing positive directions of change by building effective and sustainable partnerships. Based on the experience and performance of the existing integrated watersheds in different socioeconomic environments, appropriate exit strategies, which include proper sequencing of interventions, building up of financial, technical, and organizational capacity of local communities to internalize and sustain interventions, and the requirement for any minimal external technical and organizational support need to be identified.

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Integrated Water Resources Assessment at the Meso-scale: An Introduction to the Water and Erosion Studies of PARDYP

R White and J Merz[1]

Abstract

Water resources in mountain regions are under increasing pressure. With rapidly growing population, demand on food increases. This increasing food demand is presently met by intensifying agriculture and expansion into marginal lands. Both can result in degradation and depletion of land and water resources. However, the impact of the intensification is not yet fully understood. Often, water resources are unequally distributed with people upstream having no access to water and people downstream being affected by water diversion from mid-stream. This leads to conflicts within communities and watersheds. However, using available data to assess resource availability and subsequent improvement of planning and management decisions is difficult.

The People and Resource Dynamics in Mountain Watersheds of the Hindu Kush-Himalayas Project (PARDYP) was launched to provide an integrated and interdisciplinary approach to these issues with a long-term perspective. PARDYP provides an impetus for continuing a long-term monitoring program that is essential for understanding the environmental dynamics and rates of change in selected watersheds of the Hindu Kush-Himalayas. It is based on an interdisciplinary approach, and involves disciplines such as forestry, agriculture, sociology, economics, hydrology, meteorology, and soil science. Hydrometeorological studies with a dense measurement network in five watersheds across the Hindu Kush-Himalayas focus on generation of relevant and representative information about water balance and sediment transport related to degradation at a watershed level. Proven, and for the region, new technologies are applied for the monitoring of a variety of parameters. PARDYP's research includes studies on water availability, possibilities to retain water within the watershed for agricultural and domestic use, and recharge of heavily used groundwater bodies. In terms of high flows, PARDYP is looking at processes of runoff generation under different land uses, technical measures, and management options to prevent runoff generation and surface erosion. In general all studies focus on the assessment of the possible impact by changing conditions such as climate change and population pressure.

The paper presents an introduction to the PARDYP project followed by an insight into its water and erosion studies. The methods and techniques employed and the concepts behind the measurement network are discussed and experiences of the last 6 years highlighted.

Land and water resources in the Middle Mountains of the Hindu Kush-Himalayas are under constant threat of degradation. Rapid population growth and mismanagement of the natural resources are already causing concern and could lead to immense problems in the near future. For example:

- Top soil erosion is threatening the soil fertility of many rainfed agricultural fields in the Middle Mountains of Nepal. Nakarmi and Shah (2000) showed that losses of nutrients through erosion are significant. About 10% of the nitrogen loss and about 20% of the calcium loss are due to erosion. According to Scherr and Yadav (1996), this region is one of the hot spots in South Asia in terms of land degradation.
- Increasing irrigation demand for cash crop production with up to four crops per year may lead to decreasing water tables and drying up of river beds. A number of farmers have mentioned decreasing irrigation water availability in the

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Yarsha Khola watershed (Merz et al. 2000). The situation in the Jhikhu Khola watershed is expected to be even worse due to the close proximity of markets for vegetables and cash crops.

- Access to adequate drinking water supply is increasingly a concern to local residents. People along the watershed divide do not have access to running water at a convenient location and have to spend up to 2 hours per trip to collect water (Merz et al. 2002).
- Water quality has become a major issue in many parts of the region. Sharma et al. (2000) compiled water quality information from Nepal. The major area of focus is the Kathmandu Valley where immediate improvements have to take place if the lives of the people living in the valley are not to be endangered.

However, the reasons and the impacts of these processes are not yet fully understood partially due to inappropriate or missing data sets. The People and Resource Dynamics in Mountain Watersheds of the Hindu Kush-Himalayas Project (PARDYP) was launched to provide an integrated and inter-disciplinary approach to these problems with a long-term perspective.

The PARDYP Approach

PARDYP is a regional research for development project active in many fields of natural resource and watershed management. It succeeded two successful projects funded by the International Development Research Centre (IDRC), Canada, the 7-year "Mountain Resource Management Project", which undertook resource dynamic studies in the Jhikhu Khola watershed of Nepal (1989–96), and the "Rehabilitation of Degraded Lands in Mountain Ecosystems Project" (1992–96) in China, India, Nepal, and Pakistan involving research on the rehabilitation and "re-greening" of small patches of degraded land. PARDYP combines the regional and the integrated approach from its two predecessors. Phase I was from 1996 to 1999 while the current second phase continued till the end of 2002.

The Jhikhu Khola watershed work that started in 1989 has continued without a break and now 13 years of data on soil and water dynamics is providing new insights into both intensification and degradation processes. The lessons learned in Jhikhu Khola have been adopted and guide the current phase of PARDYP in watershed management research across the Himalayas. During the first phase, PARDYP aimed at further improving the understanding of environmental and socioeconomic processes associated with degradation and rehabilitation of mountain ecosystems and generating wider adoption and adaptation of proposed solutions by stakeholders in the Hindu Kush-Himalayas (ICIMOD 1996).

PARDYP Phase II aims at contributing to balanced, sustainable, and equitable development of mountain communities and families in the Hindu Kush-Himalayan region (ICIMOD 1999). The project activities are concentrated in six major components:

1. Understanding community institutions and their dynamics
2. Social and gender inequity, marginalization
3. Water resources for irrigation and domestic use
4. On-farm resources
5. Common property management
6. Livelihood potentials of mountain communities

All PARDYP project components are carried out in each of the five watersheds in the Middle Mountains of the Hindu Kush-Himalayas in China, India, Nepal, and Pakistan (Fig. 1). The activities include agronomic and horticultural initiatives, socioeconomic and market studies, rehabilitation of degraded lands and forestry, soil fertility studies, participatory conservation activities, and water and erosion studies. PARDYP encourages regional data exchange, and generation and dissemination of knowledge.

The overall coordination, guidance, and administration support is by the International Centre for Integrated Mountain Development (ICIMOD). The national partners are: the Pakistan Forestry Institute, Peshawar, Pakistan; the Kunming Institute of Botany in China; the GB Pant Institute for Himalayan Environment and Development, India; and ICIMOD itself in Nepal together with the Department of Forest and the Department of Soil Conservation and Watershed Management. These national focal research institutions implement, manage, and supervise the activities with the assistance of national and international partners and

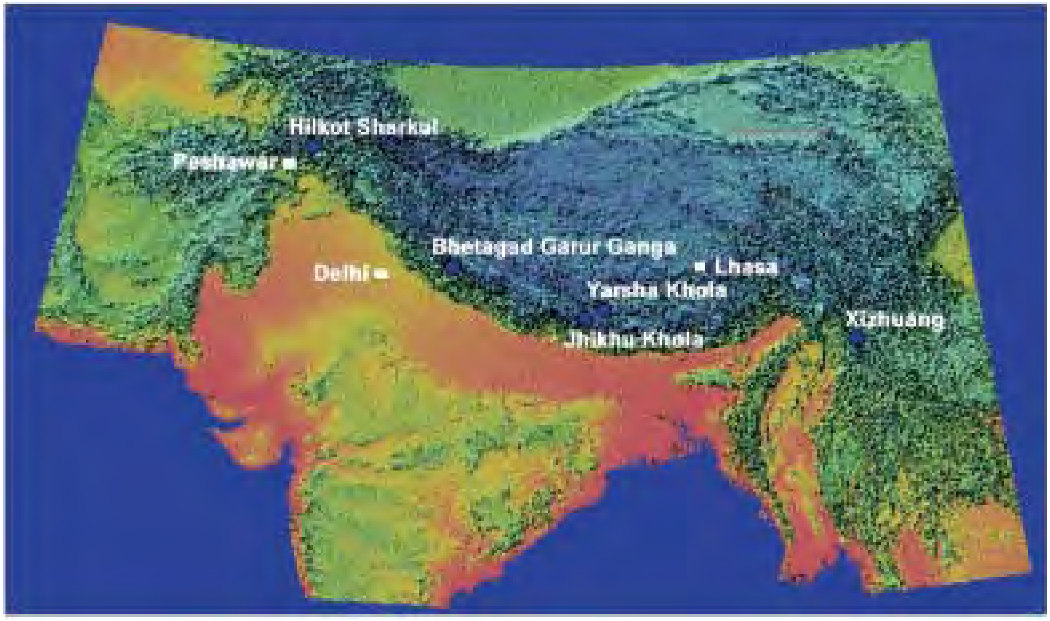

Figure 1. The five PARDYP watersheds.

collaborators. The two main international partners are the Institute for Resources and Environment at the University of British Columbia (UBC), Canada, and the Hydrology Group at the Department of Geography, University of Berne (UoB), Switzerland. Financial support comes from the Swiss Agency for Development and Cooperation (SDC) and IDRC.

The PARDYP network focuses on watersheds of similar size (50–100 km^2), at similar elevations (800 to 3,000 m), and those that carry out similar activities and surveys, and use similar instrumentation and the same software so that results are directly comparable. The broad cropping systems are the same; rice and wheat in the irrigated valley areas and maize in the rainfed areas. The teams work closely with farmers and are able to observe what works and what does not.

The approach is that farmers employed as erosion plot or hydro-meteorology readers are also the project's point of contact with farmers for research and demonstration trials and dissemination of findings. This is a cost-effective approach. Running costs for each watershed average US$ 50,000 per year; this includes salaries for the technical staff, travel costs, equipment maintenance, site running costs, and all survey costs.

Water and Erosion Studies in PARDYP

One of the main project components is research for development and demonstration focusing on water, erosion, and related matters. This component specifically aims at the generation and exchange of information on water as a resource and its role in land degradation, and at identifying and testing of options to enhance water management decisions (ICIMOD 1999). The main activities in this context are monitoring and collection of baseline information, water quality investigations, soil conservation, and water management. As shown in Figure 2, these activities are investigated in the biophysical and the socioeconomic environment. The resource monitoring is mainly done on water resources.

Resource monitoring and mapping

During the first three years between 1997 and 1999, major emphasis was on data collection. Long-term data collection was initiated with the setup of a measurement network in five watersheds in the Hindu Kush-Himalayas. A total of 89 measurement sites

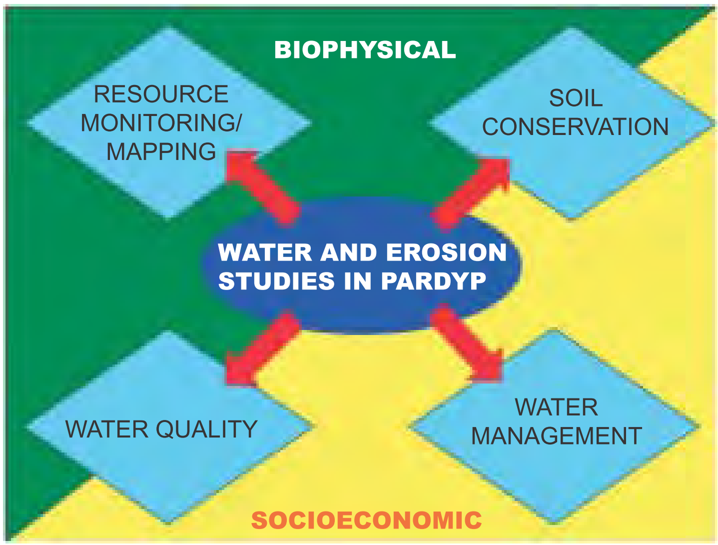

Figure 2. Water and erosion studies in PARDYP.

were operational in June 2001 (Table 1), monitored by local residents who get annual training and new instructions if needed.

The setup of the station network in all watersheds followed the same principle of the nested approach. This approach helps in investigating the processes on micro- to meso-scale, i.e., from the plot to the watershed level, and subsequently determining scale dependency of these processes. Erosion plots and, more recently, surface flow collectors were used for the plot level investigations at 100 m^2 and 2–5 m^2 respectively. Sub-catchments and catchments ranging from a few hectares to several km^2 were monitored with hydrological stations equipped with different instruments. The main watersheds ranged from about 20 to 110 km^2. The nested approach principle is graphically presented in Figure 3.

During an inception workshop the methods of data collection were as far as possible standardized or at least kept similar. Hofer (1998) gives background for the recommended data collection in all watersheds. Different manuals were prepared and distributed to the respective people in the watersheds: Discharge measurement by salt dilution (Merz 1998) and by current meter technique (Dongol et al. 1998), and measurement of runoff and soil loss by erosion plots (Nakarmi 1999). In three of the watersheds the same equipment is used for the collection of rainfall intensity and temperature data. The monitored parameters include water level, discharge, sediment concentration, rainfall, air temperature, water quality, and others.

The collected data is being thoroughly checked and then stored in a watershed database running on

Table 1. Measurement sites in the five PARDYP watersheds, June 2001.

Watershed	Hydrological stations	Meteorological stations	Erosion plots
Xi Zhuang (China)	4	10	6
Bhetagad (India)	6	5	4
Jhikhu Khola (Nepal)	5	10	7
Yarsha Khola (Nepal)	4	11	4
Hilkot (Pakistan)	4	6	3

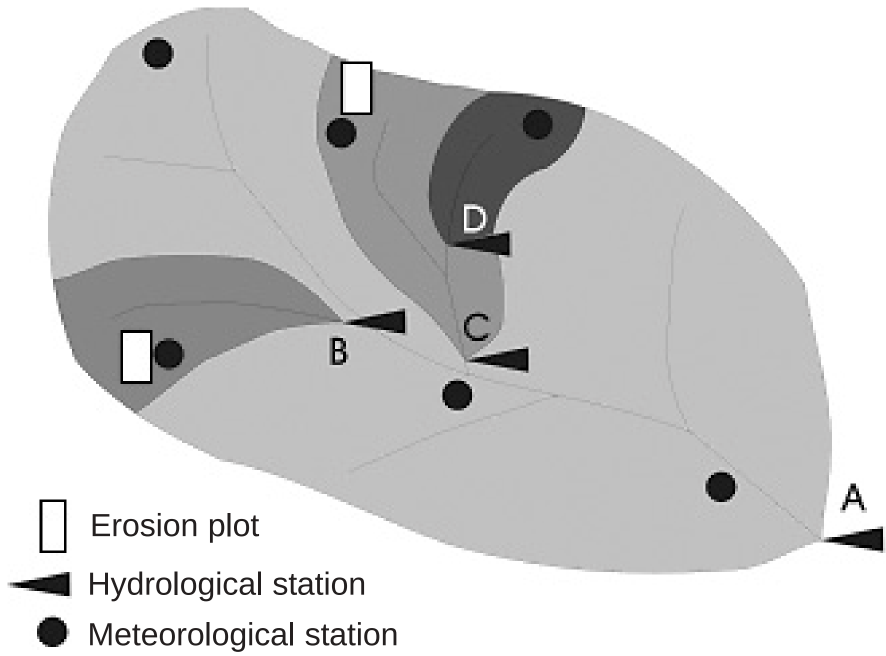

Figure 3. Principle of the nested approach (schematic).

the hydrological software HYMOS 4. The use of the same software in all watersheds ensures the exchangeability of data between the different country teams. Annually the final data is published in the form of a yearbook; the latest of PARDYP-Nepal is on a CD-ROM. In addition to the regular monitoring various surveys are undertaken. This is mostly done to obtain the necessary baseline information for further hydrological studies. Some examples from the two Nepal watersheds, Yarsha Khola and Jhikhu Khola watersheds, are given below:

- Land use was mapped with the help of aerial photographs of the scale 1:20,000. Major changes occurred in the last 15 years in Yarsha Khola; the forest cover increased and the rainfed agricultural areas decreased. In the Jhikhu Khola, forest cover and rainfed agricultural area increased while shrub and grassland areas decreased between 1972 and 1990. Shrestha (2000) has discussed the results in detail.
- In both watersheds of Nepal geological baseline maps give information on the geological bed rock of the watersheds (Nakarmi 2000).
- In Jhikhu Khola a geomorphological map was produced giving information on predominant processes. The same map for the Yarsha Khola watershed is in its final stages.
- A land systems map of the Jhikhu Khola watershed gives information on soil types and landforms. Recently a sediment source map including soil depth was completed.
- During December 1998 and September 1999 a water demand and supply survey was done in the Yarsha Khola and the Jhikhu Khola respectively, to give an indication of water surplus and water demand areas. The same survey highlights agricultural production and agrochemical inputs as baseline information for water quality surveys. The results of these surveys are presented in Merz and Nakarmi (2001) and Merz et al. (2002).
- For the allocation of water resources a detailed public water sources survey was done in both watersheds. A total of 319 springs were mapped and basic physical parameters measured in Jhikhu Khola watershed (Shrestha et al. 2000). The same

survey in the Yarsha Khola yielded 215 springs (Shrestha et al. 2001).

In addition to the topical studies mentioned above the water and erosion study team of PARDYP is conducting comparative hydrometeorological and sediment transport studies between the PARDYP watersheds and other watersheds across the region. This includes:

- Integration of the results from each watershed using geographic information system (GIS) and other technologies to construct a picture of the behavior of water and sediment in terms of time, season, land cover, and extremes.
- Comparison of these results and key findings between the watersheds to formulate and explain the main similarities and differences across the region.
- Modeling of scenarios under given and changing conditions to predict changes in the flow regimes and sediment transport.

Water quality

In all watersheds basic chemical and physical water quality parameters are being tested on a regular basis. The main aim of these investigations is the study of nutrient dynamics from agricultural land into the streams. However, a survey of all health posts in the Jhikhu Khola showed that water-borne diseases account for about 25% of the patients visiting these health organizations. PARDYP-Nepal therefore has recently undertaken a water quality assessment study in the Jhikhu Khola watershed in collaboration with the Department of Environmental and Biological Sciences of the Kathmandu University. This study, funded by the Australian Agency for International Development (AusAid), aimed at assessing the present water quality of Jhikhu Khola and its tributaries, examining the water quality of the public water supply, raising public awareness of water quality issues, and recommending simple water quality assessment methods and treatment technologies.

The main findings of this study were the high microbiological contamination of all sources and the elevated phosphate and nitrate levels in the surface and groundwater. This is attributed to the intensive agricultural practices in the area. For water quality improvement, both water treatment and long-term solutions such as spring and catchment protection are proposed and will be tested in detail in the near future. A number of springs have been renovated and will be microbiologically tested. To standardize a methodology for field-based microbiological testing, different methods were examined amongst other presence/absence tests.

For dissemination of the findings, workshops and training programs with different stakeholders were organized. Stakeholders included local residents, female health volunteers, science teachers, local authorities, and scientists.

Soil conservation

Sediment loads and their sources are of major interest for irrigation schemes and hydropower development and design. For the farmers and local users of common land resources, the loss of topsoil is of direct concern. Furthermore, sediment in drinking water supplies is also commonly high on the list of household concerns (Merz et al. 2002). The studies of sediment balances at different spatial levels and the routing of sediment from the plot level to the watershed were followed by the testing and recommendation of possible measures against surface erosion.

Initial results showed that degraded lands produced the highest surface erosion rates followed by rainfed agricultural land. To combat this soil loss PARDYP has initiated trials on the rehabilitation of degraded lands. A number of nitrogen-fixing tree and shrub species were tested (Shah et al. 2000). On agricultural land, PARDYP-Nepal is conducting a terrace improvement program under supervision of the Department of Soil Conservation and Watershed Management of His Majesty’s Government of Nepal. The first trial on cover crops failed due to dry conditions. New approaches will be studied in the near future.

Water management

Too much water during the monsoon season and too little water during the dry season are major issues in the Hindu Kush-Himalayas. Therefore, flooding, drought, and water availability are the priority issues on the list of many stakeholders. The data collected on the routine monitoring network is therefore being analyzed.

Study of water dynamics

Water dynamics research included the study of rainfall distribution in time and space, high flows and their generation, low flows and their occurrence, and rainfall-runoff relationships from areas of different land use and cover. The results are of particular interest to planners and engineers involved in water-related projects (irrigation, hydropower, drinking water).

Study of water availability

The activity on water availability is being carried out at different spatial levels, where water availability, water losses, and hence water balances are estimated. These calculations are leading to an indication of where and when water is available, where and when water supply is critical, where water harvesting will lead to considerable benefit to the residents and farmers, and how storage can be improved. This refers as much to drinking water supplies as to irrigation.

To apply the results from the above studies, PARDYP has a strong interest in improving the efficiency of water use. This starts with the retention of rainfall and storm water. In the Jhikhu Khola watershed a trial site for the retention of storm water was constructed in collaboration with a Chinese expert (Nakarmi and Neupane 2000). The knowledge of rainfall patterns and runoff coefficients helped in the design of the system. Another system of the same type was constructed in the Yarsha Khola watershed.

A trial on alternative irrigation methods was conducted using the water from the constructed underground tank. Bucket and drip irrigation were compared. In mid-2000, trials on rainwater harvesting were initiated with the help of the jar technique as implemented by the Finnida-supported Rural Water Supply and Sanitation Support Programme (RWSSSP) in Nepal. About 20 local masons from Bhutan, the Jhikhu Khola and the Yarsha Khola watersheds were trained in collaboration with the Water Harvesting Project of ICIMOD and RWSSSP. Subsequently these trainees built 13 demonstration units in the Jhikhu Khola watershed and 9 in the Yarsha Khola watershed.

Regional activities

The regional activities of the water and erosion studies have been exchange of information on methods and support in data collection and management. While the first three years of the project were mainly taken up by the setup of the measurement network, emphasis was put on data analysis in Phase II. The project staff involved in water and erosion studies were trained in hydrological data analysis during a training workshop held in Kathmandu with the main topics “basic analysis”, “low flow”, “water availability”, “high flow”, and “sediment analysis tools”. On the occasion of the training a manual on water and erosion analysis methods was produced, which could also be of value to other watershed management projects. Currently all PARDYP country teams work towards the synthesis of the water and erosion activities at a regional scale, which is envisaged to be complete by the end of the current phase in December 2002.

Experiences and Recommendations

The experience of the last 6 to 10 years has shown that best results are achieved with a small, but dedicated team of 4 to 6 core staff of different background. The field teams should be based in the watershed and have a suitable field office. Their commitment has to be full time and coordination on the country level should also be on a full time basis.

For water and erosion studies, 1 to 2 staff members are assigned. Most of the staff members are young and at the beginning of their professional career. This fits with the guiding principles of the project of capacity building. In water and erosion studies, the training and education of young hydrologists in the four participating countries and from outside the region is important. The aim is to familiarize them with new and appropriate technology in the field of water and erosion research.

For well-defined research activities students and university departments can be involved. In most cases these temporary arrangements have produced good results. For hydrological data collection the setting up of guidelines is very important. A common data management software helps in data exchange and support in case of difficulties. However, the experience with setting up guidelines for data formats failed in this case. Analysis guidelines have proven to be very useful for the synthesis and technical support.

Currently PARDYP is managed by one regional coordinator working in close collaboration with the country coordinators. For improved regional collaboration and synthesis of data in the different topic areas of the project it is suggested to have activity coordinators at the regional level. This should ensure frequent exchange of information, technical support, and strategic planning. The exchange of information with other projects of the similar kind is a prerequisite.

Conclusion

The integrated approach of watershed management research including natural and human resources at the meso-scale is proving to be very interesting. The project has gone from a pure data collection phase to a data consolidation phase and has now reached the time of data analysis. With proper synthesis of all results from the different fields, interesting findings will come up on the dynamics of natural resources and people in the single watersheds and across the region. Further information on the project can be obtained from http://www.icimod.org under projects or pardyp@icimod.org.np.

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A Dynamic Soil Erosion Model (MSEC 1): An Integration of Mathematical Model and PCRaster-GIS

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Abstract

A physically-based dynamic Soil Erosion Model (MSEC 1) was developed by the Management of Soil Erosion Consortium (MSEC) project by integrating revised Griffith University Erosion Sedimentation System (GUESS) (to predict the movement of sediment and surface flow) and PCRaster-GIS (to incorporate spatial distribution of parameters and catchment behavior). The model was applied to Huay Pano catchment, Luang Prabang, Laos using parameter values from literature and experiments. The results of runoff and predictions were satisfactory. The model results should be compared with field data for further evaluation, validation, and improvement.

Generally the amount of soil loss and water runoff under various soil erosion factors is obtained from small plot experiments on a part of slope in a watershed. The actual soil losses from the plots are collected in a tank before they are weighed and analyzed. The surface runoff is measured in the weir gate. The results when expanded to whole slope and watershed levels are not reliable and do not provide off-site effect.

Mathematical models for soil erosion estimation have been developed to provide on-site and off-site information. These physical models do not provide spatial distribution. Geographic information system (GIS) is a tool that provides spatial information. The Raster GIS format, representing various sizes of ground resolution depending on the users, is not popular as compared to the vector format due mainly to computer memory. Recently, PC is very powerful and convenient for data analysis. Therefore, the linkage with physical soil erosion model is possible and will provide a dynamic dimension and on-site and off-site effects.

The MSEC 1 dynamic soil erosion model was developed by interfacing PCRaster-GIS with the revised GUESS soil erosion equations to calculate water runoff and sediment transport and deposition in micro- and macro-watersheds. This model on PC was applied to Huay Pano catchment, Luang Prabang, Laos, using parameters obtained from literature and experiments. The results of sediment and runoff prediction were satisfactory. However, the values of parameters for different ecosystems in the Asian region need further field experiments and evaluation.

The Dynamic Model

Several soil erosion models are based on soil, topographic, vegetation cover, and annual rainfall factors. Soil erosion occurs during a rainstorm. Therefore, the amount and intensity of rainfall in an event is very important to provide time series determination of soil erosion. There are two groups of soil erosion models: empirical models and physically-based models. The empirical models are simple and use relationships of soil erosion factors under plot experiment. The models are extrapolated to larger areas by using regression equation. Some of these models are Universal Soil Loss Equation developed by Wischmeier and Smith (1978), ELEMSA (Soil Loss Estimation for Southern Africa) by Elwell (1978), and equations by Morgan and Finney (1987) and Morgan (1994). Generally these models cannot extrapolate outside the experimental plots. Since it is time and labor consuming, it also requires large budget.

The physically-based models are derived mainly from mass characteristics and movement as defined

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by the Law of Conservation of Mass which is also the basis of the Continuity and Momentum Equation. It predicts the movement of sediment and surface flow of water, both on-site and off-site. These models improve the weakness of the empirical models. However, these models require many parameters that need research support. Examples of the physically-based models are CREAMS (Chemical, Runoff, and Erosion from Agricultural Management System) developed by Foster and Meyer (1972), WEPP (Water Erosion Prediction Project) by Nearing et al. (1989), GUESS (Griffith University Erosion Sedimentation System) by Ross et al. (1983), EUROSEM (European Soil Erosion Model) by Morgan (1994) and Morgan et al. (1994). To integrate the soil erosion model into GIS, it is essential to know the details of the selected model and the nature of soil erosion. The MSEC 1 model was designed by integrating GUESS model and PCRaster and can be applied for micro- and macro-watersheds.

GUESS Model

The GUESS model for soil erosion developed by Ross et al. (1983) illustrates the processes of soil erosion, transport, and deposition. Therefore, the model can be used to predict on-site and off-site effects. The concept of the model is to use the equilibrium of sediment in the area. It calculates the movement of sediment under actual condition and then the deposition area by runoff flow for each rainfall event. Generally, two types of soil are considered: original soil and newly deposited soil. The original soil has different cohesion and aggregation, while the newly deposited soil has no cohesion and aggregation. Therefore, in each rainfall event the soil cohesion in the area will not be the same. The degree of leaching, erosion, and transport of sediments varies according to Equation 1:

$$\frac{\partial Q_{si}}{\partial \chi} + \frac{\partial (C_i h)}{\partial_t} = e_i + e_{di} + r_i + r_{di} - d_i \qquad (1)$$

where:

Q_{si} = Sediment load of sediment class *i*;

C_i = Concentration of sediment class *i* in the flow;

e_i = Rate of detachment of soil particles of sediment class *i* in the original soil by raindrop impact;

e_{di} = Rate at which recently detached soil of sediment class *i* is re-detached by raindrop impact;

r_i = Rate of detachment of soil particles of sediment class *i* by flow;

r_{di} = Rate at which recently detached soil of sediment class *i* is re-detached by flow; and

d_i = Rate of deposition.

The rate of detachment of soil particles of sediment class *i* by raindrop impact is calculated by Equation 2:

$$e_i = aC_e I/N \qquad (2)$$

where:

a = Detachability of the soil;

C_e = Fraction of the soil surface exposed to raindrops;

I = Rainfall intensity; and

N = Number of particle size classes.

The rate of re-detachment of soil particles of sediment class *i* is calculated as shown in Equation 3:

$$e_{di} = a_d C_e I/N \qquad (3)$$

where:

a_d = Re-detachability of the soil.

The detachment rate of soil particles by flow (r_i) derived from the activity of stream power (Ω) above critical (Ω_c) and shear stress is shown in Equation 4:

$$\Omega = \tau V \qquad (4)$$

where:

τ = Shear stress; and

V = Flow velocity.

The shear stress is calculated by Equation 5:

$$\tau = \gamma_f RS \qquad (5)$$

where:

γ_f = Specific weight of fluid;

R = Hydraulic radius; and

S = Energy slope (surface slope for steady state flow).

The detachment rate of soil particles by flow is calculated as in Equation 6:

$$r_i = (1-H)F(\Omega - \Omega_c)/I\Im \qquad (6)$$

where:

(1–*H*) = Fraction of the original soil surface exposed to runoff;

F = Fraction of the excess stream power of overland flow used in erosion; and

$\Im$ = Amount of unit stream power necessary to detach a unit mass of soil.

The re-detachment rate of soil particles is calculated by Equation 7:

$$r_{di} = \left(\frac{\alpha_i HF}{g}\right)\left(\frac{\sigma}{\sigma-\rho}\right)\left(\frac{\Omega-\Omega_c}{h}\right)\frac{M_i}{M} \qquad (7)$$

where:

α_i = A dimensionless parameter with a value dependent on the depth of flow;

H = Fraction of the surface soil covered by recently deposited material;

σ = Submerged sediment density;

ρ = Density of water;

h = Depth of flow;

M_i = Mass fraction of sediment class i; and

M = Total mass of material being re-detached.

The rate of deposition of sediment of class i is calculated as in Equations 8 to10.

$$d_i = \alpha_i v_{si} C_i \qquad (8)$$

$$\upsilon_{si} = \frac{gD_i^2}{18v}\cdot\frac{\gamma_s - \gamma_f}{\gamma_f} \qquad (9)$$

$$v = \frac{\mu}{\rho_f} \qquad (10)$$

where:

υ_{si} = Fall velocity of particles of sediment class *i;*

g = Gravitational constant;

D_i = Particle diameter class *i;*

ν = Kinematic viscosity of the liquid;

γ_s = Specific weight of sediment;

γ_f = Specific weight of liquid;

μ = Absolute viscosity; and

ρ_f = Density of fluid.

The Equation uses a theoretically derived expression for the maximum possible sediment concentration that can be sustained due to flow-driven erosion processes. It is based on the upper limit of sediment concentration, C_{max}, which is reached when the rate of removal of sediment is equal to its rate of deposition. The transportation capacity of the soil erosion or water flow is calculated by Equation 11:

$$C_{max} = \left(\frac{F\rho}{\Sigma\upsilon_{si}/N}\right)\left(\frac{\sigma}{\sigma-\rho}\right)SV \qquad (11)$$

Proving the equation:
From Equation 1,

$$\frac{\partial Q_{si}}{\partial \chi} + \frac{\partial (C_i h)}{\partial t} = e_i + e_{di} + r_i + r_{di} - d_i$$

$$aC_e I/N + a_d C_e I/N + (1-H)F(\Omega-\Omega_c)/I\Im$$

$$+\left(\frac{\alpha_i HF}{g}\right)\left(\frac{\sigma}{\sigma-\rho}\right)\left(\frac{\Omega-\Omega_c}{h}\right)\frac{M_i}{M} = \alpha_i \upsilon_{si} C_i$$

$$\frac{C_e I}{N}(a_d + a_d) + (\Omega-\Omega_c)F$$
$$\left(\frac{(1-H)}{I\Im} + \frac{\alpha_i H}{gh}\left(\frac{\sigma}{\sigma-\rho}\right)\frac{M_i}{M}\right) = \alpha_i \upsilon_{si} C_i$$

It is observed that in the surface runoff, when the sediment concentration is at the highest the first group in the equation is equal to zero. When Ω_c has value of 0, the maximum mass from erosion is equal to total mass. Therefore, the H value is close to 1. In this equation, it is given as 1 so that the calculation will be highest.

When $\Omega = \tau v$ and $\tau = \gamma_f YS$ in the equation are replaced by assigning $\gamma_f = \rho g$, the product is $\Omega = \rho\gamma YSV$.

From the balance of the equation, then

$$\upsilon_{si} C_i = \frac{F\rho\sigma}{\sigma - \rho} SV$$

Therefore,

$$C_{\max} = \left(\frac{F\rho}{\Sigma\upsilon_{si} / N} \right) \left(\frac{\sigma}{\sigma - \rho} \right) SV$$

as shown in Equation 11.

Equation 11 is applied either to the overland flow or the flow to the rills and it is possible to rewrite the equation as shown in Equation 12:

$$C_{\max} = \frac{F\sigma SV}{\phi\left(\frac{\sigma}{\rho} - 1 \right)} \qquad (12)$$

where:

ϕ = Mean settling velocity of sediment.

$$\phi = \frac{\sum \upsilon_{si}}{N}$$

From Equation 12, the velocity is calculated using the original Manning equation as shown in Equations 13 and 14.

$$v = \frac{1}{n} R^{2/3} S^{1/2} \qquad (13)$$

where:

n = Manning's roughness coefficient;

S = Slope; and

R = Hydraulic radius (cross section area/length of wet zone).

$$R = \frac{A}{P} \qquad (14)$$

When the equation is replaced by runoff discharge, it is written as Equations 15 and 16:

$$Q = VA \qquad (15)$$

or

$$A = \frac{Q}{V} \qquad (16)$$

where:

Q = Runoff discharge per unit area.

Therefore, the equation for velocity is shown in Equations 17 to 20:

(17)

$$V = \left(\frac{1}{n} \frac{Q^{2/3}}{V^{2/3} P^{2/3}} \right) S^{1/2} \qquad (18)$$

$$V = \frac{1}{n} \left(\frac{A}{P} \right)^{2/3} S^{1/2} \quad V^{5/3} = \frac{1}{n} \left(\frac{Q^{2/3}}{P^{2/3}} \right) S^{1/2} \qquad (19)$$

$$V = \left(\frac{\sqrt{S}}{n} \right)^{3/5} \frac{Q^{2/5}}{P^{2/5}} \qquad (20)$$

For simplicity, the flow cross section is assumed as rectangular; hence the new equation is:

$$V = \left(\frac{\sqrt{S}}{n} \right)^{3/5} \frac{Q^{2/5}}{L^{2/5}} \qquad (21)$$

$$V = \left(\frac{\sqrt{S}}{n} \right)^{3/5} L^{-2/4} Q^{2/5} \qquad (22)$$

When V is replaced in Equation 12, the new Equations 23 to 25 are derived.

$$C_{max} = \frac{F\sigma S}{\phi\left(\frac{\sigma}{\rho} - 1\right)} \left(\frac{\sqrt{S}}{n}\right)^{3/5} L^{-2/5} Q^{2/5} \quad (23)$$

$$C_{max} = kQ^{0.4} \quad (24)$$

where:

$$k = \frac{F\sigma S L^{-2/5}}{\phi\left(\frac{\sigma}{\rho} - 1\right)} \left(\frac{\sqrt{S}}{n}\right)^{3/5}$$

$$\left[\frac{[kg/m^3] * \left[m^{2/5}\right]}{m/s} \frac{1}{m^{1/5} s^{3/5}}\right] = \left[[kg/m^3] * \frac{\left[s^{2/5}\right]}{m^{1\frac{2}{5}}}\right] \quad (25)$$

From the equation, it is seen that the transport capacity of the flow is dependent upon k and runoff values. In the equation, the transport capacity is calculated for each rainfall event. To have runoff in a steady state, it is necessary to obtain the "effective runoff discharge" (Q_{eff}) and ensure that k value is stable. The new equation can be rewritten as in Equations 26 to 30.

$$\overline{C}_{max} = \frac{\Sigma k Q^{0.4} \times Q}{\Sigma Q} \frac{\text{tot sed flux}}{\text{runoff rate}} \quad (26)$$

$$\overline{C}_{max} = \frac{k \Sigma Q^{0.4}}{\Sigma Q} \quad (27)$$

$$\overline{C}_{max} = k\left[\left[\frac{\Sigma Q^{1.4}}{\Sigma Q}\right]^{\frac{5}{2}}\right]^{\frac{2}{5}} \quad (28)$$

$$\overline{C}_{max} = kQ_{eff}^{0.4} \quad (29)$$

$$\left[[kg/m^3] * \left[\frac{s^{2/5}}{m^{1\frac{2}{5}}}\right] * \left[\frac{m^{1\frac{2}{5}}}{s^{2/5}}\right]\right] = [kg/m^3]$$

where:

$$Q_{eff} = \left[\frac{\Sigma Q^{1.4}}{\Sigma Q}\right]^{\frac{5}{2}} \quad (30)$$

$\overline{C}_{max}$ = The flow-weighted or the average value of C_{max} during an erosion event.

From Equation 28, it is then possible to calculate the soil erosion in each rainfall event. To obtain precise calculation, the soil cohesiveness and vegetation or surface cover could be added as shown in Equations 31 and 32.

$$\overline{C} = \overline{C}_{max}^{\beta} \quad (31)$$

where:
β = Erodibility parameter (or soil erodibility); and
$\overline{C}$ = Actual flow-weight sediment concentration.

$$c/c_b = \exp(-k_s C_s) \quad (32)$$

where:
c = Real soil erosion:
c_b = Bare soil erosion;
C_s = Fraction of surface contact cover; and
k_s = Non-dimensional (obtained by experiment).

Finally, the total mass of soil lost during an erosion event (M) is shown in Equation 33:

$$M = k^{\beta} Q_{eff}^{0.4\beta} \Sigma Q \exp\left(-k_S C_S\right) \qquad (33)$$

GIS in PCRaster

Currently, GIS has been employed intensively to manage and analyze data including watershed management and soil erosion and modeling. It has been applied in empirical models such as the USLE. However, the physical soil erosion models would require specific software that provide similar condition as natural processes where time sequences and changes of parameters are involved.

PCRaster is a GIS raster software that has both functional and operational packages for real dynamic soil erosion modeling. The software, similar to other GIS packages, is capable to store, manipulate, analyze, and retrieve geographical data. This software is also capable for cartographic and dynamic modeling to simulate soil erosion, on-site and off-site effects through surface water flow and sediment transportation. There is no digitization or scanning for data input available in the software. Rather, all data are transferred to and from other GIS package. The information on PCRaster is in the PCRaster Manual Version 2 by Faculty of Geographical Sciences (2000).

Main components in PCRaster

There are two main components in the PCRaster: cartographic model; and dynamic modeling module.

Cartographic model

The cartographic model is employed for spatial data. The value of each cell (pixel) changes according to the "point operations", "neighborhood operations" and "area operations". The point operations include functions that operate only on the values of the map layers relating to each cell. The simplest of the point operations are the arithmetic, trigonometric, exponential, and logarithmic functions of mathematical operation. The neighborhood operations relate the cell to its neighbors by mathematical functions. The main operations are "local drain direction (LDD)" operations and the friction path operations, for transportation of material over LDD. The area operations are used for analysis of map operations. The map operation uses non-spatial (attribute data) that links to the map.

Dynamic modeling module

The dynamic modeling module is the advanced module of GIS function in PCRaster. This model uses simple language and is designed for movement of materials under the cartographic model. Therefore, its operation is similar to most mathematical calculations. Hence, the users may not necessarily be programmers, but can do modifications for specific application. The dynamic model is used for modeling of soil erosion processes over time. In this model, new attributes are computed as functions of attribute changes over time. It is built with language provided by PCRaster. Within this language, the model can be programmed with the PCRaster operations of cartographic modeling. A script, i.e., a program written in the dynamic modeling language, consists of separate sections. Each section contains a certain functional part of the script. The division in sections is an essential concept of the dynamic modeling language. It tells the computer how to execute a program and it helps the user to structure the component of a model.

The basic sections needed for building a dynamic model are the binding section and the area map section used at the dynamic section for the iteration at the first time step. The dynamic section defines the operations for each time step i. that result in a map of values for that time step. Each time step consists of one or more PCRaster operations that are performed sequentially. The results of time step i. are the input values for time step i. + 1 and so on. This section reads dynamic data from the databases or stored model results in the database for each time step.

Data types

The data types used in PCRaster are Boolean, Directional, LDD, Nominal, Ordinal, and Scalar. The scalar fields are used to describe intensities and potential of the physical field such as precipitation.

Directional fields apply to attributes that have a circular and continuous scale such as aspect of the terrain. The vector fields have both magnitude and direction and can be used to represent (horizontal) fluxes and forces such as infiltration or rainfall.

The LDD data type has been introduced to provide for the definition of the direction of potential flow. It is a data type that supplies the raster database with the topological linkages needed by the operators that describe lateral fluxes of the fluids or materials. In general, this LDD map is derived from a Digital Elevation Model (DEM), and represents the direction of surface flow through this elevation map, but any scalar field showing potential difference can be processed to determine a LDD map.

From the models and structure of the PCRaster-GIS, it is very useful for physical soil erosion modeling. The model is well used to analyze all soil erosion data through commands or script in the PCRaster. The model runs from the beginning stage of soil erosion processes to the end continuously.

Integration of PCRaster-GIS and Modified GUESS Model

Principle

The main principle of integration of PCRaster-GIS and GUESS model is to simulate soil erosion in a real situation or as virtual simulation in each rainfall event. The process is to integrate GIS function into operators in the PCRaster. The model will calculate soil erosion according to the GUESS model by time steps or rainfall events. The results of soil erosion calculated at every time step will show the direction of flow according to the topography or DEM or LDD. The calculation of soil erosion starts from the first time step or the first rainfall event and sediments transported and deposited before the second time step or second rainfall event begins. This calculation process will continue until the last time step or the last rainfall event.

The amount of sediments transported and deposited may be obtained in the pit or outlet of the micro-catchment or watershed. This effect can be considered as “off-site effect”. The model also provides changes of sediments during each rainfall event according to the LDD. Therefore, it is possible to plan measures to reduce soil loss from the field. The structure and function of database in PCRaster will support the GUESS mathematical model. The raster format helps in the movement or transportation of sediments through LDD map. Therefore, it is possible to simulate soil erosion according to the nature of the model. Several steps should be followed to meet the simulation.

Evaluation processes

Synchronize GUESS and PCRaster function

This step includes parameter selection and the range of each parameter according to the nature of soil erosion and the preparation of data structure according to the PCRaster format. The data types such as Boolean, Nominal, Ordinal, Scalar, or Directional must be identified. They must also be appropriated for each parameter. The operators are identified according to the mathematical function of the GUESS model.

Parameter setting according to GUESS equation

According to Equation 31, it is possible to set groups of parameters. The soil parameters that are mostly related to soil characteristics, both chemical and physical properties, are sediment density, soil erodibility, and mean settling velocity of sediment. The sediment density is the ratio of dry soil mass and the volume of soil particle. It is calculated from the following equation:

$$D_S = m_S / V_S$$

where:

D_S = Solid phase density/sediment density (kg m^{-3});

m_S = Dry soil mass (kg m^{-3}); and

V_s = Volume of solid phase (m^{-3}).

The dry soil mass can be obtained from the bulk density and volume of soil mass as below:

$$M_s = D_b \times V_b$$

where:

D_b = Bulk density; and
V_b = Total soil volume.

The equation can be rewritten as:

$$Db = m_S / Vb$$

$$Ds = Db \times Vb/Vs$$

Assuming that a cubic meter of soil (solids and pores) weighs 1.33 t, the bulk density (Db) can be calculated as:

$$Db = m_S / Vb$$
$$= 1.33/1$$
$$= 1330 \text{ kg m}^{-3}$$

If Vs = 0.5 m^3, then Ds = 1330 × 1/0.5 = 2600 kg m^{-3}

The soil erodibility (β) is the resistance to flow of water, which is related to soil cohesion or aggregation. The cohesion has negative relationshipwith distance between particles. But it has positive relationship with specific surface area of soil particles. Clayey soil has high cohesion. The cohesion reduces as the particle size increases due to water molecules between the particles. As the distance between soil particles increases, the soil moisture also increases, but the soil cohesion decreases. The critical shear velocity increases with decreasing particle size; the finer particles are harder to erode because of cohesiveness of the clay mineral.

Since the cohesion varies according to soil moisture at different rainfall events, there is no field experiment to find out the actual values of soil erodibility. But, from the mathematical calculation in the GUESS model and statistics, the range of soil erodibility has values between 0 and 1. This calculation, based on static, not dynamic, considers the amount of clay, varying from 0 to 100% clay. Therefore, it is the potential cohesive element.

The velocity of sediment I can be calculated from the Stoke's law:

$$V = (Ds - Di)gd^2/18n \text{ (cm s}^{-1})$$

where:

V = Speed of deposition of sediment class i;

Ds = Particle density (g ml^{-1});

Di = Density of fluid (g ml^{-1}), for water (1000 kg m^{-3});

g = Gravity (980 cm s^{-1});

d = Diameter of particle size class i. (cm); and

n = Viscosity coefficient of fluid (poise).

When k = (Ds –Di)g/18n, Stroke's law will be written as:

$$V = kd^2$$

Velocity is a function of distance divided by time.

$$V = s/t$$

where:

s = Distance of sediment transportation; and

t = Time for deposition.

As $V = kd^2$
$kd^2 = s/t$ or
$t = s/kd^2$

The mean settling velocity of sediment (ϕ) is calculated as:

ϕ = Rate of deposition of sediment class 1. +... class i./total sediment classes or

$$\phi = \sum_{i=1}^{I} \frac{\upsilon_i}{I}$$

υ_i = settling velocity of any arbitrary size class i

I = Total number of equal mass size classes..

The land use/land cover in the GUESS model is applied for Manning's coefficient and contact cover. Manning's (n) value is friction between sediment in water and the soil surface developed during the runoff. It has values between 0 and 1. Land cover protects rainfall detachment and reduces surface runoff. In the GUESS model, the contact cover (Cs) has value of 0–1. This contact cover is exponentially related to ks (an empirical, dimensionless factor) of soil erosion on bare soil as shown in the equation below:

$$C / c_b = \exp(-k_s C_s)$$

where:

C = Amount of soil loss with land cover; and

c_b = Amount of soil loss under bare soil.

The topographic factor including slope (%) and aspect of slope or LDD is obtained from DEM. The amount of rainfall is obtained from each rainfall event that collected from actual measurement using automatic rain recorder. The surface runoff depends on surface soil characteristics, contact cover, and amount of rainfall of that event. The runoff values may be obtained from Rational Method, C-N Method, and Water Balance and Empirical Method. The popular method is the C-N method by using the equation given below:

$$Q = \begin{cases} \dfrac{(P - 0.2\,S)^2}{P + 0.8\,\mathrm{S}} & P > 0.2\,S \\ 0 & P \leq 0.2\,S \end{cases}$$

where:

P = Precipitation (mm h^{-1}); and

S = Maximum storage = 0.2* initial infiltration (mm)

The maximum infiltration is estimated by the equation below:

$$\mathrm{S} = \frac{25400}{\mathrm{CN}} - 254$$

However, the GUESS model requires runoff discharge (Q) ($m^3\,s^{-1}$) and effective runoff rate (Q_{eff}). Q can be estimated by Equation 15. Since there is only event data and no data on a smaller timescale, for instance one minute, this equals the total amount of runoff per event (∑Q). According to the model, ∑Q is 15% of the amount of rainfall per event. To obtain actual runoff, it is necessary to collect more information of each rainfall event.

A fraction F of the stream power is used in the process of erosion by flowing water (commonly in the range of 0.1–0.2, sometimes higher). F can be called the effective excess stream power, as it is assumed to be a function of the stream power minus the threshold stream power (the limit of water velocity by which the particles are not moving yet). In the steady state situation, deposition is as big as erosion. This situation occurs theoretically even if conditions are not steady.

Data Preparation for PCRaster

It has been mentioned that setting parameters must follow the requirement of the model. It is also necessary to prepare the data according to the demand of the model. The file name must follow the script as has been developed as MSEC 1.

The spatial data must be already prepared using Arc/Info or other programs, before the topology is constructed. Then the database input according to parameters such as soil, land use, and contour line is commenced. The data will be converted into ArcView as Shape File and Converse File in the raster (grid) format. This is done by command *shape → grid and export to ASC format*. All files must have the same grid size. Grid files are obtained and ready to be imported into PCRaster. When the shape files are converted into grid files, it is necessary that the column must be the same name of the map; e.g., cohesive or sedden.

The spatial data in the ArcView (grid file) can be imported into PCRaster by using command *Arc2 ase*. However, the table file may be prepared from another program, but need to have the format that can be read by PCRaster.

Written script and data analysis

The next step after parameter preparation is the command that will make PCRaster "run". The data processing under PCRaster follows the GUESS mathematics model that is employed by MSEC 1. There are five steps in the command or script as show below:

1. Binding section: To identify parameters that will be used in the analysis of the next step; for example:

Ldd = Ldd.map

It means that when referred to Ldd in the model, the data can be taken from Ldd.map or Ldd map.

Manning = manning.Tbl

It means that when referred to manning in the model, the data can be taken from manning.Tbl or manning table.

2. Area map section: To construct base map or Map Extent as reference for every map.

3. Timer section: To set the time or time step that will be used in the dynamic model; for example, rainfall event.

4. Initial section: To set the starting point of data before any analysis is conducted; for example, set soil erosion is equal to zero before start.

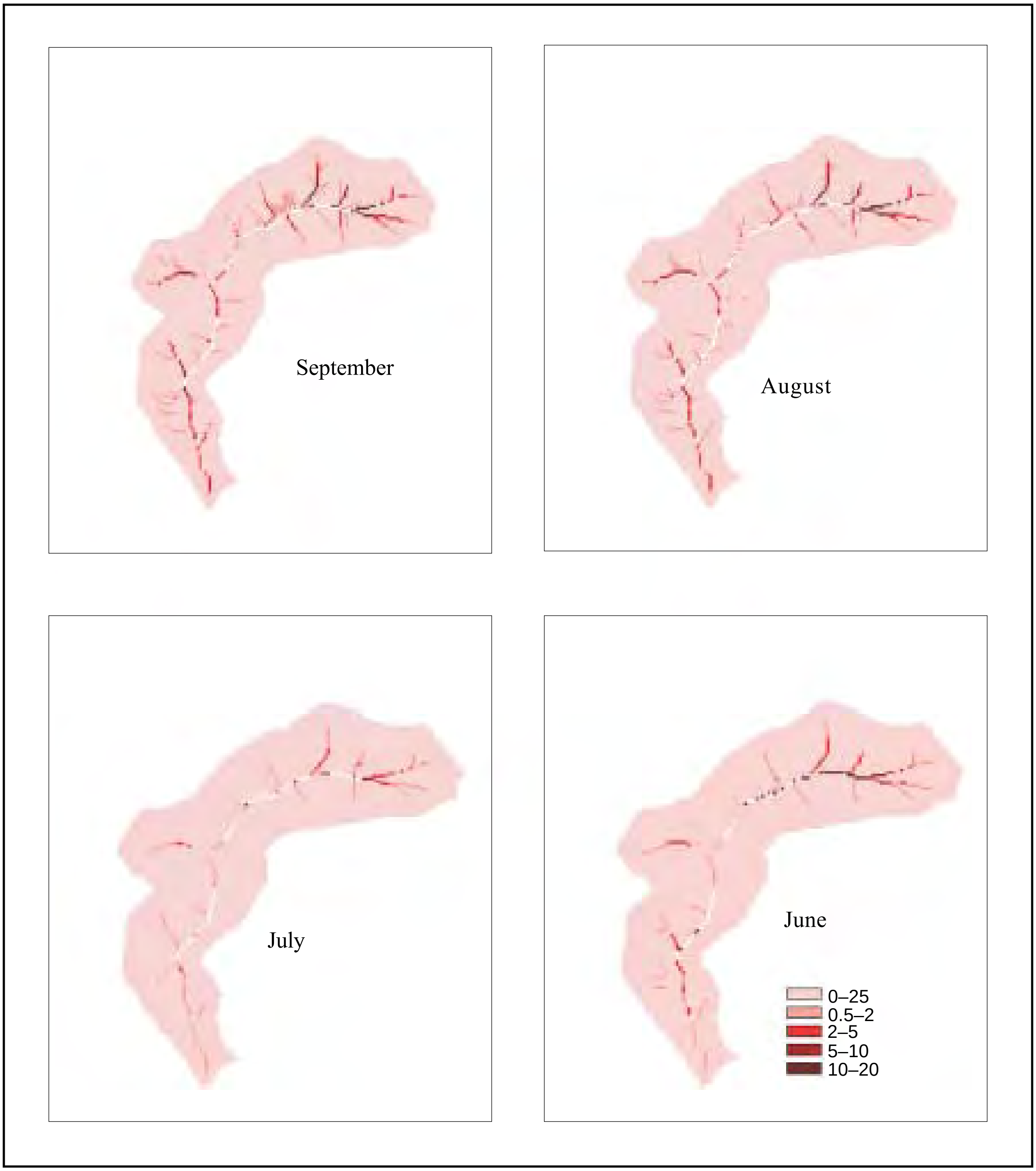

Figure 1. Monthly soil erosion (t ha^{-1}) during 2001 in Huay Pano catchment, Luang Prabang, Laos.

5. Dynamic section: To calculate according to the model for each time step by using operators and function of PCRaster.

To run script, it is recommended to use command *PCRaster-F,* followed by model name that has been developed in MSEC 1.

Interpretation of results

There are four outputs derived from the data analysis as given below:

- Runoff file: Shows runoff in cubic meter per plot or per pixel of each raifall event.
- Erosion file: Shows soil erosion as ton per plot or per pixel of each rainfall event.
- Eroflux file: Shows soil erosion at off-site of each plot or each pixel according to the LDD of each rainfall event.
- Erostore file: Shows soil erosion or sediment that is transported and deposited in each plot or each pixel of each rainfall event.

Test of model

The MSEC 1 model was tested using Huay Pano catchment in Luang Prabang, Laos as shown in Figure 1. The amount of sediments varied from 5 to 30 t ha^{-1} depending on combination of soil erosion factors, particularly the amount of rainfall during the event. It has been observed that the rainfall data were rather high. This model should be compared with field data for validation and improvement in the future.

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About ICRISAT

The semi-arid tropics (SAT) encompass parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, chickpea, pigeonpea and groundnut – five crops vital to life for the ever-increasing populations of the SAT. ICRISAT's mission is to conduct research that can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services and publishing.

ICRISAT was established in 1972. It is supported by the Consultative Group on International Agricultural Research (CGIAR), an informal association of approximately 50 public and private sector donors. It is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP) and the World Bank. ICRISAT is one of 16 non-profit, CGIAR-supported Future Harvest Centers.

About IWMI

The International Water Management Institute (IWMI) is a non-profit scientific research organization focusing on the sustainable use of water and land resources in agriculture and on the water needs of developing countries. With the mission of "*Improving water and land resources management for food, livelihoods, and nature*", IWMI's research is organized around five themes. These are: (1) integrated water resource management for agriculture, (2) sustainable smallholder land and water management, (3) sustainable groundwater management, (4) water resource institutions and policies, and (5) water, health and environment.

IWMI works with partners in the South and North to develop tools and methods to help these countries eradicate poverty through more effective management of their water and land resources. It has research projects running in 21 countries in Asia and Africa. Work is coordinated through regional offices located in India, Pakistan, South Africa, Sri Lanka, and Thailand. The Institute has subregional offices in China, Nepal, Ghana, Kenya, Senegal and Uzbekistan. The Institute is a member of the Future Harvest group of agricultural and environmental research centers that is supported by 58 member governments, private foundations and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR).

About ADB

Asian Development Bank (ADB) is a non-profit, multilateral development finance institution dedicated to reducing poverty in Asia and the Pacific. Established in 1966, it is now owned by 60 members with headquarters in Manila, Philippines and has 22 other offices in the borrowing countries around the world. ADB institution engages mostly in public sector lending for development purposes in its developing member countries. ADB's clients are its member governments, who are also its shareholders.

The adoption of poverty reduction as a strategy gives primacy to ADB's fight against poverty in Asia and the Pacific. It helps improve the quality of people's lives by providing loans and technical assistance for a broad range of development activities. In doing so, the institution emphasizes on promotion of pro-poor, sustainable economic growth, social development and good governance. ADB carries out activities to promote economic growth, develop human resources, promotion of gender and development thereby improve the status of women, and protect the environment, but these strategic development objectives now serve its poverty reduction agenda. Its other key development objectives, such as law and policy reform, regional cooperation, private-sector development, and social development, also contribute significantly to this main goal.

Asian Development Bank formulates operational strategies for individual countries, including economic and policy analyses, and undertakes country performance reviews, which provide a basis for policy dialogue with the governments of developing member countries. ADB develops country assistance plans, which include identification of individual technical assistance and loan projects and programs. It also establishes and maintains relationships with DMC governments for overall country economic reporting and for loan negotiations.

The operations strategic focus of ADB is on promoting growth to reduce poverty in poor inland provinces, improving economic efficiency and improving environmental protection and natural resource management. Over the years, ADB has played a significant role in economic and social transformation in Asia and the Pacific, boosting economic growth, fostering social development, and helping improve the quality of life for millions of people.

Integrated Watershed Management for Land and Water Conservation and Sustainable Agricultural Production in Asia

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