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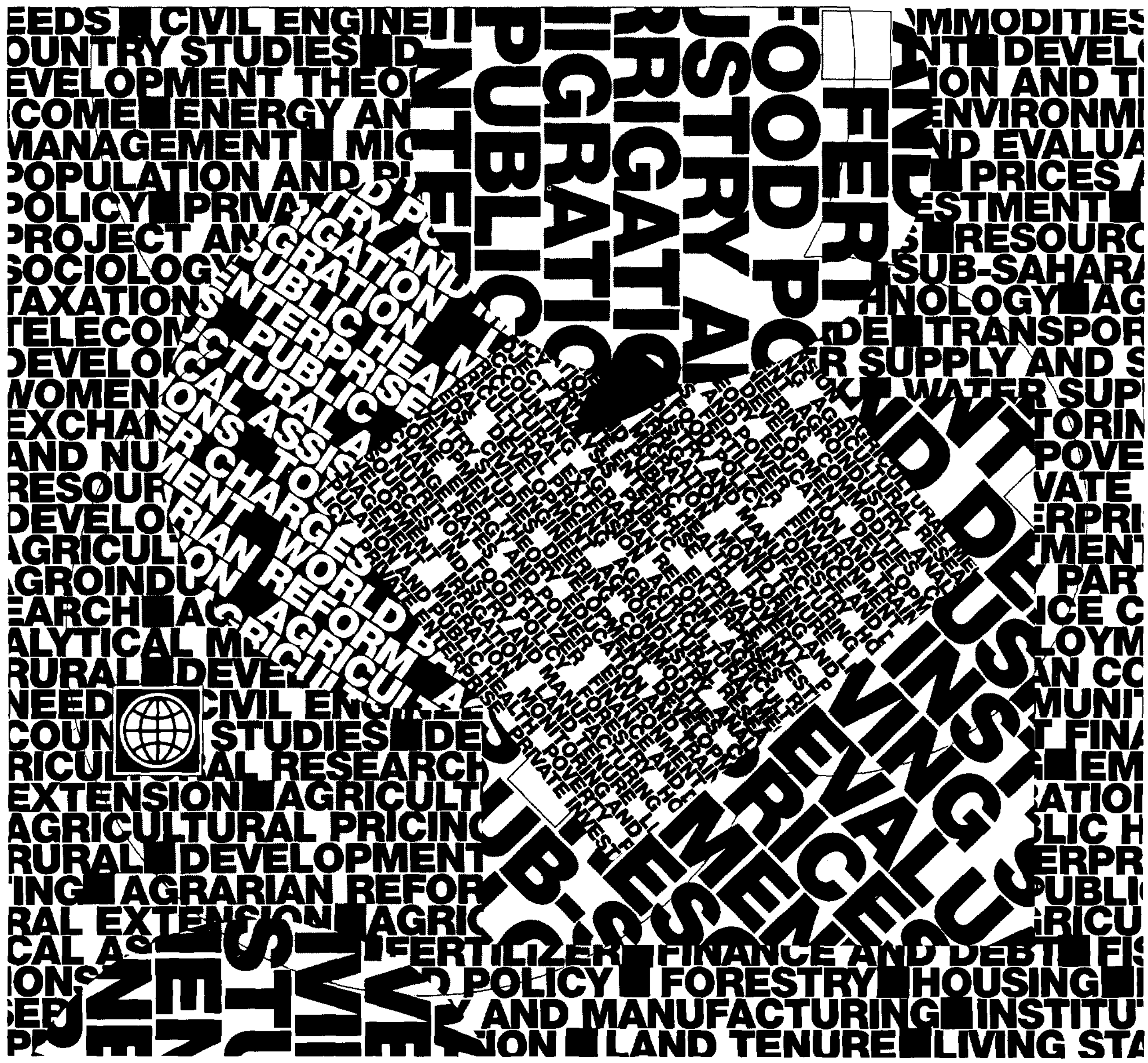
Watershed Development in Asia

Strategies and Technologies

John B. Doolette and William B. Magrath, editors



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FOREWORD

This review of watershed development issues arose from the realization that a number of current and planned World Bank-supported projects in the Asia region deal with the linkages between upland productivity and environmental conditions and are, in various ways, motivated by concern with downstream impacts such as flooding and sedimentation. A collaborative effort emerged, involving the Environment Department (within the Bank's Policy, Research and External Affairs Complex) and the Technical Department of the Asia Region. From the start, it focused on deepening the Bank's collective understanding of watershed development. High priority was attached to identifying discrete operational problems that could be better understood from review of existing data and analysis. In addition, the review was to provide overall guidance to the Bank's dialogue with borrowers on strategies for resource management.

Working papers on six issues of direct operational concern were initiated, to be conducted by World Bank staff and consultants in the context of ongoing operations. These working papers, presented as chapters in this report, illustrate methodological approaches to project analysis, summarize the state of the art on solutions to technical problems and discuss institutional and social processes that bear heavily on the viability of watershed management projects.

In addition to the research and operational work that has gone into the working papers, a colloquium on watershed management was held at the World Bank in October 1988. Experts from research organizations and other agencies presented results of their work on a number of topics, including the impact of erosion on crop yields, sedimentation processes, and the impact of land tenure on development investments. The first chapter draws heavily from the presentations at the colloquium, discussions with officials in the region and a review of literature on watershed management.

Daniel Ritchie

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Washington, D.C.
July, 1990

OVERVIEW

Watersheds as hydrologic units provide appropriate units for conceptualizing and implementing development investments. They comprise combinations of arable and nonarable land and drainage lines and are utilized by permanent and transient populations with varying skills and commitment to long term resource husbandry. The range of issues relevant to watershed management is enormous and includes environmental issues, crop and livestock production, a whole range of social and cultural concerns, infrastructure planning and entire questions of governance and control. This volume presents the results of a highly selective program of research and consultation.

In Chapter 1, Magrath and Doolette present a discussion of the major watershed development problems of the Asia Region. Taking a policy and investment perspective, the chapter tries to sort out what can and cannot be reasonably expected from watershed management efforts. While not minimizing the importance of linkages between upstream landuse and downstream environmental quality, the authors suggest that there are severe limits to our ability to manage these linkages in a cost effective manner. However, they observe a wide range of technological opportunities for intensifying productive activities in the uplands that, in addition to being privately profitable, will ultimately have positive impacts on downstream areas. In light of this they conclude by proposing an overall approach to watershed development that focuses on small farm development and common property management.

In Chapter 2, Doolette and Smyle examine the fundamental building blocks of watershed management projects. They present a careful review of the impacts of a broad range of land management technologies and illustrate the potential and constraints facing projects that attempt to influence erosion, runoff, and agricultural productivity. They make the point that, despite the availability of a wide range of options, most development projects have relied on a limited and generally high cost set of interventions. Emphasizing emerging, low cost methods of vegetative soil and moisture conservation, the authors reinforce the conclusion that agricultural productivity in upland areas can be intensified in an environmentally sound and sustainable manner.

In Chapters 3 and 4, Magrath demonstrates how benefit-cost analysis techniques can be used to assist in the selection of watershed management technologies. Chapter 3 compares alternative systems for soil and moisture conservation and shows an approach for integrating information on the physical and economic dimensions of erosion and for overcoming uncertainty about the impact of new technologies. Chapter 4 employs a similar approach to small multiple purpose conservation structures that are seldom subject to analysis.

In Chapter 5 Banerjee takes on revegetation of denuded forest land. The discussion addresses both technical issues, especially the need for moisture conservation practices that enhance survival rates, and social considerations, focusing particularly on generating participation in the early stages of project planning.

Molnar, in Chapter 6, explores one of the most analytically troublesome subjects in conservation policy, land tenure. The chapter discusses the range of land tenure systems found in the uplands of Asia and examines the forces that operate within these systems to encourage or discourage conservation. Project interventions have often interacted with these forces to produce unanticipated results. The analysis in this chapter argues that efforts to understand local social processes, to utilize existing local groups and to identify privately profitable technologies will have high returns.

Morgan and Ng, in Chapter 7, elaborate the connections between planning, monitoring and evaluation of watershed projects. These projects, which often are spread over large and remote areas, employ new and sometimes unproven technologies, and call for unusually high levels of community participation and local involvement, present unique management problems. In addition to conventional, sound management systems, watershed development projects can benefit from special studies, with carefully thought out experimental designs. Morgan and Ng point the way toward the incorporation of efforts of this kind into standard project practice.

These topics were selected and addressed on the basis of available expertise, and the operational priority of pressing issues. The list of other topics that could have, and need to be, examined is indeed long. However, to have attempted to treat them all would have precluded serious examination of any. There continues, for example, to be pressing need for policy research on livestock management systems in upland areas, for work on environmentally sound upland infrastructure and for serious examination of connections between upland development strategies and water quality. Notwithstanding, we believe that together, the chapters in this volume provide a unified treatment of what we consider to be significant and generally unappreciated topics in watershed management.

1. STRATEGIC ISSUES IN WATERSHED DEVELOPMENT

William B. Magrath and John B. Doolette

Following a description of the significance of watersheds to the Asia region, this chapter defines the problems in watersheds as loss of agricultural productivity due to erosion, deforestation, population pressure and poverty, sedimentation of infrastructure downstream, flooding and erratic stream flows. The main themes emerging from analyses of watershed problems are summarized and a strategy to address them is presented. The rationale for a watershed management approach is explored in the context of physical, economic and political linkages and takes into account the interplay between upland and lowland areas. In proposing how investments may be made to solve watershed problems, a case is made that the most technically and economically efficient approach would focus on site-specific technologies that are environmentally benign. Specific actions that development agencies should pursue in their operations and in discussions with governments are presented.

INTRODUCTION

Land that can be defined as watershed in the Asia region is a significant proportion of the total.1/ Of a gross area of 1,700 million hectares (ha), about 236 million (14%) has slopes exceeding 30% (upper watershed) and another 664 million (39%) in the 8-30% slope category (lower watershed). The 900 million hectares covering more than half the region constitute what is conventionally accepted as the watershed area. However, it is difficult to ignore nonirrigated land below 8% slope, because most strategies discussed for steeper lands are relevant and can usefully be treated on a watershed basis. About 65% of the region's rural population of 1.6 billion live and earn their livelihood in these rainfed, watershed areas. Despite the existence of soil conservation agencies and watershed management authorities in Asian countries, the real managers of these lands are local farmers and villagers. Constrained by poverty and technology, their pursuit of arable land, food and fodder has profound effects on the land and water resources of both upland and lowland areas. Mounting pressure on scarce land and forest resources, stemming from rising human and animal populations, is leading to severe environmental degradation throughout the region.

The extent of degradation has not been exactly measured, but it is manifest in numerous ways, including high rates of soil erosion and declining

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1/ The simple definition of watershed acknowledges the hydrologic concept of a watershed being the dividing line between two catchments: this has devolved to include the area of land contained within a drainage divide above a certain specified point on a stream. The latter is intended herein, and the land area above 30% slope is regarded as upper watershed and that between 8% and 30% slope as lower watershed.

yields on large areas of agricultural land, reduced livestock-carrying capacity, sedimentation of dams, reservoirs and irrigation systems, and clearance of forests with consequent loss of biological diversity and forest products. Together these trends threaten the ability of upland people to sustain an already precarious existence.

It is misleading to speak of the watershed problem of the Asia region. There are, in fact, multiple problems, some directly amenable to solution through physical actions requiring investment, some requiring policy reform and research first, and some, principally the consequence of geology and climate, which require continued adaptation and accommodation. These watershed problems are, however, connected by the fact that they can best be understood and dealt with in the context of physical planning units defined by the flow of water. It is important to recognize significant physical differences between watersheds of the large river systems of the Hindu-Kush-Himalaya region, characterized by high rates of erosion linked to ongoing processes of tectonic uplift, and the smaller, steeper watersheds of insular Southeast Asia. The latter, which result from quite different geologic processes including volcanic activity and upheavals of the ocean floor, offer considerably different responses to human activity. The review attempts to distinguish between these differences where appropriate and avoid inappropriate generalizations.

DEFINING PROBLEMS AND RESPONSES

Major Watershed Problems

Loss of Agricultural Productivity Due to Erosion. The uplands of Asia include widely diverse land forms. The Hindu-Kush-Himalaya region extends from Pakistan across northern India, Nepal, Bhutan and China and includes the world's highest mountains and poorest countries. The range is in a continuous state of formation as tectonic drift drives the Indian plate under the Eurasian Plate at a rate of 5 cm per year, lifting the Himalayas 1 cm per year in altitude. Volcanic activity, on the other hand, is responsible for the original formation and continuous change of much of insular Southeast Asia. These geologic processes, combined with intense tropical rainfall, are also responsible for the formation and high agricultural productivity of the alluvial plains of the region. Uplifted marine sediments provide yet another facet of the Asian uplands' fragile calcareous soils.

The estimated distribution of the region's major soils is summarized in Table 1.1. The diversity of soil types is often just as pronounced at the local level as for the region as a whole. An important common characteristic of the soils of the region is their susceptibility to productivity loss due to erosion. Those soils that are particularly susceptible, principally the Luvisols, Acrisols, Nitrosols, Lithosols and Ferrasols, constitute nearly 75% of the arable upland area. Of the remainder, volcanics (Andosols), deep loess deposits and some alluvial soils (Fluvisols), which together account for only about 10% of arable area, have deep effective rooting depth and are highly insensitive to productivity loss from erosion.

Table 1.1: EXTENT OF SLOPING LAND IN THE ASIA REGION BY SOIL TYPE AND SLOPE CLASS
(000 ha)

	Bangladesh	Bhutan	Burma	China	India	Indonesia	Kampuchea	Korea	Lao PDR	Malaysia	Nepal	Papua New Guinea	Philippines	Sri Lanka	Thailand	Vietnam	Total	Percent of total
Rolling to Hilly (8 - 30% Slope)																		
Acrisols				20,516	7,022	10,734		2,843				3,310					44,225	2.4
Cambisols				13,986	13,514	979		496		24	443			581			30,123	1.8
Chernozems				36													36	-
Ferrasols					10												10	-
Lithosols					971	6,199						578					7,748	0.4
Kastanozems				27,453													27,453	1.6
Luvisols			786	40	35,830	3,586							3,433	452			44,363	2.6
Nitosols			4,964		12,224	1,144							10,170				28,502	1.7
Podzols						2,104											2,104	0.1
Arenosols					14,808	440											15,248	0.9
Regosols					917												917	-
Andosols						567					1,298						1,865	0.1
Vertisols					5,993	525											6,518	0.4
Xerosols				11,591													11,591	0.7
Yermosols				19,330													19,330	1.1
Subtotal Rolling to hilly			5,750	92,953	91,889	26,278		3,139		24	1,741	3,888	13,603	1,033		236	240,033	13.8
Steeply Dissected to Mountainous (Slopes > 30%)																		
Acrisols		2,665	34,879	108,038	7,123	13,673				448		1,256		938			168,520	9.8
Cambisols	1,863	524	9,256	4,470	14,198	13,894		1,206			5,976	20,256		154			71,796	3.0
Rendzinas						2,112						4,004					6,116	0.1
Ferralsols						5,008											5,008	0.3
Phaeozems					1,775												1,775	0.1
Lithosols		1,138	1,610	357,244	29,042	6,349	42	47		400	3,103	691		106	1,356	907	402,035	23.4
Luvisols			317	2,695	2,427	8,003			64	1,160				443	638	408	16,155	0.9
Greyzems													2,343				2,343	0.1
Nitosols		123			7,654												7,777	0.5
Regosols					491	314											805	-
Andosols						6,379		132				1,735	1,248				9,494	0.4
Subtotal Steeply dissected to mountainous	1,863	4,450	45,562	472,447	62,710	55,722	42	1,384	64	2,008	9,079	27,942	3,591	1,641	1,994	1,315	691,824	38.8
Total sloping			51,312	565,399	154,099	82,010		4,523		2,032	10,820	31,830	17,194	2,674	1,994	1,551	931,857	52.6
Total area	13,400	4,700	65,800	932,600	297,300	181,200	17,700	9,800	23,100	32,900	13,700	45,000	29,800	6,500	51,200	32,500	1,727,600	
Percent																		
Percent Rolling to hilly			8.7	10.0	30.7	14.5		32.0			12.7	8.6	45.6	15.9		0.7	13.9	
Percent Steeply dissected to mountainous	13.9	94.7	69.2	50.7	21.1	30.8	0.2	14.1	0.3	6.1	66.3	62.1	12.1	25.2	3.9	4.0	40.0	
Percent sloping	13.9	94.7	78.0	60.6	51.8	45.3	0.2	46.2	0.3	6.2	79.0	70.8	57.7	41.1	3.9	4.8	53.9	

Sources: FAO/UNESCO, "World Soil Map."
Total land areas from World Resources Institute, World Resources Report (1986).

A study of the costs to the economy of soil erosion on the uplands of Java illustrates the magnitude of these damages. Based on analysis of factors causing erosion, the impact of erosion on the productivity of different soils, and the economics of alternative cropping systems, it was estimated that erosion costs the economy US$315 million annually. In Nepal, overall yields of cereal fell by over 1% per year from 1970/71-1980/81 in the Hills (Yadav, 1987) (Table 1.2). Erosion's role in this decline is not known but in the Terai where erosion is less significant, yields were essentially constant. The impact of runoff and erosion on productivity and yield is discussed in Chapter 2.

Table 1.2: NEPAL - ANNUAL GROWTH RATE OF CEREAL CROP AREA, PRODUCTION, AND YIELD, BY REGION, 1970/71-1980/81

	Hills		Terai		Total Nepal	
Crop	Percent	t-statistic	Percent	t-statistic	Percent	t-statistic
Paddy						
Area	1.98	8.93	0.71	2.96	0.93	4.10
Production	0.72	1.45	0.73	0.87	0.73	1.03
Yield	-1.24	-3.25	0.02	0.02	-0.20	-0.39
Maize						
Area	0.72	4.94	-0.86	-3.99	0.24	1.81
Production	-1.14	-2.30	-0.88	-1.11	-1.06	-2.62
Yield	-1.84	-4.70	-0.02	-0.02	-1.30	-3.68
Wheat						
Area	2.08	3.41	8.50	6.60	5.82	10.18
Production	3.86	6.05	12.79	5.17	8.64	7.54
Yield	1.74	3.51	3.96	2.13	2.67	2.74
Barley						
Area	0.24	1.00	-3.35	-1.89	-0.71	-2.35
Production	-1.61	-3.48	-0.20	-0.08	-1.19	-1.83
Yield	-1.85	-4.16	3.25	2.61	-0.49	-1.26
Millet						
Area	0.69	2.07	-0.24	-0.56	0.54	1.78
Production	-0.54	-0.86	0.16	0.31	-0.44	-0.81
Yield	-1.22	-3.54	0.41	2.41	-0.97	-3.32
Total cereals						
Area	1.27	8.77	1.50	5.90	1.42	8.13
Production	0.12	0.38	1.44	2.30	0.95	2.10
Yield	-1.14	-3.87	-0.06	-0.12	-0.46	-1.39

Notes: Computed from unpublished data on area, production, and yield from the Department of Food and Agricultural Marketing Services, Nepal. 1979/80 is omitted because it was a drought year.

Investments in agricultural research and extension oriented toward upland crops have lagged behind those for lowland areas, as evidenced by considerably lower rates of penetration of high-yielding varieties in the uplands. In Nepal, for example, high-yielding varieties account for 33% of rice, 91% of wheat, and 30% of maize in the Terai, while in the Hills, respectively, only 21%, 87% and 16%, and in the mountains only 6%, 72% and 7% (see Table 1.3).

Table 1.3 AREA COVERED BY IMPROVED VARIETIES IN NEPAL
(Percent of Total Cropped Area)
(1985)

Crop	Mountain	Hill	Terai	Nepal
Paddy	6.0	21.0	33.0	20.0
Maize	7.0	16.0	30.0	18.0
Wheat	72.0	87.0	91.0	84.0
Potato	6.0	5.0	5.0	5.0

Source: R.M. Joshi and M.K. Khatiwad, "Agriculture Handbook Nepal," 1986.

Deforestation. Approximately 19% of the region is under closed forest. It is estimated that forest cover is receding at around one percent per year and that, in addition, degradation through overcutting and grazing is reducing productivity on much of the remaining stand. In much of the region forest resources are integral to the agricultural system as sources of fodder and minor products. In India, for example, fodder available from forest and wasteland is estimated to be almost 30% of the total availability (600-620 million tons, dry matter).

It is important to understand the dimension of degeneration in forest areas. In the Asia region, the steeper upper watershed areas were mostly naturally forested. Over time, characteristically they have been overexploited for timber, fuel and fodder, and now many areas are no longer forested and in others the forest is extremely degraded. Regarding runoff/erosion, evidence suggests that trees by themselves in such circumstances provide little soil conservation benefit except to the extent that they foster the understory.2/ This understory of shrubs, herbs and litter is what protects the soil surface, maintaining the natural higher rates of infiltration. Without it, even dense forests, as seems to be the case with some tree species, have high rates of erosion even when reasonably managed, while degraded forest with dense undergrowth of grass and shrubs with intact litter have low erosion rates. Data on volcanic soil with 10% slope in Indonesia

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2/ This discussion pertains to rill and interrill (sheet) erosion. At the same time it is readily acknowledged that the root system of trees is probably the best of all kinds of vegetation in providing slope stability in landslip-prone areas.

show the estimated rates of surface erosion in tons/ha/year as 5 tons or less for both degraded forest with dense undergrowth and a pristine forest with litter intact, yet greater than 75 tons for both a 40-year-old teak plantation and a forest with all litter removed (Carson, 1989). In discussing the ambivalent effects of vegetative cover for soil erosion control, Stocking (1988) points out that even at slopes of 55%, rates of erosion from undisturbed forest are usually less than 0.5 tons/ha/year, whereas planting a monoculture of Eucalyptus species as an erosion control measure stifled ground cover and accelerated sheet erosion.

<u>Population and Poverty</u>. The population of the upper watershed areas in Asia is roughly 128 million, of which 27 million people live in the Himalayan region, 50 million in the steep uplands of China and about 30 million in the uplands of insular Southeast Asia.

<u>Table 1.4</u>: UPLAND POPULATIONS OF THE ASIA REGION
(Million)

Country	Rural Population	Upper Watershed Population Slope >30%
Bangladesh	84.62	0.58
Bhutan	1.25	1.25
Burma	28.88	
China	577.10	50.00
India	586.05	17.50
Indonesia	124.80	12.00
Kampuchea	-	-
Korea	14.94	6.55
Lao PDR	3.15	
Malaysia	9.98	
Nepal	15.81	8.46
Papua New Guinea	2.92	1.34
Philippines	41.50	18.00
Sri Lanka	12.72	2.92
Thailand	43.13	8.42
Vietnam	50.64	
Total	1,598.19	127.72

Source: Bank Staff Estimates.

There are few reliable data to indicate whether poverty and landlessness are more acute in upland areas than elsewhere in the region. Data from Indonesia indicate that landlessness is more common in lowland villages than in the uplands of Java, but conclude that many households in the uplands are among the poorest in Java (World Bank, 1989a). In the Philippines, it is estimated that recent immigrants to the uplands have an average per capita income of Peso (P) 2,168, well below the official poverty line (World Bank, 1989b).

Downstream Sedimentation. The deposition of eroded material in reservoirs and irrigation systems is a major management problem throughout the region, yet a relatively small percentage of the total number of watersheds have such infrastructures. It is clear that sedimentation imposes a high cost in terms of shortened investment life, high maintenance requirements and reduced services. Sedimentation on Java alone is estimated to cost the economy about US$26-91 million per year (World Bank, 1989a) (Table 1.5). Comparisons of the design and currently estimated lives of reservoirs in India show that erosion and sedimentation are not only severe and costly, but accelerating (Table 1.6). It is now obvious that the original project estimates of expected sedimentation rates were faulty, based on too few reliable data over too short a period.

Table 1.5: TOTAL ESTIMATED ANNUAL COSTS OF SOIL EROSION ON JAVA (US$ million)

	West Java	Central Java	Yogyakarta	East Java	Java
On-Site	141.5	29.1	5.7	138.6	315.0
Off-Site					
Irrigation System Siltation	1.7-5.7	0.8-2.7	0.1-0.5	1.2-4.0	7.9-12.9
Harbor Dredging (1984/85)	0.4-0.9	0.1-0.3	-	0.9-2.2	1.4-3.4
Reservoir Sedimentation	9.0-41.3	3.5-16.3	-	3.8-17.3	16.3-74.9
Total	152.6-189.4	33.5-48.4	5.8-6.2	144.5-162.1	340.6-406.2

Source: World Bank (1989a).

Flooding. Although floods are a natural feature of the lowland areas of the region, they nonetheless impose severe hardship on local population and national economies. In India between 1953 and 1976, 1,240 lives were lost, 77,000 cattle destroyed and annual property damage occurred in excess of Rupees (Rs) 2 billion annually due to floods. In 1988, the flood in Bangladesh claimed some 1,500 lives. As Rogers et al. (1989) point out, flood disasters in lower basins are caused by two much rainfall (or snow melt) in too short a time for the soil and the channels to handle, and are determined more by basin characteristics, river constrictions by bridges and roads, large amounts of compacted surface in cities, glacial outbursts, landslides, inadequate levees and increasing flood plain occupancy, than by forest use or even forest conversion per se.

Table 1.6: SILTATION OF SELECTED INDIAN RESERVOIRS

Reservoir	Assumed Rate (acre-feet per annum)	Observed Rate (acre-feet per annum)	Expected Life as Percent of Design Life %
Bhakar	23,000	33,475	68
Maithon	684	5,980	11
Mavurakshi	538	2,080	27
Nizam Sugar	530	8,725	6
Panchet	1,982	9,533	21
Ramgange	1,089	4,366	25
Tungabhadia	9,796	41,058	24
Ukai	7,448	21,758	34

Source: Brown and Wolf (1984).

There are no reliable estimates of the economic damages caused by flooding. In addition to direct damages, floods, or more properly, the expectation of flooding, reduce perceived returns to investment and probably slow growth to a significant but unmeasurable degree. While it is likely that the floods of 1988 were the worst on record from an economic perspective, there is evidence that the physical severity of flooding has not worsened. An often neglected positive effect of flooding downstream is the delivery of nutrients to agricultural land. Soil moisture stored when flood waters recede also contributes to dry season yields. For example, in the dry season following the 1988 Bangladesh floods, production reached near-record levels.

Dry Season Stream Flows. A direct consequence of excessive surface runoff that contributes to flash flooding is the reduced temporary storage of water in the soil profile and groundwater aquifers. Some of this stored water would normally have rejoined the surface water and contributed to stream flow in the dry season. Reduced dry season stream flow has serious consequences on downstream uses for power, irrigation and municipal supplies.

Policy Responses

Governments. Governments in the region and multilateral and bilateral donors have attempted to respond to the various watershed management problems of the region in a number of ways. Responsibility for watershed management is typically disbursed across a number of government agencies, including agricultural and forestry line agencies and in some cases free-standing watershed development agencies and soil conservation services. The common administrative approach is to focus on the implementation of physical investments on public and private land, often with a predominant single technical solution, and on encouraging the adoption of conservation-oriented farming practices on private land. Traditional low-technology farming systems have frequently been not only risk-minimizing, but also soil-conserving, whereas cash crops are much riskier in both respects. Cash cropping has sometimes exacerbated erosion problems (Carson, 1989).

Donors. Greater interest in environmental issues by donor agencies has led to an increase in the level of support for watershed management projects and programs. World Bank involvement in watershed management has, over the past decade, primarily been through forestry, agriculture and integrated rural development projects. To the extent that there has been a Bank strategy towards watershed development, it has focused on attempting to improve the productivity of smallholder agriculture, thereby leading to a reduction in environmental deterioration. Table 1.7 lists Bank-financed projects now under implementation in the Asia region.

Table 1.7: WORLD BANK-ASSISTED WATERSHED MANAGEMENT RELATED PROJECTS UNDER IMPLEMENTATION

China	Red Soils Area Development Gansu Provincial Development
Indonesia	Yogyakarta Rural Development Upland Agriculture and Conservation Forestry Institutions and Conservation
Thailand	Northern Agricultural Development /a
Philippines	Central Visayas Regional Watershed Management & Erosion Control
Bhutan	Forestry Development
India	Kandi Watershed and Area Development /a Himalayan Watershed Management Haryana and Jammu Kashmir Social Forestry National Social Forestry Pilot Project for Watershed Development
Nepal	Second Rural Development Mahakali Hills Community Forestry Development and Training Second Forestry Marsyandi Hydroelectric

/a Recently completed.

The Evolution of Conservation Technology. The pattern of investment and organizational design followed by governments and donors has failed to keep pace with the rapid evolution of soil and moisture conservation technology for tropical situations that has occurred during the past 20 years. Early approaches to soil conservation were developed for large landholdings in temperate regions and were based on structural and engineering treatments, such as graded earth banks and broad grassed waterways. Attempts to apply these approaches to developing country agriculture, characterized by small holdings, diverse cropping systems, extremes of topography and climate and severe limits on financial resources and skills, have proven disappointing. With rigorous attention to appropriate design criteria, engineered systems can, under some circumstances, function in tropical environments. However, experience has shown that these criteria are usually lacking. Moreover, the high unit costs of these technologies and their indivisibility imply that they are beyond the means of all but the most favored farmers and communities unless heavily subsidized. Even with government subsidies for initial investment costs, recurrent costs in the form of maintenance and land taken out of production seem, judging by farmer response, to make these approaches uneconomic.

While recognition of the technical shortcomings of traditional approaches to conservation--so far as smallholdings in the tropics are concerned--is growing, alternative technical and institutional approaches are emerging. For example, although it has long been known that maintaining continuous vegetative cover is the most effective way of reducing sheet erosion, it has been difficult to promote heavy applications of mulch and retention of significant areas under permanent cover on small farms. Typically, the pressure on smallholders to cultivate all available land and to utilize all available fodder militates against maintenance of permanent vegetation. Even when individuals farmers are inclined toward such practices, the widespread practice of free grazing makes such a strategy impractical.

The concept of conservation-oriented farming in the uplands in which farming systems and individual production treatments combine to conserve soil and water and improve total production and net benefit is now recognized. Currently, two complementary strategies for the development of conservation-oriented upland farming are evolving. The first is the adoption of a problem-solving approach aimed at identifying, on a site-specific basis, the key constraints to and opportunities for expanding output. The second, possible because of the uniquely nonsite-specific characteristics of vetiver grass, Vetiveria zizanioides, is the widespread promotion of this grass for use as a contour hedgerow. Properly balanced, these two strategies can form the basis for a comprehensive approach to treatment of upland areas in the Asia region. A focus on small farmer development does not deny the seriousness of downstream watershed problems in the region. It is, however, a recognition of both the difficulties of reducing downstream problems and of the complementarities between agricultural development and environmental improvement. The next section elaborates on the difficulties of dealing with downstream damages through land-use changes, such as reforestation and development of vegetative barriers, in upper watersheds, and the following section returns to the theme of strategies for small farmer development and common property management.

INTERSECTORAL LINKAGES

Discussions of watershed management are generally dominated by concern about physical linkages related to movement of soil and water within drainage basins. While the significance of the hydrologic cycle for water resource planning cannot be overstated, research and project experience, however, show that conventional approaches to watershed management have little effect. Often neglected in analyses of watershed management are political, economic and social linkages between upstream and downstream. Understanding of and intervention in these three areas provide an underexploited avenue to improve productivity and the quality of life of upland populations.

Physical Linkages

The need for watershed management arises from the interconnected nature of soil, water and land-use systems. Explicitly recognized is the fact that upstream land use generates not only direct outputs such as timber, crops and fodder, but downstream impact on sedimentation and water yields. In the absence of unified management, or some comparable arrangement, upstream users will adopt practices without regard for impacts on downstream residents. An additional consequence is that the party that undertakes watershed management will not be able to charge for all the services it provides. Charges are feasible for certain products, such as timber, but experience with cost recovery through charges for reductions in sedimentation and flood control are not encouraging.

Types of Physical Linkages. The physical connections between upland and lowlands are manifested in two specific ways: (a) sedimentation, the delivery of eroded material into or adjacent to waterways and infrastructure; and (b) stream flows, the quantity, distribution and timing of flows from upper catchment to lower channels. The two are intimately connected by the fact that a major source of sediment movement is provided by raindrops as they strike and flow across the soil surface. In addition, the ability of soil to permit rainfall infiltration and (at least temporarily) retain moisture tends to be associated with its ability to withstand detachment and transport. Another major source of sediment when it occurs mostly in young active mountain systems, subject to high rainfall, is mass wasting.

The initial movement of soil particles is termed detachment and ultimately all eroded material is deposited downhill and then downstream. However, the processes of delivery are highly dependent on the local environment, including catchment size and topography, levels and intensity of rainfall, slope, soil type, vegetation and land use. The time that may elapse between the initial detachment of the soil and its final flushing out from the system is frequently measured in decades for watersheds larger than 100 km^2.

Flows of water are much faster but no less complex. The movement of water from its original landfall, to minor and major channels and ultimately to the sea, is influenced by antecedent moisture conditions, the inherent infiltration and storage capacity of the soil, vegetation and land use. Typically, in a mild rain and during the initial phases of more intense storms, water that reaches the ground through any vegetative canopy first enters into storage in the upper layers of the soil. A portion of this stored water will evaporate, some will be taken up by plants and transpired, and the remainder will percolate to the groundwater from which some portion will be returned as surface water. As the storage capacity of the soil diminishes, water accumulates on the land surface and moves downslope through various processes of inter- or overland flow. Depending on the length and intensity of the storm, topography and other factors, this inter- or overland flow may continue to a watercourse or may end in percolation into the downhill soil. If a storm of sufficient duration occurs and soils begin to be saturated or a storm of sufficient intensity occurs such that the soil's infiltration capacity is exceeded, then several processes (surface and subsurface) deliver water to the drainage lines and streams. Vegetation affects these processes by storing water on leaf and stem surfaces, increasing surface roughness (thus slowing runoff and affording greater opportunities for infiltration), adding to the storage capacity of the soil by the presence of roots, reducing the initial intensity of raindrop impact, and to a minor extent, by immediately absorbing moisture through the root system.

The two important aspects of stream flow are quantity and distribution over time. Quantity of flow has obvious implications for the viability of downstream investments in power, irrigation and municipal water. Alternative land uses can have significant impact on water yields principally through the substitution of more or less moisture-using vegetation. Hamilton and King (1983), reviewing the literature on the impact of forests on stream flow, found that forests are heavy water users and that conversion of forested watersheds to agricultural or other uses tends to increase total water yield, but increase peak flow and stream flow for any storm event.

The distribution of flow throughout the year also has obvious implications for downstream investments and stream bank erosion, but peak flows are more importantly related to the danger of flooding. There is some uncertainty as to the effects of environmental conditions in upper watersheds on the frequency and severity of flooding, because the effects diminish as distance down the watershed increases.

Disentangling the impact of upland land use from other factors in determining the frequency and severity of downstream flooding has proven an elusive task. Both the quality and quantity of historical data on land-use changes and flood occurrence are so poor as to make statistical analysis impossible. The large number of variables involved similarly makes theoretical analysis speculative and somewhat hazardous. A consensus among policy analysts is now starting to emerge, however, that suggests that agriculture and forestry in upper watersheds play a relatively minor role in exacerbating the effects of major catastrophic flood events (Hamilton, 1987; Ives and Messerli, 1989; Rogers _et al_., 1989).

Data on annual runoff, sediment load and high and low flows for the Brahmaputra river system for the period 1955-79 show no definitive trend towards a deterioration in environmental quality. Moreover, the data on high and low flows are not consistent with the generally accepted expectation of land degradation causing higher peak flows and lower dry season flows (for details see Ives and Messerli, 1989, pp. 136-7). Data on the incidence and physical severity of floods in the Ganges-Brahmaputra delta do not support the hypothesis of a trend toward worsening floods. It is likely, however, that concern over flood damages is growing as a function of greater economic activity in flood-prone areas.3/

3/ See, for example, Kumra and Rao (1985) who found that the value of agricultural flood damage has been falling in Bangladesh while nonagricultural damage has been increasing.

Erosion-Stream Flow Interaction. As noted, the tendency of some soils to resist erosion is often associated with their infiltration and storage capacities. In addition, land management practices to reduce erosion frequently have the effect of reducing runoff (see Chapter 2). Another way in which erosion and stream flow may interact to exacerbate the danger of flooding is via the accretion of river bottoms. Diminished channel capacity due to sedimentation lowers the magnitude of flow required to cause flooding and may contribute to the frequency and severity of flood damage.

Watershed Management Investments. In practice, most watershed management projects have multiple objectives. In many circumstances, it is possible to improve the environment and increase the output of goods and services at the same time, particularly when a project also averts long-term economic losses due to productivity declines. This aspect of trade-offs in watershed management is frequently misunderstood.

The fact that watershed management projects can accomplish more than one objective has important policy implications. Generally, tax or subsidy schemes are recommended to resolve an externality problem in order to "internalize" it. Farmers might be given subsidies to adopt soil conservation practices or be taxed if they fail to adopt. Subsidies are the more frequently used approach and their budgetary cost is justified on the basis of reduced downstream damages. However, when watershed management practices make both upstream and downstream residents better off and leave no one worse off, this simple justification no longer holds. Some subsidies may, however, be justified on other grounds, such as an inability on the part of poor farmers to finance purchased inputs or to wait for the maturation of tree crops (that is, capital market imperfections).4/

In order to be both multipurpose and to leave no one worse off, watershed management projects must be able to address a characteristic of unimproved watersheds, namely, technical inefficiency, or to introduce technological change. Typically, projects do both.

Economic Linkages

While physical linkages remain the basis for watershed management interventions, a strategy that also takes advantage of social, economic and institutional linkages between upstream and downstream provides the greatest opportunity for success. Upland areas have critical connections with national economies in three significant ways.

Sources of Raw Materials. Despite difficult conditions, upland areas often possess a comparative advantage in the production of certain commodities. In much of the Asia region, timber and grazing represent the primary resources with potential in upland areas. In Indonesia (Roche, 1987), upland

4/ It is conceivable that situations will arise where there are real and significant conflicts between alternative uses. This situation was first analyzed by Gregory (1955) and (1957). Such conflict and the tax-cum-subsidy schemes it suggests, are more relevant to developed country, low-population density watersheds.

areas may have advantages in specialty crops such as clove, high-value horticultural crops and animal products. Significantly, many agricultural products for which upland areas are well suited possess a high income-elasticity of demand, so that income growth in lower areas can contribute to strengthening economic linkages between uplands and lowlands. In so doing, the strengthening provides opportunities for expanding sustainable agriculture in the uplands.

Sources and Sinks for Labor. Upland areas in the region were historically, with some exceptions, notably Nepal's Terai, relatively sparsely populated. Recent increases in population pressure in more favored downstream environments has resulted in increased migration to the uplands. This has been offset to some extent by growth in nonfarm employment opportunities in urban areas. Seasonal employment opportunities in lowland agriculture and urban areas are increasingly important contributors to upland income. Shifts in the opportunity cost of labor brought about by changing opportunities off the farm also have important implications for farmer interest in adopting more intensive soil conservation measures. On the one hand, they may be more likely to afford the costs but, on the other, have less time.

Markets for Downstream Production. Because of low incomes and high transport costs, upland areas have generally not been major markets for goods produced in lowland areas. Upland areas, however, where incomes have grown and infrastructural investments have reduced transport costs, do constitute significant markets.

Political Linkages

Upper watersheds, in addition to being physically remote, are often politically remote as well. The attention of national policymakers is naturally drawn to the concerns of urban and more affluent lowland agricultural populations. To the extent that developments in upper watersheds are a major item on the national agenda, it is because of their impact, via the physical linkages related to movement of sediment and water, on the well-being of downstream groups. Political forces further bias policy and investment against upland areas in other ways. Watersheds are physical units that frequently do not conveniently overlap with administrative boundaries. Although the downward flow of the physical consequences of land use do not observe these boundaries, limits on the ability of government agencies to transcend them are severe.

Asymmetry and Rigidities of Linkages. From the perspective of investment analysis and policy-making, the most important aspect of the various linkages described in this chapter is whether or not they can be manipulated. In this respect, certain of these linkages are either rigid and hence not amenable to manipulation or they are asymmetrical. The most obvious asymmetry is the one-way flow of soil and moisture in watersheds. This implies a role for involvement by public agencies.

Temporal Asymmetry. As noted, the movement of sediment in watersheds may involve extended periods of time. A corollary to this is that remediation may also involve long time delays after the intervention. Pearce (1986) estimates that the time required for sediment to be flushed from drainage systems of large basins may exceed 40 years. In a present value sense, any reductions in sediment made possible by the adoption of watershed management practices will be of minimal economic significance. However, there are downstream benefits to be achieved within shorter time periods from conservation land treatments, like contour hedge rows, as the focus moves upstream to subwatersheds. These benefits relate to both sediment and flooding in nonmajor storm events (Hamilton, 1988).

Geologic Erosion. While in principle it is possible to stop erosion, the underlying potential of soil to move is frequently so great as to preclude stopping erosion at any reasonable economic cost. This underlying rate of soil loss is termed geologic or natural erosion and provides a partial but useful guide to the design of soil conservation policies. Much of the steep uplands of the Asia region are naturally prone to erosion due to their geology.

Asymmetry of Policy Linkages. Agricultural policy linkages, particularly price and incentive policies, between uplands and lowlands have not received the attention they deserve. Theoretical analysis of farmers' incentives for soil conservation, however, have been largely unable to demonstrate how these linkages operate. Barbier (1988), for example, using an optimal control framework, modeled farmers' decisions to implement soil conservation practices and showed that price of products and other agricultural policies could play a significant role in determining privately profitable soil management strategies. Barrett (1988), using a similar approach, found product price to be unrelated to soil management.5/

Taking a different approach, Roche (1987) analyzed the impact of these policies and growth patterns on upland land use in Indonesia. He notes that rapid lowland income growth, due in part to the successful intensification of irrigated rice production and industrialization, influenced by high income-elasticities of demand for vegetables and fruits, has created an incentive for upland farmers to shift to cropping patterns that are less likely to cause erosion. Observations further indicate that in upland areas with access to good markets, and particularly where the demand in these markets for meat and livestock products is strong, the incentive for establishing and maintaining permanent vegetation is also strong. The aggregate environmental impact of these incentives has never been assessed.

Hyde (1988) explored the consequences of unemployment in lowland areas of the Philippines on the environment of the uplands through a general equilibrium model. The model, which allowed migration as an equilibrating process, showed that tax policies which in the aggregate favor capital have a significant influence on migration to upland areas. Similarly, rice subsidies were found to increase both the agricultural labor force and the upland population. Trade policies that would encourage exports were found to have a positive impact on the uplands via an expansion of lowland industrial employment.

5/ Similar models have been presented by McConnell (1983), and Bhide, Pope and Heady (1982).

INVESTING TO INFLUENCE LINKAGES AND SOLVE PROBLEMS

Altogether, the data reviewed on watershed linkages suggest that although physical connections shape the environment for investment planning and policy interventions, there are marked rigidities in both time and space. These rigidities limit the scope for economically viable investments aimed primarily at resolving off-site and downstream problems. Fortunately, there is ample opportunity for directly productive investment in upland areas. Most of the approaches that would fit into such a strategy are also consistent with the long-term objective of preventing or ameliorating the downstream consequences of watershed deterioration.

Essential elements of a strategy for upland development are the same as would apply in lowland areas and include the need for a positive incentive framework and the availability of appropriate technical innovations. In contrast to lowlands, upland areas are characterized by much greater agro-ecological diversity, are less amenable to large-scale investments (especially irrigation), and generally face runoff and soil erosion problems. Accordingly, strategies for upland areas require greater emphasis on generating a capacity for site-specific recommendations, and particularly a focus on improving rainfed agriculture through low-cost methods of soil and moisture conservation. Due to the greater reliance of upland farm households on non-arable land such as forest and communal grazing land, farm development strategies in the uplands also need to focus more on diversification than farming systems in the lowlands which can be more commodity-oriented.

Technologies and Techniques for Improving Upland Agriculture

Although the development of agricultural technologies for upland areas lags far behind those for the lowlands, the general principles for increasing yields are known and numerous interventions can be recommended for specific applications. The two key constraints to improving agriculture in upland areas relate to soil and moisture conservation.

In practice, productivity decline due to soil erosion is related to the following soil characteristics (discussed in more detail in Chapter 2): rooting depth, water reserves available to the plant, distribution of plant nutrients in the soil profile and the chemical/physical properties of the subsoil. Of primary importance for design of an upland strategy is the connection between soil moisture and erosion. In tropical soils, water-use efficiency (kg dry matter produced/liter of water use) can be cut more than half, despite high rates of fertilizer application, if topsoil is progressively removed up to 35 cm.

General Approaches to Enhancing Upland Agriculture

Better agronomic techniques, improved varieties, higher-quality seeds and improved pest management and tillage practices often provide the best opportunities for increasing agricultural output. A key technique that is integral to improvements in rainfed agriculture is contour cultivation. Compared with the traditional up-and-down slope cultivation, contour cultivation and ridging across the slope 6/ have produced 6-66% yield increases on 3-32% slopes, with further increases if combined with other treatments such as mulching. The evidence to support the general recommendation that all rainfed cropping activities, annual or perennial, be carried out on the contour is overwhelming.

Recent and less frequently the subject of published research is the application of cropping/farming system technology to on-farm soil conservation. It is motivated by the acknowledgement that social, economic and tenurial factors influence farmers' ability and willingness to adopt and maintain soil conservation measures. Farmers, especially poor smallholders, need direct short-term benefits from any innovation in their farming systems. Investments in soil-conservation measures apparently have not met this criterion and, indeed, frequently have been perceived as taking away from the farmer's limited resource base by demanding space for banks and water disposal structures. By contrast, downstream farmers in irrigated areas respond quickly to investments in similar structures that have immediate benefit, as is the case with levees for rice paddies.

Farming systems research has not commonly been applied to soil conservation. Yet attempts to implement physical conservation works and land-use planning are usually frustrated by lack of acceptability. It becomes important, therefore, to find points within farming operations where practices that meet soil conservation objectives and increase incomes without unduly increasing risks can be introduced.

Specific Techniques

While there is clearly a need to design a package of conservation and yield-increasing interventions to be consistent with the needs of a specific site, there are several generic approaches which have widespread usefulness as well as potential for misapplication. They can be grouped as structural and vegetative/cultural. Current conservation practices in the Asia region focus on structural approaches and there is a need to assess the potential for fuller utilization of alternatives. While Chapter 2 provides a fuller discussion of these approaches, some aspects are relevant to a strategy for upland development.

Structural Treatments. Structural treatments, earth banks, land leveling, and terracing have been applied extensively in watershed projects throughout the region. Experimental and project-level results with structural measures have been mixed but generally poor. These observations may seem inconsistent with the fact that terraces, in particular, are a widespread and integral part of the agricultural landscaping of the region (see Box 1.1). However, several features of structural approaches may account for their generally poor performance.

6/ Contour cultivation refers to cultural treatments that follow surveyed guidelines linking points of the same elevation marked at 2-3 m vertical intervals, whereas across-the-slope refers to treatments at right angles to the general slope direction and, hence, deviate at times from the true contour.

Box 1.1: ROLE OF BENCH TERRACES IN ASIA

Bench terraces are part of the landscape of the Asia region, especially Southeast Asian countries, China and the Philippines. Reverse-sloped bench terraces and outward-sloped bench terraces are used in steep uplands of humid and semi-arid regions, respectively, to change the slope of the land in order to increase the area that can be cultivated "safely" and "control" runoff. Level bench terraces (irrigation-type) are used for rice paddy and conservation bench terraces are used in arid regions to harvest rainfall on part of the slope and direct it to a level bench.

While it may be questionable whether bench terraces represent the best treatment for the respective locations in terms of land-use capability or meeting the needs of the population, they are in place over vast areas and future land development programs should start from this reality.

A review of research on the effectiveness of terraces of the first two types in uplands regarding sediment yield, runoff and productivity (Chapter 2) highlights widely divergent results. Although terrace technology is well understood and engineering design readily available, it is frequently poorly applied. There are three common shortcomings: failure to relate soil type-rainfall characteristics-cropping pattern to design; not viewing the water disposal component of terrace systems as integral--farmers are reluctant to lose the 3-5% land required--and compromise in design increases runoff and damage; shoddy operation and maintenance by farmers compared with level benches used for paddy, which implies a questionable economic situation.

Developing a program for correcting these shortcomings should start by defining the treatment options. Carson (1989) discussed the limitations of terraces in several agro-ecological zones in Indonesia and suggests some appropriate soil conservation strategies. The key issue is identifying a farm production system attractive enough to induce the majority of occupants to become involved and finding a way for them to convert to it. After this, the treatment options can be laid out, with priority going to vegetative-cultural measures which should be cheaper to implement and maintain. For example, if the horizontal grade of the existing terrace exceeds 1%, judicious use of a vegetative barrier such as vetiver grass would induce natural and rapid leveling and at the same time control the effluent point, which in turn would change the dimension of waterway rehabilitation. Only then would structural treatments be considered for problems still without solution.

The upper limit of slope is normally 60% for any sort of terrace. Beyond this slope, riser height and width are too great, bench width too narrow, and the net arable area down to about 50%.

(a) High Unit Costs. Costs for terracing in Indonesia are estimated to range from US$400-1,000/ha. Construction of earth bunds in India is estimated to cost between US$23 and US$150/ha depending on soil type and slope. Aside from high initial costs and the financing burden they impose, structural techniques inevitably require high levels of maintenance. Failure to maintain structures properly can lead to their total failure and can actually accelerate soil loss.

(b) Inappropriate Design. With structural measures there has been widespread failure to adjust designs and standards to accommodate the engineering properties of particular soils and local rainfall patterns. The inherent instability of some soils can result in massive failure of structures. For example, saturation of the topsoil over relatively impervious subsoil results in soil slumping.

(c) Inadequate Drainage. Operating on the principle of slowing water, with structural measures water is usually directed along field boundaries toward natural drainage ways. Drainage ways need to be large enough to accommodate peak flows, otherwise they will be overtopped, damaging the adjacent field or the drains themselves will fail. Moreover, the natural drains may receive more runoff than they are capable of safely handling, resulting in a danger of gully erosion. The planners' incentive to design drains to accommodate peak flows runs counter to the farmers' desire to minimize land taken out of production. This conflict usually results in no drains or undersized drains prone to failure.

(d) Exposing Subsoil. Construction of soil conservation structures usually entails earth movement that exposes infertile subsoil. This reduces yields in early years of the structure and amounts to an additional construction cost.

Research has added very little to traditional farmers' understanding of the potential use of structural measures. Detailed analysis of terrace designs and maintenance in Nepal, for example, has shown that use of outward-sloping terraces is an effective means of allowing surplus water to move off the terrace while causing minimal surface erosion. Attempts to reduce runoff by introducing backsloping terraces resulted in collapse of the "improved" terrace due to concentration of water. Similarly, the apparently low levels of maintenance and poor-quality construction of terraces supplied by projects in Indonesia may reflect the interaction of farmer perception of the dubious value of terracing and the attractiveness of the assorted subsidies and incentives provided. In the absence of compelling evidence that a significantly new and attractive on-farm structural technology can be suggested to farmers, there seems limited justification for the central role such structures now play in watershed development projects.

Vegetative/Cultural. Vegetative/cultural measures to improve upland agriculture include contour cultivation, techniques to reduce tillage, addition of new crops and changes in timing or cropping pattern (intercropping, etc.) or stand architecture to provide for more continuous and effective soil cover. In some cases the use of vegetative treatments is intimately mixed with cultural practices, such as contour cultivation with grass strips, while in other cases vegetative measures stand alone as in the establishment of permanent cover. Vegetative measures have been shown to be highly effective in minimizing erosion by reducing the impact of raindrops as they strike the soil. Mulches, certain agroforestry options and permanent cover crops can perform this function.

Plants can also be used to form a physical barrier to slow runoff and arrest already moving soil. For a long time, suitable species have been sought and several have been proposed for use in this manner, including napier grass, vetiver grass, and the tree species Leucaena. The utility of different species in this capacity will vary, depending on circumstances. The particular features of vetiver grass, discussed in detail in Box 1.2, make it particularly well suited for this application.

Box 1.2: VETIVER GRASS - CONTOUR SYSTEM FOR SOIL AND MOISTURE CONSERVATION

The notion of carrying out all farming operations especially cultivation and planting on the contour in any rainfed situation, on any slope, for any crop is overwhelming. Customarily, barriers are constructed on the contour at certain vertical intervals according to slope to break the length of the slope so as to check the velocity of runoff water and trap silt. These also serve as guidelines for contour cultivation. Graded earth banks (bunds) usually with a horizontal gradient of up to 1% to feed excess water into a prepared waterway have been employed extensively. These structures have severe limitation in the tropics (Chapter 2) and do not fit small holdings due to loss of arable area for the bank itself and the waterway.

Vegetative barriers on the contour have distinct advantages over earth banks, namely, vegetative barrier requires about one tenth of the space and no water disposal system is necessary, vegetative barrier slows down surface runoff and causes it to deposit the silt load while the water seeps through spread out, with increased opportunity to infiltrate. This also avoids the problem of waterlogging which is common behind the bank.

A plant suitable for a vegetative barrier requires particular morphological characteristics. Its root system should be aggressive and deep without rhizomes or stolons so as not to spread out of line; the crown should be below the surface for protection against fire and overgrazing; the culms tough and unattractive to animals and pests; and the flowers, if any, essentially sterile so as not to permit spreading by seed. The plant should be a perennial and persistent, tiller freely and intermingle with its neighbors (some clump grasses do not). To date, the only plant know to meet these criteria is vetiver grass, (Vetiveria zizanioides). It has an extremely wide range of climatic conditions over which it is adapted and further exhibits adequate growth over a wide range of soil types, including those with highly unfavorable properties for many plants. Vetiver grass has been used for this purpose and as permanent field boundaries for a long time, and hence it is known to persist, once established, without maintenance indefinitely. It is propagated by root slips which the farmer may plant himself on a roughly surveyed contour lines. Given moderately favorable conditions, the hedge would be complete after three growing seasons, fewer with high fertility, high rainfall and close planting.

Apart from physical advantages, establishing and maintaining the system is low-cost and can be carried out entirely by the farmer. Compare this with the engineered system which requires earth-moving equipment, complete cooperation among neighbors especially for water disposal components that may impose an intolerable burden on those further down the slope, and regular rebuilding every three to five years.

Vetiver grass has other applications due to its unique morphology. Among these are protecting paddy banks, dam catchments and drainage lines from siltation, roadsides and stream banks from erosion, and performing the soil- and moisture-conservation function when planted in V-ditches with fruit and forest trees.

The same technology can be used for the stabilization of degraded nonarable lands. Vetiver grass can be used, but in these nonarable situations, shrubs that can be coppiced for fuel or fodder could also be used as barriers on the contour. The search for suitable shrubs continues.

Vegetative systems, of whatever species, have a number of advantages over structural systems:

(a) Cost. Vegetative measures for soil conservation generally can be promoted at low cost. Costs for establishing vetiver grass hedgerows in India are estimated to be US$18/ha. In many cases the major cost item for promoting these measures is for extension advice.

(b) Adaptability. Unlike structural measures which require detailed engineering and site planning, vegetative approaches are relatively insensitive to issues such as proper alignment on contours, irregularities in field boundaries and minor errors in placement. Hence, surveyed contour guidelines can be replaced by planting across the slope.

(c) Farmer-Controlled. Because vegetative methods are relatively inexpensive and do not require use of machinery or sophisticated surveying, individual farmers can take the initiative in adopting conservation measures. An indigenous system of contour alley cropping using bands of *Leucaena* has been used widely in the steep lands of Cebu in the Philippines. A particular advantage is that the cropping area sacrificed to the conservation measure is considerably less than with the typical structural approach, and is especially true in the case of grass contour hedgerows. Farmers' willingness to devote arable land to essentially permanent cover is often largely dependent on the degree to which livestock are integrated in the farming system.

Investing in Nonarable Areas

A large proportion of a typical watershed anywhere in the region is nonarable in the sense of not being suitable for agriculture due to soil or slope characteristics. Yet the consequences of runoff/erosion on nonarable lands are quite significant. Productivity is lost, and more so than on arable lands, sedimentation and local flash flooding are increased, and dry-season stream flows reduced.

Land use and ownership are generally less complicated in arable areas, where crop-based agriculture and mostly private ownership prevail, than in the nonarable areas divided among forest, grazing and community lands and variously owned by government (mainly forest department), communally and privately. The condition of nonarable land is further complicated by de jure and de facto rights of access by both landed and landless rural families. This diversity of use and ownership has exacerbated the effect of degradation and makes remediation more difficult on nonarable land.

In order to redevelop nonarable areas, something has to be done first to restore soil moisture status. Contour vegetative hedge treatments improve infiltration. Lowering livestock populations would reduce soil compaction, as would less use of heavy equipment in forest harvesting. Controlling fire, which induces water repellancy in some soils, can also assist.

Redefining land use becomes the important next step. While it may be the most advantageous use of land and the best soil conservation strategy to try to return bare land or degraded forest areas to the original mix of species, other options could include closed mixed-species forest, single-species plantations, fuelwood plantations, silvipastoral plantations or pasture. It is not within the scope of this study to develop guidelines for determining which option might be employed under any given situation. At the same time, the importance of doing so ought not to be underestimated since it takes account of the needs of the population and may ultimately determine the success of the investment.

Treatment of Forest Areas

Stabilization. Denuded slopes in nonarable areas need to be stabilized by using vegetative barriers on the contour at approximately three to four meter vertical intervals first, before any of the options are applied. This treatment cuts down runoff, increases infiltration and traps erosion products. This stabilization technology can be applied on village common land, grazing land and wasteland, as well as forest land. The vegetative barrier should ideally comprise indigenous, locally adapted shrubs that are unpalatable, deep-rooting, easily propagated and capable of forming a dense hedge, planted into a V-ditch or trench. In the absence of suitable shrubs, vetiver grass would form a suitable hedge in most circumstances in the region. As noted above, the cost of of establishing this treatment is likely to be on the order of US$18 per hectare. It would be applied regardless of what the interhedge spaces might later be used for.

Revegetation. Artificial forestation is the option most commonly applied to nonarable land, probably because most areas are under the jurisdiction of forest departments whose mandate is to plant trees and manage plantations. The success rate for forestation is low and costs per hectare high, which call the technology into question. Questioning the technology is valid, but only when the issues of stabilization/soil moisture status and land use are resolved. Chapter 5 reviews the methods of revegetation presently practiced in Asia. There are key shortcomings regarding selection of species and quality of planting materials, land preparation, methods of planting and planting geometry, protection and management. A serious nontechnical shortcoming has been that forestation has been carried out without the support or agreement of local people who may customarily harvest some resources from these areas. The technical shortcomings are well understood and little or no additional research is required to be able to grow most tree species successfully. Addressing all these issues so as to do everything well, however, results in costs per hectare in the range of US$500-1,000. This cost is generally too high to be replicable over wide areas.

The Problem-Solving Approach

Beyond doubt, removing the vegetative cover causes accelerated erosion so, if over time an undisturbed vegetative cover can be recreated, the problem is solved. However,

(a) time may not be an option, in which case intervention is required to accelerate growth of vegetative cover;

(b) natural regeneration may not be an option, if the soil moisture and nutrient status have been changed due to degradation; and

(c) an undisturbed vegetative cover may not be an option, if land is to be used for arable agriculture, grazing, fuelwood or fodder production, in which case a vegetative/cultural farming system, or structural intervention or combination of interventions is required.

The issue is how to decide, within the choices, which to take and how to avoid the common mistake of opting for a single solution to a complex problem. Information specific to the site and a clear understanding of impact are required. There are two main questions. The first is one of scale: what should be the size and definition of the planning unit? The larger the area of the planning unit the greater the heterogeneity of land use, land capability, microclimate, soils, vegetation and people. The larger the size the more likely that one or two widely applied solutions will fail. The second question relates to what must be achieved. If, for example, the objective is solely to reduce downstream sedimentation, then it might be achieved by a simple technique such as a checkdam, but the dam would have no effect on erosion-induced productivity decline in arable areas. The objectives are rarely simple and hence invariably require a set of solutions.

Folly of a Single Solution. Terracing as a treatment is a common choice in the tropics and done properly can be effective. Yet terraces by themselves do not necessarily conserve soil or moisture, improve productivity or decrease sedimentation. In fact, poorly farmed terraces may result in greater degradation, and inappropriate types of terraces or terracing inappropriate soil types may reduce productivity and accelerate soil loss. Even when properly used, terrace technology is only part of a system. Whether or not terracing is a sound proposal depends on the type of terrace in relation to rainfall, soil depth, drainage and structural strength, land ownership patterns, crops to be grown on the terrace, farming systems and quality of the extension services. This is true of all soil conservation interventions. There is no one technology that applied in isolation will achieve a soil conservation benefit on anything but a very small scale.

Importance of Planning at a Micro Level. For selecting appropriate on-site soil conservation practices, it is possible to construct guidelines that can be easily followed at the local level. At the regional planning level it is more difficult due to increased heterogeneity and the limited quality of information available. Information on where and under what circumstance various soil conservation technologies are applicable is available; whether this information can be used depends on the quality of the information from within the planning area. Given the importance of scale and linkages ascribed to economic functions, ascertaining the nature and optimum dimension of the planning unit is critical. There are advantages and disadvantages in using a hydrological (physical) unit, an administrative (political) unit or a set of villages (social unit) and a case can be made for each. Since villages tend to be located close to drainage lines in order for occupants to exploit lower arable and higher nonarable lands, the boundaries of a village's area of influence frequently coincide roughly with watershed boundaries. As a general rule, the hydrological unit is preferred. A typical watershed (100,000-200,000 ha) comprises a series of subwatersheds (5,000-15,000 ha) which in turn are made up of five to ten microwatersheds (500-2,500 ha). Experience seems to suggest that the subwatershed, as it is defined here, is a convenient planning unit, provided that plans respond to an aggregate of information from constituent microwatersheds.

Having avoided the single solution trap, the preferred approach in developing a conservation strategy is to define the problems that are evident in the subwatershed and to define the objectives of possible solutions. Since there is no immediate linkage in very large watersheds (above 200,000 ha) between erosion in the upper catchment and downstream sedimentation, the most supportable programs are those whose objectives are to raise farm incomes and increase on-site sustainability of both arable and nonarable land in the upper watershed.

Techniques such as rapid rural appraisal (see Box 1.3) can be used in problem definition through interactive planning with the population. In a short time, it would be possible to identify the population's dependencies, needs and aspirations, perceptions of the dimension and causes of degradation, to describe the microwatershed itself in terms of land classes (arable, non-arable, private, village, public) and identify respective needs for treatment, and by this method to come up with objectives, a strategy and action plans.

Menu of Solutions. Within any subwatershed there will be a number of treatments appropriate to addressing the problems defined in the interactive planning process. A list of eligible treatments can be assembled easily, given what is known about the efficacy of each in particular agro-ecological situations, their synergism and cost. It remains then to match solutions to the problems, an exercise that has several dimensions. For private arable land, farmers will undoubtedly choose treatments that are income-enhancing in the short term. Although support may be required, little coercion would be needed. Treatments such as stabilizing or revegetating nonarable areas or treating drainage lines would require the population's consent and cooperation, and would mostly be implemented by an agency or organization rather than individual farmers.

Incentives for Participation in Watershed Development

Three well recognized factors influence farmers' willingness to participate in watershed development programs, and more specifically to implement soil conservation treatments:

(a) land tenure;

(b) profitability of the farming system and scope to improve profitability; and

(c) economic status, whether a cash or subsistence farming system, and portion of income derived from the farm.

Box 1.3: PROBLEM DEFINITION IN A MICROWATERSHED

Interactive Planning

Numerous approaches have been developed around the world for carrying out interactive village planning in microwatersheds. These planning approaches have as their objective to put planners, agency staff, and villagers on a common ground for identifying key problems, analyzing their causes, and devising realistic action plans that reflect local needs and the availability of government and local resources. Successful approaches are those which include techniques for collecting and discussing information in an open-ended way, which draw strongly upon indigenous technical knowledge as well as professional expertise, and which are conducted in stages to allow villagers to participate in devising action plans, rather than simply reacting to plans drawn up by government extension agents or officials.

The Technique

Rapid rural appraisal is a technique that is often employed in interactive planning. It is not a methodology, but a set of investigative tools adapted to short-term analysis of particular sets of problems of natural resource management. It is often used to gain an initial understanding of problems on the basis of the analysis of secondary data combined with a structured field investigation. In combination with other formal surveys, it can be used in monitoring program performance and evaluating program efficiency or program impact. Unlike traditional research, rapid rural appraisal teams include planners as well as researchers, and their investigative tools are designed to encourage as much interaction with villagers as possible. These tools include: (a) group and individual interviewing; (b) cross-checking information (triangulation); (c) direct observation; (d) use of sketch maps, diagrams, village transects; (e) sampling tailored to a shortened time frame; and (f) redesign of plan as hypotheses change and new options emerge.

A Sample Application to Watershed Development

A watershed development program which includes soil and moisture conservation, forestry, on-farm tree planting, and pasture improvement is being implemented by several government agencies in a subwatershed. A team of one or two persons trained in the technique and government extension agents would visit villages to analyze people's needs and conduct individual interviews with different types of households. The team reviews environmental/economic problems with the villagers, adding to villager statements with their own observations, and plotting the information with villagers on sketch maps showing village areas of influence. Conflicts over use of the resources within the village or between villages and over government regulations or uses are important topics, as are the institutional mechanisms for resolving these problems. Villagers discuss options that they feel will help to resolve their problems and with the team draw up an action plan, based on their own time and resources and the available government inputs, programs, and resources of the extension departments represented.

Land Tenure. Tenurial arrangements on arable land are complex. Insofar as they affect implementation of soil conservation measures, the issues go beyond guaranteed long-term access to land to include access to credit, ability to make decisions on land development, the proportion of returns that accrue to the user, and the ability to transfer rights. About eight categories of tenure, ranging from very secure for privately owned land with title to very insecure for some forms of sharecropping and for private cultivators on public lands, pertain. The attributes, categories and consequences for participation in development programs on arable land are discussed in Chapter 6. An important conclusion of that review is that tenurial arrangements do have an important influence on the land user's decision to participate or not to participate. On private land, low adoption rates have frequently been attributed to tenurial constraints whereas poor technology options are the real constraint. Two significant changes in recent Bank-assisted projects are:

(a) greater use of vegetative, cultural and farming systems-related conservation treatments that are, overall, more effective and more amenable to a wider range of tenure categories, and

(b) presentation of a menu of technical options from which the farmer may choose according to personal conditions rather than a single package that may be intimidating and therefore rejected.

Profit, Sustainability and Risk. An on-farm production system that is more lucrative than the current one and involves minimal increase in risk provides incentives to farmers to participate. Evidence suggests that in all but the most marginal situations (shallow stony soils, steep slopes), total production can be improved by managing soil moisture and restoring soil fertility, which techniques generally mitigate runoff and soil erosion. Yield increases, for example, from contour cultivation alone which involves very little cost can be 50% or more: the resulting improvement in soil moisture then allows modest levels of applied fertilizer to be effective. Improved plant density due to seeding rate and adjustments in row spacing, an improved fertilizer strategy or intercropping can also improve yield and soil protection.

Support for Participants. However attractive the incentives may be, most smallholders need support in several ways to implement new initiatives:

(a) to lay out, establish and maintain hedges on the contour (for example, with vetiver grass);

(b) to reshape inappropriately designed terraces, plant surface risers with suitable fodder plants;

(c) with good-quality planting materials of the most suitable cultures;

(d) with demonstrations of improved farming systems and cultural treatments; and

(e) with credit and extension.

RECOMMENDED APPROACHES TO WATERSHED DEVELOPMENT

The data reviewed make clear that there is no single watershed management problem in the Asia region. Rather there is a complex of issues related to increasing soil and moisture loss, land degradation, sedimentation and irregular stream flows, and poverty that can best be understood in the framework of watersheds as physical planning units. The analysis suggests that the donor community should continue, and accelerate, its efforts on the development of environmentally sound and higher-productivity, upland farming systems. Greater attention should be given to the diversity of upland agriculture and the need to develop local capacity for diagnosis of constraints to productivity growth and design of site-specific solutions. Forest lands and livestock grazing systems similarly need to be addressed, because few soil and water conservation measures are in place on them. Projects promoting single-solution, structural approaches to soil conservation problems should be reduced and greater effort given to the use of vegetative techniques. Technology development projects, with provision for careful experimental design and rigorous testing of proposed techniques, may be required before large-scale projects can be expected to be viable.

Flooding and Sediment

The potential for reducing flood and sediment damage downstream in large basins by means of land-use changes, rehabilitation, and reforestation in the upper watersheds of the Asian region appears limited. Catastrophic floods seem to be the result of heavy rains largely falling on already saturated soils and nonabsorbant surfaces in lower reaches; and by nature, deltic regions, formed by flood-borne deposition of eroded material, are subject to flooding. No statistical evidence indicates a secular increase in the occurrence of flood events, yet increases in flood damage are largely explained by increased population and higher-value land use in floodplains.

Data on sedimentation support the argument that in large river basins whose headwaters lie within the geologically young, unstable mountain ranges of Asia (for example, Himalayas), the largest portion of sediment load is the result of natural processes, and the damages therefrom are to the same extent ascribable to geological processes. Human-induced sedimentation, while having severe impact within smaller watersheds, has much less impact within the context of larger river basins. Reducing geologic erosion is not practicable and reducing human-induced erosion in areas with already widespread disturbance by altering land use or reforesting, for example, will not necessarily have the impact required. This relationship is particularly true, given the prolonged residency of sediment within a catchment whereby sediments currently stored within channels and floodplains will continue to move through the system for extended periods. Nonetheless, at some point, watershed rehabilitation must be undertaken to begin the process of reducing the transport and deposition of sediment, though for large basins the time lag for noticeable reduction downstream may be decades or centuries. While the problems caused by sedimentation are real and significant, they should be dealt with by such means as operating practices, dredging and appropriate infrastructure design. In particular, decisionmakers should give greater attention to assessing the validity of assumptions about sedimentation rates and predictions of investment life. In some cases, it may be necessary to either accept or reject water resource developments, depending on whether the expected lifetime in the face of sedimentation is sufficiently long. However, the likelihood of eventual sedimentation must be recognized.

Similarly, recognition of the probability of flooding should be factored into policy-making with respect to downstream areas. The design of infrastructure and buildings and the decisions to site developments in floodplains and to promote settlement should recognize the certainty of an eventual flood.

Cost Sharing and Cost Recovery

A corollary of the limited impact of upstream land-use changes on downstream damages is that there is limited justification for schemes to compensate upland farmers and communities for adopting conservation practices. There is considerable scope for identifying techniques that will reduce or at least not increase erosion and runoff and that are profitable for upland farmers. Various subsidies and compensation schemes may be required to bridge the gap between adoption of a conservation measure and the realization of a sustainable net return. If so, such compensation should be seen as transitional and not as part of a policy of ongoing subsidy.

Experience with subsidy schemes for adopting conservation measures has not been encouraging. Unless carefully designed, subsidies can lead to an overemphasis on construction of structural measures and neglect of maintenance requirements and serve as a disincentive to less-expensive measures that would otherwise be adopted by farmers on their own. An example of a promising strategy has been used in the Central Visayas Regional Project in the Philippines. To promote adoption of contour hedgerows, the project lends breeding cattle to farmers, conditional on establishment and maintenance of a hedgerow sufficient to support stall feeding of the offspring. This provides a powerful incentive for both establishment and maintenance of the hedgerow and has been extremely effective.

Rural Infrastructure

Road and trail construction in upland areas can contribute to either environmental improvement or deterioration and is one of the few ways of significantly affecting downstream sedimentation. The extension of road networks can lead to deterioration of watersheds by facilitating access to fragile remote areas. On the other hand, improved access to markets can improve incomes which can generally be expected to lead to adoption of more conservation-oriented farming. Road and trail design and construction methods need to incorporate adequate safeguards to minimize erosion and sedimentation. As attention is shifted from use of structural conservation measures to agronomic approaches, the engineering expertise of soil conservation agencies can be reallocated to road construction and rehabilitation.

Analytic Methods

There are no special characteristics of watershed development projects vis-a-vis other development projects that require a fundamentally different approach for their economic analysis. Standard approaches to the analysis of agricultural projects, based on a with-without comparison, will produce a satisfactory estimate of project worth. Special attention may be required, however, to understanding incentives as perceived by farmers and communities, given the importance of common property resources and the often precarious nature of land tenure systems.

While this review concludes that the downstream impacts of land-use changes within large river basins will generally be of marginal importance over any time period of economic interest, there are no conceptual constraints on taking any such benefits into account. Meaningful judgments on the physical impacts of a specific intervention can be developed through approaches such as sediment budgeting, as well as on the basis of long-term measurement and modeling studies. Well-established approaches can then be used to translate physical impacts into economic terms.

More relevant to most watershed development projects is the need to integrate technical judgments on the impact of erosion and of conservation practices on crop yields with economic and financial analysis of cropping systems. Although data are seldom available for a particular project site, there is usually sufficient evidence from other sites to guide economic analysis. Input from experienced agricultural specialists is needed to ensure the validity of assumptions made in these calculations. Input from social scientists is also important in order to assess constraints to adoption, especially on common property and public land.

Guidelines

There appears to be no need to prepare technical guidelines for watershed development projects. Annex 1.1 lists guidelines issued by several government and international agencies on various aspects of watershed development projects.

Funding Procedures

New approaches to disbursing project funds are required, given that: (a) overall project costs can be estimated by extrapolating from detailed plans developed at the microwatershed level; (b) a number of different government and quasi-governmental agencies and nongovernmental organizations can legitimately be involved in implementing watershed actions; and (c) not all activities need to be synchronized. For example, it is reasonable to envisage a program-type watershed development fund from which approved agencies may be reimbursed for completing treatments eligible for reimbursement. This requires definition of the eligible treatments, definition of the organizations who may implement them and verification procedures relating to implementation. The Bank and other development agencies would be advised to explore more effective funding procedures.

Need for Commitment

Watershed management projects are complex interventions that require effective multidisciplinary collaboration, commitment by governments and local communities, and sustained efforts. For development agencies to be effective partners in this process, it is necessary to recognize that watershed projects, while not necessarily large or expensive, require heavy inputs of staff, particularly in preparation and supervision. Agencies also need to recognize and act on the need for government commitment in resolving watershed problems. Without serious commitment by governments and their field staff, investments are unlikely to succeed.

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2. SOIL AND MOISTURE CONSERVATION TECHNOLOGIES: REVIEW OF LITERATURE

John B. Doolette and James W. Smyle

This chapter reviews research literature concerning on-farm impacts of soil and moisture conservation technologies on surface runoff, erosion/sedimentation and productivity and yield. It is preceded by a brief discussion of the range of treatments applied in relevant World Bank projects. The review includes data from more than 200 studies globally that appear to be based on valid experimental methods. The limits to extrapolating from the data to other sites and projects are noted. The literature covered is presented in bibliographies in Chapter 8.

INTRODUCTION

The process of watershed improvement involves several important aspects, not the least of which is the selection and application of technical methods for bringing about stabilization of degraded land surfaces, that is, the reversal or arrestment of degradation, or protection against it in newly exposed watersheds, and redressing the loss in agricultural productivity due to diminished soil and nutrient status.

Erosion Effects and Control Measures

World Bank Project Interventions. The World Bank has financed many projects with substantial watershed development components. Staff appraisal reports on 35 relevant projects (20 in the Asia region), spanning 1976-87, show estimated total project costs (in current dollars) in excess of US$500 million. In most cases, unit costs for individual treatments were estimated at appraisal, but project benefits were less frequently estimated. Table 2.1 shows the technologies to be implemented over the 35 projects, their unit cost and the impacts anticipated. Categorized by on-farm and off-farm conservation interventions, respectively, the unit costs and assumed benefits are looked at more closely in Tables 2.2 and 2.3.

This substantial investment, combined with the sizable commitment implicit in projects under preparation or in the pipeline, prompted regional staff to question the technologies and treatments from the standpoint of efficacy, synergism between them, the benefits accruing from them, and relative cost and replicability. This questioning called for a systematic review of the performance of on- and off-site 1/ soil and moisture conservation treatments in terms of physical effectiveness and benefits. The literature

1/ On-site refers to the area under treatment in a micro- or subwatershed, whether it be on-farm or off-farm, whereas off-site is further downstream below the area under treatment and outside of the micro- or subwatershed.

review herein especially focuses on determining benefits and, to the extent possible, on establishing links between physical treatments and socioeconomic analysis.

Perceptions of the Effects of Soil Erosion. A basic premise is that soil erosion is undesirable for reasons that are generally easy to support in quantitative and economic terms. It is important to understand that erosion effects and runoff effects are closely related and, indeed, in terms of cause and effect, runoff comes first. Defining the effects of runoff/erosion is important in determining the relevance and benefits of technical measures. In this context, surface runoff and the concomitant soil erosion result in:

(a) loss of agricultural productivity through:

(i) reduced rainfall infiltration and moisture-holding capacity in the soil;

(ii) reduced depth of topsoil;

(iii) impaired soil surface characteristics and seedbed quality; and

(iv) loss of soil nutrients.

(b) increased sedimentation which impacts on:

(i) downstream agriculture through siltation of irrigation canals and deposition of silt on farm lands; and

(ii) reduced reservoir life, damage to fisheries, reduced water quality, pollution from agricultural chemicals which are adsorbed to soil particles, increased maintenance costs in waterways and harbors, and stream aggradation.

(c) flooding; and

(d) decreases in dry season stream flow.

Types of Runoff and Erosion Control Measures. The total range of treatments is better seen when grouped in terms of land-use categories, namely, on-site--arable land, nonarable land including forest and drainage lines--and off-site--downstream drainage lines and compacted areas. Within each group there may be the option of structural or vegetative/cultural measures. The following measures have been applied and to varying extents have been studied:

On-Site

(a) arable land

- contour farming;
- contouring with vegetative (vetiver grass) barriers;

- contouring with earth banks and waterways;
- earth banks on field boundaries;
- furrowing, ridging, ridge tying;
- tillage practices, subsoiling;
- vegetative ground cover, mulching, manuring;
- grass cover, grass strips, grass barriers;
- improved farming (cropping) systems;
- agroforestry;
- terracing; and
- land leveling, smoothing.

(b) nonarable land
- vegetative barriers on the contour;
- earthen or rock barriers;
- afforestation, reforestation, revegetation;
- area closure;
- reduced grazing pressure, stall feeding;
- pasture improvement;
- silvipastoral plantations;
- buffer zones; and
- trail, rural road and forest road treatments.

(c) drainage lines
- gully control structures;
- checkdams, silt traps;
- diversion drains; and
- vegetative stabilization of natural drainages.

Off-Site

(a) drainage lines
- grassing of artificial waterways;
- stream bank protection; and
- channelization.

(b) compacted areas - roads; overall design, retaining walls for cut batters; and

- settlements; diversion drains.

LITERATURE ON THE IMPACT OF CONTROL MEASURES

Methods

The body of work on soil erosion/degradation processes is extensive, yet predominantly empirical in nature, making results site-specific. A review of the literature pertaining to the on-farm impacts of soil conservation technologies on surface runoff, erosion/sedimentation, and site productivity was conducted. The sources for the review were obtained through comprehensive searches of the USDA's Agricultural Library (Beltsville, Md., USA), and the World Bank's Sector Library (Washington, D.C., USA). In both libraries the computerized on-line bibliographic search facilities 2/ were used. The review considered only that literature which appeared to result from valid experimental design and methodologies. Even so, the research conclusions available from the selected literature are included without making judgment as to their validity. Such judgments would require extensive analysis beyond the purview of this exercise. In addition, a special review of the Indonesian experience with soil conservation technologies was carried out within the country. A lack of standardization in field and laboratory research methodologies makes comparison of results difficult. Problems of scale compound the difficulties of applying research results, for example, when modelers try to apply pan or small-plot data to answer questions that arise on a watershed scale. Considerable work is still required for a more complete understanding of the physical/chemical/biological processes that drive the erosion/degradation process. That work must be accomplished before an accurate "universal soil loss" process-based model can be formulated. Quantitative studies on the wide array of approaches to soil conservation technologies are scanty and only available in a few widely scattered research locations. Gaps exist in work that is applicable to tropical areas, especially high rainfall, mountainous areas. Lack of standardized methodologies and problems of scale also create problems with the applicability of these studies. Despite the problems with modeling, quantifying erosion/soil degradation and predicting quantitatively the impacts of proposed soil conservation technologies, there is sufficient understanding to allow the application of soil conservation treatments in a straightforward, systematic manner.

The review groups the literature on the impact of control measures into three subjects, namely:

(a) on soil moisture and surface runoff;

(b) on erosion rates and sedimentation yields; and

(c) on productivity and yield.

2/ USDA library facility = "AGRIS" and "SILVER PLATTER".

Erosion is a term easily misused. This review is concerned with what is often called "upland erosion" in the literature; it is what the universal soil loss equation estimates: rill and interrill erosion. Rill erosion takes place when water is concentrated into tiny rivulets and proceeds predominantly by the erosive force of flowing water. Interrill erosion (often referred to as sheet erosion) proceeds predominantly by the force of raindrop impact. A further source of confusion may relate to whether soil erosion or soil loss is meant. Erosion takes place if a soil particle is at all disturbed; soil loss takes place if the particle is at all moved. The difference then is one of measurement. Since it is almost impossible to measure average soil disturbance in any fashion that is meaningful, due to spatial and temporal variability, researchers set up collectors and capture sediment. The sediment captured represents soil loss and the data used to infer erosion rates. Soil loss is then defined by where the collector is placed and, therefore, so is the erosion rate. The problems of scale are beyond the scope of this report. The only confusion that can be resolved easily is semantic; the terms to be used will be "erosion rate" and "sediment yield."

Evidence suggests that tropical soils erode more quickly when disturbed and that the impact of erosion is greater than in temperate counterparts (27, 50, 51, 93, 95, 97, 158, 160, 215).3/ El Swaify (51) also reports that the downstream impacts of sediment on water quality may be greater from oxidic tropical soils than from temperate soils.4/

On-site erosion/sedimentation control practices that have been studied may be broken down into two broad categories, namely vegetative/cultural practices and structural practices. Since these two categories are not mutually exclusive and are often mutually supportive, the question of which approach to take must be decided on the basis of site-specific factors and goals. Often a combination of the two approaches is necessary, such as when vegetatively stabilizing a stream bank, it is necessary to control structurally the forces that cause further degradation so that the vegetation may be established (22).

IMPACT ON SOIL MOISTURE AND SURFACE RUNOFF 5/

Clearing Land for Agriculture

Evidence from several studies on small watersheds shows that land clearing increases surface runoff, especially when carried out with heavy equipment (6, 62, 100, 118, 166, 201). The one exception is where heavy ash inputs, following manual slash-and-burn clearing, increased soil permeability

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3/ Numbers refer to list of references in Table 8.1, which are then cited in Tables 8.2, 8.3, and 8.4.

4/ Where possible, soil types are presented using the FAO-UNESCO (1974) soil taxonomy. The translation from USDA to FAO-UNESCO was done based on: Breimer, R.F., van Kekem, A.J., and H. van Reuler, 1986. Guidelines for Soil Survey and Land Evaluation in Ecological Research. MAB Technical Notes No. 17, UNESCO, pp. 29-30.

5/ Literature cited in Table 8.2, page 191.

so that surface runoff decreased (181). Conversion of land from forest to grass has been found to increase surface runoff and total water yield (20, 62, 77, 134, 160, 176) except when grass production is high (77, 176). Conversion to agricultural lands also has significant impact on surface runoff from small watersheds (63). The impact is, however, use-dependent. Poor land management will increase surface runoff; significant reductions in surface runoff are usually associated with intensively managed areas (155). Little effect of soil/moisture conservation practices has been noted on water yield from areas larger than 120 hectares (155).

Vegetative and Cultural Measures

Grass Cover and Strips. The effect of a grass cover on surface runoff varies--runoff reductions from 56% to 90% have been observed on slopes from 0.5% to 46% when compared to surface runoff from other agricultural types (50, 68, 102, 103, 173, 182)) and one study (161) showed no difference in surface runoff between a grass cover of Imperata cylindrica or Saccharum spp. compared with secondary or plantation forest on 36-70% slopes. Yet, Pennisetum spp., Cynadon spp., Urochloa spp., Panicum spp., and Desmodium spp. showed no effect on surface runoff when compared to conventional cultivation in two cases with, respectively, 5% and 46% slopes (102, 202). Effects of grass barriers or strips have not been well investigated, though it appears that they do have an impact on surface runoff. On 12-22% slopes, grass strips reduced surface runoff 9-14% (3, 183), and planting grass strips on bench terraces on 28% slopes reduced surface runoff 69%, compared to unplanted terraces (102). The spacing of strips and types of grass affect the impacts on surface runoff--2.5 meter spacing of grass barriers gave a 59% greater reduction in surface runoff than grass barriers spaced 5 meters apart, and Eragrostis spp., guinea grass, and South African pigeon grass barriers reduced surface runoff 30% and 25%, respectively, on 0% and 23% slopes (102).

Mulching. Mulching protects the soil from raindrop impact, reduces evaporation from the soil surface, and slows down runoff, giving more time for water to infiltrate (96, 160). Measurements of soil moisture storage on mulched plots showed an increase of 38% when mulch was applied at 1.1 t/ha; by increasing the amount of mulch to 4.4, 8.8 and 12 t/ha, moisture storage was increased 61%, 93% and 104%, respectively (180, 197). Mulch applied at 9 t/ha conserved the equivalent of 23 days of a soybean crop's moisture requirements (189) and 0.66 t/ha of mulch increased soil moisture storage 3% (38). Surface runoff, an indicator from which increases or decreases in soil moisture storage could be inferred, has been shown to be reduced by 16% to 91% on slopes ranging from 1% to 46% as the result of mulch applications (54, 97, 102, 122, 188, 189, 192, 199, 213). Rainfall simulator studies have shown that mulch has no effect on surface runoff from low-intensity rainfall (171), yet reduces surface runoff by 11-96% on 5% slopes (with mulching rates of 0.63-4.94 t/ha) for higher-intensity events (113). One study (21) on 2% and 8% slopes showed a combination of mulch and manure at different rates to reduce surface runoff from 64% to 93% compared to untreated plots. Stubble mulching with crop residues has also been shown to increase soil moisture storage (180) and to decrease surface runoff (84, 116).

Cultivation practices may also be effective in reducing runoff. As a general principle, tillage and cultivation reduce the size of soil aggregates and promote pore clogging which can result in decreased infiltration (66, 133). Increases in surface runoff of 150-1,317% have been reported as a result of taking land out of permanent grass and putting it under cultivation (158). However, infiltration increases ranging from 72% to 860% have been observed as a result of different tillage and cultivation practices, compared with untilled land, as a result of increased surface roughness slowing down or detaining surface runoff (28). Poor tillage practices, such as up-and-down slope cultivation, can increase runoff, even when combined with beneficial practices such as cover cropping or mulching (54, 68). No-till/minimum till methods on 1-18% slopes have decreased surface runoff from 7% to 86% in comparison to traditional and conventional cultivation methods (90, 116, 122, 157). No-till systems combined with mulching have reduced surface runoff from 43% to 92% on slopes from 3.5% to 14%, compared to unmulched, traditional cultivation (116, 190). On slopes as high as 21%, no-till carried out on the contour reduced runoff 43% compared to clean tillage (73). Increased surface runoff has been observed in a no-till/stubble mulch/chemical weed control system compared with conventional tillage/stubble mulch. The study reported a 16% increase in surface runoff attributed to chemical weed control (212). Disk plowing/stubble mulching were shown in one study (116) to reduce surface runoff about the same amount as a no-till/mulch system.

Contour Cultivation. Reports from India on contour cultivation and planting, based on 30 years of work at an agricultural experiment station, suggest that this practice alone will reduce surface runoff 25% when compared to up-and-down slope cultivation (46). Other studies have found a decrease of 70% in surface runoff on a 25% slope (68) and an 82% decrease on a 20% slope when contouring was combined with mulching (102). These two studies were also in comparison to up-and-down slope cultivation. A 29% and 48% decrease in surface runoff was observed on 2.2% and 6% slopes, respectively, when the only difference was contour cultivation (16, 60). Direct measurement of soil moisture showed an 8% increase in storage on medium- and fine-textured soils on contour-farmed lands and no soil moisture benefits in coarse-textured soils that are contour-farmed (24). Compared to a control continuously under shrub and grass, contour-cultivated land showed a decrease in surface runoff of 8% on a 25% slope and an increase of 14% on a 30% slope (54).

Ridge and Furrow. Ridged and furrowed plots have demonstrated deeper percolation of water (164, 218), with increases of 121% in soil moisture storage (47) and decreases in surface runoff on the order of 31-86% (122, 131); combined with broadbedding or field banks, surface runoff has been reduced on the order of 38-68% (130, 142, 180). There have been, however, concerns that runoff may increase in situations where water is allowed to concentrate in the furrows (178). In a structurally unstable soil, broadbed and furrowing caused a 38% increase in surface runoff and a 67% increase in peak discharge on a slope of less than 1% (142). It has also been noted that there are few or no moisture conservation benefits from this practice in sandy soils, in clay soils which become compacted from in-field operations, on rough or broken land, on steep slopes, or where large amounts of sediment will accumulate (78, 120, 200).

Structural Measures

Earth Banks. Earth banks require frequent repair and maintenance (26, 68) and in some structurally poor soils (142) or poorly drained soils are impractical--as one author, working in vertic soils, commented that traditional farming consisted of "...breached banks, local varieties and no fertilizer" (203). Also, ponding of water behind banks may occur on poorly drained soils (68). Grading of banks and putting them on the contour can reduce runoff 23-37% when compared to ungraded/uncontoured banks; however, a 50% decrease in depth of percolated water (168) and a 70% increase in surface runoff (169), as well as 18% and 37% decreases in runoff (142, 187), have been observed with contour-banked compared with unbanked plots.

Land Leveling. Little work was encountered on soil moisture/runoff impacts of land leveling. One study showed that a leveled area accumulated in seven months the soil moisture that 19-21 months of fallow would accumulate (126). But this same study also concluded that benefits were dependent on the timing and distribution of rainfall; this may explain the lack of any effect of leveling on soil moisture found in the other study (112).

Terraces. Studies conducted on terracing generated a wide range of findings. No changes in surface runoff were found between terraced land and contour-planted corn on 2-18% slopes (177); between terraced and unterraced land (10, 74); and on coarse-textured soils and other soils with low water-holding capacity (75). Direct measurement of soil moisture found either no changes from terracing (76), that any changes were temporal and may only be observed during the rainy season (58), or that there was a 50% decrease in the depth to which water percolated (168). Terraces, when compared with graded furrows on gentle slopes, were found to increase surface runoff on the order of 25%, with the greatest increases coming in small storms (84, 155) or to perform no differently (68). Compared to unterraced plots, terraced plots have been found to increase surface runoff if antecedent moisture conditions are high or decrease it if they are low (10). As the result of terracing, increases in surface runoff of 20% (10), 116% (169), 140% (182) and 31-201% (183) have been observed. Significant increases in peak discharges and time to peak discharge, decreases in soil moisture, and low flows have been observed as the result of completely terracing small watersheds (108, 110). Conversely, a 28-year study reported that terracing decreases peak flows with the magnitude of decrease inversely proportional to the size of the watershed (10), and in an 11,500-ha watershed there was a reported 11% decrease in surface runoff after 42% of the watershed was terraced and a 44% decrease in surface runoff after 75% of the watershed was terraced (89). When comparing terracing to other practices, such as clean cultivation on slopes of 9-47%, terracing reduced surface runoff 31-86% (72, 102, 103, 163, 191). The moisture retention function provided by terraces in some situations (75, 124) has also created difficulties in carrying out tillage as a result of excess soil moisture (17) in others. It is apparent, however, that when terraces are used in conjunction with other improved practices they do enhance moisture conservation. In general, the experience in the United States has been that contour-farmed terraces reduce surface runoff 9-37% compared to unterraced agricultural land (74, 219). Inclusion of such practices as conservation cropping, permanent covers, mulches, rotations, and deep tillage have been shown to decrease runoff 20-90% on terraced lands (10, 11, 103, 167).

IMPACT ON EROSION RATES AND SEDIMENT YIELDS 6/

The effect of treatments on erosion rates and sediment yields is arranged by climatic zones, which is not to suggest that research from one climatic zone is not applicable to another. Physics is not changed by rainfall and temperature regimes; what does change, however, is the relative importance of individual parameters in the erosion/sedimentation process. For example, antecedent moisture conditions are much more important in a monsoonal climate than a semi-arid climate. Since soil types are also loosely correlated with current climatic regimes, climatic zone seems a useful basis for compartmentalizing research results.

Climatic Zones

Equatorial Monsoon - receives both monsoons, no regular dry season [precipitation (Pt) = 2,000+ mm/yr], and,

Continuously Wet Tropics - humid for more than nine months (Pt = 1,400+ mm/yr)

The review found limited quantitative research on soil conservation in these two climatic zones. It is reasonable to assume that given their large volume of annual precipitation, soils are often near or at saturated conditions. Extensive overland flow in well-vegetated areas could be expected as a common phenomenon (176) and erosion/sedimentation hazards high in disturbed catchments. Research available shows that for slopes of 3.5-22% techniques such as minimum tillage with mulching could reduce sediment yields 56-99%, compared with unmulched traditional farming systems and that grass strips reduce sediment yields 93% compared to bare soils (3, 190). Commercial fertilizer applications and manuring were also found to reduce sediment yields 99%, compared to nontreated plots, due to increased yield (21). These results suggest the linkage between a productive cover crop, infiltration, and reduction of runoff velocities. Some evidence from these zones supports the idea that traditional hill-slope agriculturalists practice farming systems that minimize erosion (160). No research on structural soil conservation treatments in these two climatic zones was encountered.

Dry/Wet Monsoon - One monsoon predominates, receiving relatively little precipitation from the other (Pt = 1,800+ mm/yr).

A wide variety of research exists for this climatic zone. Work has been done on permanent grass covers in comparison to clean cultivated agricultural lands (7, 30, 41, 68, 102, 152, 161, 167, 202); research findings taken from slopes ranging 5-70% show decreases in sediment yields of 50-94%. Grass strips alone have proven effective on slopes up to 30% (no available research at slopes beyond this figure), reducing sediment yields from 71% to 99.7%, compared to clean cultivation (33, 102, 103, 205). The effectiveness of grass strips in reducing short-term erosion rates, however, may not be as great. Compared to clean cultivation, erosion rates ranged from not significantly

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6/ Literature cited in Table 8.3, page 203.

different to 24% less on areas with grass strips (4,183). The addition of mulch in conjunction with grass strips was very effective on slopes of 23-28%, reducing sediment yields 97-99% compared to clean cultivation (102). Mulch alone reduced erosion rates from 16% to 99% (1, 188, 189) and sediment yields from 64% to 152% (41, 116) on slopes up to 35%.

Research on cultural treatments for soil conservation in this zone found that no-till/stubble mulch systems can decrease sediment yields 64-93% (116), and that contour cultivation by itself (based on 30 years of experiment station research in India) decreases sediment yield 30% in comparison to up-and-down slope cultivation (46). Research in other areas found reduction in sediment yield from contour cultivation to range from 30% to as high as 80% when used in combination with mulching (68, 102) in comparison with uncontoured plots. One study reported that at higher slopes, 25% in this case, contour cultivation alone was ineffective and yielded 14 times more sediment than a bench-terraced plot (143). Other cultural practices such as mixed cropping reduced erosion rates by 74-99% on 20% slopes when compared to strip cropping or monocultures (106, 213), and the addition of manure (16 t/ha) reduced erosion rates 42% on a 16% slope (2). Finally, when compared to seed-bed preparation by plowing on a 10% slope, burning and dibbling reduced erosion rates 38% in a corn field (30).

The structural treatment of contour banks (syn. bund) appears to have a limited life span of 2-5 years in this zone and at slopes above 11% to fill rapidly with silt and have trap efficiencies on the order of 30-50% the first year and 0% the second (79, 116). Contour banks also have been found to be useful only where soils have good drainage (116, 159), otherwise they are susceptible to breaching and failure (68, 79, 116, 159, 203). They have, however, been shown to decrease sediment yields 32-46% on well-structured soils, in comparison to unbunded plots (169,187). Many types of terraces have been tested in this zone, such as inward-sloping, outward-sloping, level-drainage and level-retention bench terraces. As a generic type of structural practice, over a range of slopes from 10% to 30%, terraces have been found to decrease sediment yields 50-90% (33, 68, 102, 103, 104, 143, 169, 205); they have also been shown to reduce erosion rates 20-95% on slopes ranging from 9% to 40% (71, 152, 163, 184, 191). Compared among themselves, it is evident that evaluation of slope, soil, and rainfall/runoff regime should decide the type of terrace used. Sediment yield increased 17 times with outward-sloping, compared with inward-sloping bench terraces (104) and no difference in sediment yields was found in two studies between the less costly approaches of graded terracing and hillside ditching, compared with bench terraces (68, 169). Erosion rates may also be effected by terrace type; flat-bench terraces and sloping-bench terraces increased erosion rates 125% and 800%, respectively, when compared to ridge terraces in an upland situation (140).

Over the range of slopes researched in the dry/wet monsoon climatic zone, 5-30%, it appears that vegetative/cultural approaches such as grass cover, grass strips, and mulch are almost as or are as effective as structural approaches.

Wet and Dry Tropics - Clearly defined wet and dry seasons. Dry season persists for 3 to 6 months (Pt = 1,000+ mm/yr).

A variety of soil conservation work has been carried out in this zone. No research was encountered that investigated the effects of grass strips. Permanent grass cover has been found to reduce sediment yields 84-100%, compared with clean cultivated plots (54, 62, 182, 215). Mulch, tested on slopes of 3-8%, reduced sediment yields 38-98% in comparison to traditionally cultivated plots (122); on 30% slopes, the mulching of plots that were cultivated up and down slope reduced sediment yields by 28% (54). Experiments with a 50% cover of asphalt mulch reduced erosion rates 68% (149).

Poor cultural practices such as cultivation up and down slope have been shown to accelerate erosion rates, even when combined with good practices such as cover cropping or mulching (54). When compared to conventional tillage and bare soil, no-till systems have proven to decrease sediment yields by 61-98% on slopes ranging from 1% to 52% (27, 67, 122, 157); when combined with mulching, a no-till system reduced sediment yields 99%, compared to conventional cultivation (139). Land clearing and cultivation, especially on sandy soils, may increase erosion rates drastically (up to 115 t/ha/yr) (97, 98, 100). Burning to clear a site for agriculture, then practicing no-till cultivation decreased sediment yields 85%, compared to conventional tillage (90); bulldozing, leveling and conventional tillage increased sediment yields 105% versus burning and conventional tillage (90). Hand cultivation versus mechanized cultivation reduced sediment yields 38%, compared to plowing and harrowing or mouldboard plowing and 70%, compared to plowing and bare fallowing (139). Other practices found to be effective when compared to up-and-down slope cultivation are cross-slope and contour cultivation and ridge and furrow systems which have reduced erosion rates 43-96% on slight slopes (16, 90). One study (122) showed that on one of two sites no-till, minimum till, and contour cultivation actually increased sediment yields 33-205% when substituted on 3% slopes for a traditional mixed cropping scheme. Tillage practices appear to be site-specific in impact. Deep tillage when compared to shallow tillage on a erodible sandy soil subject to compaction decreased the erosion rate 63% (36); on a highly weathered Ferrasol, deep tillage increased the erosion rate 100% in comparison to shallow tillage (114). Shifting cultivation by traditional practitioners on steep slopes appeared to result in little accelerated erosion (150, 209), but practiced by newcomers to the area resulted in disaster (209).

Terracing, compared to unterraced lands and the same cultural practices, showed 26-89% decreases in sediment yield on slopes of 5-45% (56, 94, 129, 182). When comparisons were made among terrace types, a study on 5% slopes (56) demonstrated that sediment yields from different types of terraces could range from a 70% decrease to a 69% increase, depending on whether the terrace was backsloped or broad-based in comparison with level or out-sloping. One contour banking study showed that earthen banks were superior to stick or stone banks on 30% slopes. The earthen banks were 34-39% more efficient at reducing sediment yields versus the stick or stone type; compared to bench terracing, however, the earthen banks were 58-70% less efficient on these steep slopes (129).

Temperate Zone - Rainfall every month or well marked rainy season. May be snow in winter (Pt = 600+ mm/yr)

The majority of work done on soil conservation has been done within the temperate zone. The applicability of this work to the tropics has always been in dispute, though Sanchez (160) states that for soils that are Entisols, Vertisols, Yermosols, Solonetz, and others with little or no iron or aluminum oxides, the classic concepts of soil conservation developed in the temperate zones are entirely applicable.

Research on grass strips has found a 40-70% reduction in sediment yields in farm fields on relatively flat lands, compared to no grass strips (31, 74, 217). Vegetative riparian buffers and very wide (> 50 ft) grass strips were found to have a trap efficiency for sediment of 84-99% for runoff moving at low velocities (39, 217). Mulches alone, at rates of as little as 0.33 t/ha, have been shown to reduce sediment yields by 42% (171). Doubling that rate of application to 0.66 t/ha of mulch reduced sediment about 66% and mulch at about 2.5 t/ha reduced sediment yields 80-97% (99, 113, 123 171).

Cultural operations such as contouring were considered to be most effective on slopes of 3-9%, reducing sediment yields by 50-86% compared with uncontoured fields (73, 219). Most research on cultural operations involved a treatment package of different tillage types with mulch/chemical weed control/crop residue management or stubble mulching. Ranges of sediment yield reductions were 26-99.9% on nearly level to 21% slopes (12, 31, 73, 74, 137, 178, 195, 219). There is also evidence that some tillage practices, for example, ridge tillage without crop residue management, are inappropriate and may increase erosion/sedimentation when not used in combination with other practices (178).

Structural approaches to soil conservation were, again, found to be site-specific in their application. On 9% slopes in shallow erodible sand, contour banks increased sediment yield 200% (121), whereas on a 32% slope, contour banks reduced sediment yields 25%, 77%, and 99.9%, depending on whether the banks were placed every 10 rows, every 5 rows, or every row (148). Research has characterized terraces as effective, but not necessarily more effective than grass or graded furrows, at reducing sediment yield (74, 177, 219) (155, 177); expensive ("more expensive per ton of soil erosion reduction than any other alternative for soil erosion control") (198); and prone to failure if used in structurally unsound soils (23, 87).

Semi-arid, Tropics - One rainy season, marked by 4-8 month dry season (Pt = 400+ mm/yr), and

Semi-arid, Temperate - One rainy season or patchy rainfall distribution (Pt = < 600 mm/yr).

In these two climatic zones, natural upland erosion can reach its peak. Density and distribution of vegetation are patchy, long-term wetting and drying cycles create hydrophobic conditions in soils; initial infiltration rates, especially in sandy soils, can be quite low; and finally, what precipitation does occur often comes in the form of high-intensity rainfall. The little soil conservation research encountered for these climatic zones was mostly of the cultural practice-type, where methods to increase infiltration and contain runoff for future crop use predominate.

Permanent grass cover as an alternative to wheat was found to decrease sediment yields 98% on 8% slopes (50), but as an alternative to natural cover on 0.5-1% slopes to increase sediment yields 6-12%. In comparison to other agronomic treatment, though, the grass-covered plots produced from 74% to 92% less sediment (173). One study on grazing effects (211) showed a 200% increase in sediment yields when short-duration grazing (a few days of high-density grazing) was practiced in place of moderate continuous grazing. Cultivated fallows are a common practice in semi-arid zones as a means of storing soil moisture for later crops. This practice has been called into question due to erosion hazard and, on very gentle slopes, sediment yields from these fallows have been shown to be 850-1,239% higher than natural cover and to be 22-214% higher than when in crops (86, 173). Manuring and mulching have proven effective in reducing sediment yields on slopes of 2-25%: decreases of 73-98%, depending on whether used alone or in combination, have been reported in comparison to bare fallow and no sediment yield increase has been reported in comparison to a vegetated fallow (21, 167).

Contour cultivation has been found effective on slopes ranging from 3% to 8%; at less than 3%, cross-slope cultivation approximates the contour and at greater than 8% increased washouts negated short-term benefits (54, 58). Broadbed and furrow systems have been found to increase sediment yield on poorly drained soils compared to better drained soils (130, 142) for traditional cropping systems. One study (142) warned of structural instability for furrowing or bunding in a fine-textured Alfisol. A broad-based terrace study, the only terrace study encountered that was concerned with erosion/sedimentation, demonstrated a 92% decrease in sediment yield in comparison to an unterraced field (144).

IMPACT ON PRODUCTIVITY AND YIELD 7/

Inevitably, erosion decreases the productivity of a site. If the subsoil characteristics of eroded sites are favorable, then erosion necessitates higher production costs without affecting yields (93, 95). Generally, soils with favorable subsoil characteristics are Andosols and Cambisols, while soils with unfavorable subsoil characteristics are often Ferrasols, Acrisols and Nitosols. On shallow, infertile tropical soils, productivity may decline more rapidly than in similar temperate soils (93, 95). Some studies on the effect of natural erosion on yield have found a yield decrease of an average 0.14 tons/ha per mm of soil loss (95),8/ or that yield declines 3-7.5% after 1 mm of soil loss and declines 10-25% after 8 mm of soil loss (115). Other studies have shown that an erosion rate of 5-14 mm/yr (77-216 t/ha/yr) resulted in yield declines of 50-70% (57). In comparing crop yields from plots that had eroded down to subsoil and plots where topsoil was intact, a decrease of 15-28% was found for the various crops planted in the exposed

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7/ Literature cited in Table 8.4, page 219.

8/ For purposes of conversion of soil depths or soil volumes to soil mass, a conversion factor of 1.4 grams per cubic centimeter was used.

subsoil (31). Certain volcanic soils (Andosols) and loessial soils have fairly uniform physical, chemical, and structural characteristics present to great depths in the soil profile. In such soils the loss of several centimeters of topsoil will have little or no effect on crop yields (93); convincing the cultivators of such soils to employ soil conservation measures may be difficult.

Causes of Productivity Decline

Causes of erosion-induced yield decline differ among soil types, ecological environments, climatic conditions and crops, with no single factor or combination explaining yield variability. There are obvious causes such as decrease in net arable area or burial by erosion products. There are indirect causes such as when timeliness of farm operations is disrupted by difficulties in seedbed preparation or delayed planting. The significant causes of yield or productivity decline are primarily due to changes in three soil variables, namely, plant-available soil water, plant-available soil nutrients, and organic matter.

Soil Moisture Loss. The conclusion of the United States National Soil Erosion-Soil Productivity Research Committee was that the primary effects of erosion on productivity are due to loss of plant-available water (93). The reduction of soil water reserves available to the plant is due to several factors, namely:

(a) Increased Surface Runoff. The increase is dependent on slope, vegetation (type and distribution), soil characteristics, climatic regime, level of disturbance, and subsequent management practices. Estimates of loss due to increased surface runoff vary widely.

(b) Decreased Soil Depth. The decrease directly reduces water-storage capacity and effective rooting depth, especially in soils with shallow/rooting lithic contacts, unfavorable subsoil characteristics or restrictive layers.

(c) Decreased water-storage capacity due to physical changes in soil structure (e.g., loss of noncapillary porosity, crusting) and the preferential depletion of soil organic matter and certain clay fractions by the erosion process; organic matter and clays contribute disproportionately more to water-holding capacity relative to other coarser soil fractions.

The literature does not disaggregate the separate effects of these factors, nor does it distinguish moisture from the other key soil factors. It mostly concerns water-use efficiency. Drought effects are magnified on eroded soils (95) and water-use efficiency of crops is decreased (186). A 4-5% decrease in plant-available water in an eroded soil caused a 12-36% decrease in yield (61). Yost et al. (186) report reduction in water-use efficiency due to soil loss. Kilograms of dry matter per liter of water used ranged from 0.66 kg to 0.7 kg in uneroded control, 0.39-0.64 kg when 10 cm depth was removed and 0.07-0.45 kg for a loss of 35 cm. Water-use efficiency for a soil that lost 35 cm was only 50% that of an uneroded control.

Soil Nutrient Loss. The impacts of erosion have been investigated by removing soil from plots and attributing subsequent yield differences to the depth of soil removed. These soil removal studies are useful only as indicators of the effects of erosion. This is true, in part, because the process of erosion under natural conditions preferentially removes soil components, namely, organic matter and certain clay particles that are important in maintenance of cation exchange capacity (CEC) and moisture-holding capacity. Soil removal, on the other hand, impartially removes all soil fractions. The experience with soil removal studies has been, averaging across different soil and crop types, that the removal of 5 cm of soil reduces yields on the order of 60%, of 10 cm reduces yield on the order of 65%, and of 20 cm reduces yield on the order of 80% (95, 96, 118, 221). It should be noted that these percentages are useful only as indicators of the magnitude of the response, in that it is the removal of the top few centimeters that has the greatest impact. Lal (93) states that the available data on yield reduction per unit loss of topsoil is more drastic for the tropics than for the temperates. Other studies have combined soil removal and fertilizer inputs to look at the unrecoverable productivity decline associated with soil loss (117, 221). One study (96) analyzed sediment and surface runoff from different slope classes to determine the amount of nutrient export taking place. Combining both parts of the study, nutrient flux off site for slopes of 1-15% ranged from 9 kg to 235 kg/ha/yr nitrogen, 0.7-9 kg/ha/yr available phosphorus, 4-6 kg/ha/yr potassium, and 50-3,070 kg/ha/yr organic carbon. Looking at nutrient loss as a function of soil loss, it was observed that on slopes of 3-6.5%, losses of organic carbon and nitrogen were soil-dependent (52). On well-drained sands, losses were 0.97 kg of nitrogen and 10.7 kg of organic carbon per ton of soil loss per year. On other soils, losses were 2.1 kg and 15.4 kg of nitrogen and organic carbon, respectively, per ton of soil loss per year. Losses of phosphorus were the same irrespective of soil type, with 0.16 kg of phosphorus per ton of soil loss per year. On 18% slopes, nutrient losses per ton of soil loss per year were 30 kg of organic matter, 1.5 kg of nitrogen, 1.0 kg of phosphorus, and 2.0 kg of potassium (30). Artificial stabilization of a soil surface decreased the loss rate of major nutrients by more than 90% (44).

Maintaining and/or replacing nutrients is the basis for sustainable productivity. The most common approaches to nutrient management have been to use organic or commercial fertilizers. Organic matter is essential in unfertilized systems--it supplies nitrogen and sulfur, blocks phosphorus fixation, maintains CEC, improves structure of the soil, and forms complexes with micronutrients (160). Organic matter is important in soils with a low CEC or in poorly aggregated sands. Commercial fertilizers, by providing for increased on-site productivity, increase soil organic matter through the decomposition of roots. In choosing between organic or commercial fertilizers, the decision, if soils are adequate, should be based on economics, transport, accessibility, and social criteria (160).

Organic Matter. Organic matter effects soil moisture by enhancing soil permeability, infiltration capacity and moisture retention. In terms of soil nutrients it supplies most of the nitrogen and sulfur and half of the phosphorus taken up by unfertilized crops (the slow release pattern from organic matter is an advantage over chemical fertilizers), it limits phosphorus fixation and can form complexes with micro-nutrients to restrict their leaching. Its depletion in eroding soils is serious. Typically in tropical soils, the zone of enrichment is narrow and removal of the top layer exposes subsoil layers with very little organic matter, poor structure, porosity and nutrient content. Under forest conditions, tropical soils are high in organic matter due to the rapid rate of replacement, but once cleared, even without erosion, the high rates of decomposition, mineralization and leaching lower organic matter content rapidly. Losses of organic matter are high with erosion products and rates of replenishment low because of the competition for crop residues and other sources for fuel and fodder. Organic matter in whatever form is essential to preserve and protect top soil, for optimizing soil water and for the efficient use of chemical fertilizers. It is the only soil amendment that can be produced on or near the farm.

Treatment Effects. Soil treatments variously affect productivity and yield and the literature reviewed isolated the effects of several treatments as follows:

(a) Cover. Vegetative soil covers have been shown to conserve or increase soil nutrients. On a grassed plot, soil nutrient decline was only about 19% of what it was on a bare tilled plot (182), and on plots cover cropped with legumes there was about a 52% increase in major nutrients compared to clean cultivated plots (85). Mulches have been shown to increase yields from 7% to 188% in comparison to yields from unmulched plots (38, 91, 105, 149, 153, 174, 185, 193).

(b) Clearing of land with heavy equipment for agricultural use, compared with clearing by slash-and-burn, has had yield impacts ranging from none (40) to 16-74% declines in various crops (136, 166); subsequent fertilization did not return yields from the mechanically cleared plot to yield levels of the slash-and-burn plots (136). The observed yield differences were attributed to the benefits of ash on the slash-and-burn plots versus soil compaction and topsoil disturbance by the heavy equipment.

(c) Tillage, by itself, significantly reduces nutrient loss in agricultural systems by incorporating fertilizers into the soil (44). A comparison of shallow hand cultivation (to 5 cm), deep mechanical cultivation (15-20 cm) plots, and uncultivated plots showed a 22-103% yield increase and a 8-73% yield increase for hand and mechanical cultivation, respectively (36). Deep tillage was shown to increase yield an average of 28% in 10 crops, over four years, in seven regions of India (153). One author (158) warns that physical degradation and productivity decline caused by mechanized agriculture is more rapid in the tropics than the temperate regions; therefore, the beneficial effects of tillage will not last without liming or inclusion of rotations with deep-rooted grasses. No-till/minimum till systems have shown a range of impacts from a 21% yield decrease (in peanut yields, attributed to the low growing habit of peanuts, exacerbating the effects of weed competition) to a 51% increase in yield compared to traditional cultivation (97, 122). In combination with mulches, no-till has shown a range of impacts, from a 7% decrease (in peanut yields) to a 139% yield increase (mung beans) compared to traditional cultivation (190, 212).

(d) Contour cultivation and ridging across the slope have shown yield increases of 6-66% on 1.5-32% slopes, when compared to traditional or up-and-down slope cultivation (16, 34, 46, 104, 105, 122, 131). Based on 30 years of research station experience in India, contour farming increases yields up to 35% (46). The inclusion of mulch with contour farming increased yields on a 28% slope by 105%, compared with up-and-down slope cultivation (123).

(e) Vegetative Barriers on Key Contour Lines. The vegetative barrier-contour cultivation system using vetiver grass, *Vetiveria zizanioides* (Chapter 1, Box 1.2), being developed and promoted in World Bank projects in India, has not yet been referenced in the research literature and data to quantify its benefits are just being collected. A recent set of data from Karnataka, India compared two factors, namely, soil moisture in the top 15 cm and yield, on a contour-cultivated field with vetiver hedges and a field cultivated up-and-down slope. It showed that, on the contour-cultivated field, the soil's wilting point was delayed 14 days, the yield of finger millet without fertilizer increased by 25% from 550 kg/ha and with fertilizer by 57% from 790 kg/ha: in short, a classic pattern of increased growing season, yield and response to fertilizer. Data from the first year of experiments in Maharashtra showed the same yield pattern and reductions in soil loss, ranging from 38% to 73%; the maximum observed difference was a decrease in soil loss from 33 tons/ha to 8 tons/ha when cross-slope cultivation was changed to contour cultivation with vetiver grass contour hedges. Surface runoff decreased 20-60% with treatments of vetiver grass, explaining the observations of increased crop-available soil moisture.

(f) Ripped furrows in semi-arid zones have shown 250% and 300% yield increases over nonfurrowed areas (25, 47). Furrow dams in a semi-arid study area increased yield 15-20% compared to no-furrow dam areas (180).

(g) Construction of banks as soil or moisture conservation structures has failed to show any significant or stable increase in yield in controlled experiments at ICRISAT (86). In poorly drained Vertisols, contour-banked plots showed yield decreases in each of eight years, due to ponded water interfering with tillage and damaging crops (68). A 1962 experiment (209) found 35% yield increases with banking and 98% yield increases with banking and land leveling combined, and on a structurally stable, high-quality soil, contour banks were as effective at increasing yields as contour banks in conjunction with terracing or mulching on 9-12% slopes (5).

(h) Land leveling and level pans have shown yield increases ranging from 0% to 180% in comparison to unleveled plots in semi-arid areas (88, 112, 126).

(i) Terracing is a technology whose experimental effects on yield vary widely. On the negative side, terraces have been found to have anything from no effect on yield to a 32% decline in yield (17, 18, 35, 56, 68, 76, 104, 105, 182). Reported are impacts such as significant increases in loss of major nutrients (excepting N) (182), yield reductions persisting for six years due to topsoil disturbance (17), topsoil disturbance resulting in the necessity of high levels of commercial fertilizer inputs (18), and poor drainage resulting in degradation of soil tilth from tillage operations and crop damage from excessive moisture (35, 68). As an agronomic practice, terracing alone may have no effect on yield (74, 76). On the positive side, terraces have been shown to increase yields from 16% to 100% (34, 56, 68, 75, 105, 111, 124). The important question is, what caused these differences? Soil disturbance is one causal factor--a study of five different terrace types, four structural and one vegetative, found that yield was 18-45% higher on the vegetative terrace due to lack of soil disturbance (42, 68); another study found that replacement of two inches of topsoil on bench terraces (to cover subsoil exposed by terracing) increased yields as much or more than the highest fertilizer applications (18). Terraces, and bench terraces especially, require deep fertile soils on moderate slopes to permit the topsoil removal that is necessary for leveling (17). Shallow droughty soils do not have the level of productivity required to justify the annual maintenance cost, let alone the initial cost (30). Construction of the wrong type of terrace is another problem. Level-absorption terraces and conservation-bench terraces are for use in climates where retention of moisture is important and will not be appropriate in humid climates or in areas with poorly drained soils. Outward-sloping terraces are useful in areas with well-distributed, low-intensity rainfall, and well-structured permeable soils. Inward sloping and level drainage terraces are useful in humid climates. All terraces require soils that have good engineering properties--silts and fine sands are unsuitable soils in which to terrace. Certain landscapes in Indonesia such as the upland marls are physically unsuited to classic bench terraces and can be severely destabilized by their construction (30). Depth of soil over parent material and the parent material itself are important. Shallow soils over slick parent materials (e.g., granites and shales) (23) that are not well-weathered can result in massive terrace failures. The proper terrace type may also be crop-specific; in Indonesia (135) rice yields were 18% higher on bench terraces compared to ridge terraces, but the more expensive bench terraces produced no greater yields for peanuts or cassava than did the ridge-terraced lands. Whether or not to choose terracing, and then, which type(s) to choose are site-specific questions.

NEED FOR STANDARDIZED RESEARCH METHODS

There is an urgent need for standardizing methodologies to increase the reliability and accuracy of data on soil erosion, soil moisture, productivity and yield. This is particularly important in determining magnitude on a global or regional basis. Despite the extensive literature, reliable quantitative data are limited, having been derived by survey and visual assessment and experiments lacking standardized methodologies. At the local level, sound results from well-designed and properly equipped experiments are required to enable scientists and policymakers to develop watershed management strategies. Further, as the review discovered, the types and range of experiments must be expanded to cover the extreme situations experienced by small farmers, particularly those farming the steep slopes of upper watersheds.

The International Society of Soil Science through a subcommittee on soil conservation and environment has published "Soil Erosion Research Methods"9/ which attempts to standardize methodologies. The book addresses the issues of evaluating erosion problems with nonstandard methods, data precision and reliability, and then deals with the methodologies involved in laboratory, field runoff plots, and large river basins; the design and use of rainfall simulators; modeling soil erosion processes; methods of monitoring erodibility and erosivity and of canopy cover; and assessing the impact of erosion on productivity.

For more effective physical monitoring of Bank-supported projects, a number of these techniques may be considered. Generally they are labor-intensive but relatively inexpensive and their application in projects would add greatly to the understanding of the effectiveness and benefits of treatments.

9/ Soil Erosion Research Methods, 1988, R. Lal, ed., Soil and Water Conservation Society, Ankeny, Iowa.

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Table 2.1

SUMMARY OF WORLD BANK PROJECTS

REPORT #	COUNTRY	PROJECT	TECHNOLOGY	AREA \ QUANTITY	UNIT COST	ASSUMED IMPACTS OF TECHNOLOGIES	ERR	REMARKS
4317-IN 1983	INDIA	HIMALAYAN WATERSHED MGMT. - UTTAR PRADESH				-GRASS -- FUELWOOD PLANTATION =.5-3 ton/ha @ yrs 1-8,11-18 FODDER PLANTATION = 2-4 ton/ha @ yrs 1-20 -FUELWOOD -- FUELWOOD PLANTATION = 23-48 ton/ @ yr 10 & 20 FODDER PLANTATION = 18 ton/ha @ yr 10 & 20 FARM FORESTRY = 5 ton/ha @ yr 10 & 20 -FODDER -- FUELWOOD PLANTATION=.1-.5 ton/ha @ yrs 3-20 FODDER PLANTATION = 1-5 ton/ha @ yrs 3-20 -SOIL CONSERVATION/SEDIMENTATION BENEFITS	23%	REPORTS REDUCTION OF SOIL LOSSES FROM 30-40 ton/ha/yr TO 1-3 ton/ha/yr SHOWN IN INDIA FOLLOWING IMPLEMENTING SOIL CONSERVATION MEASURES "SIMILAR" TO THOSE PROPOSED. NO CITATION GIVEN FOR THIS FIGURE. * - does not equal 6000 ha of terraces, rather 6000 ha of land will have terraces constructed on it.
			FUELWOOD & TIMBER PLANTATIONS - MIXED SPECIES	59,000 ha	US$ 274/ha(Govt) US$ 379/ha(Civ)			
			FODDER TREE PLANTATIONS	27,800 ha	US$ 158/ha(Civ) US$ 12/ha(Priv)			
			FUELWOOD & FODDER PLANTATIONS	81,000 ha	N/A			
			BRUSH & STONE CHECK DAMS	1,650	US$ 11 ea.			
			CRATE WIRE DAMS	1,300	US$ 316 ea.			
			DROP STRUCTURES	700	US$ 1,053 ea.			
			TERRACES	6,000 ha *	US$ 526/ha			
			CATTLE EXCHANGE PROGRAM	10,500 ha	US$ 368/ha			
4561-IN 1983	INDIA	PILOT PROJECT FOR WATERSHED DEVELOPMENT IN RAINFED AREAS				-AT YEAR 13 -- FUELWOOD - 194,000 m3 FODDER - 130,000 tons -SOIL CONSERVATION/MOISTURE BENEFITS	46%	REPORTS THAT WORK PERFORMED @ ICRISAT (6 YR. STUDY) PARTITIONED RAINFALL : ON A FALLOW -- 25% - RUNOFF,25% - EVAPORATION (SOIL 9% - DEEP PERCOLATION 41% - HELD AS SOIL MOISTURE : 'ON CROPPED FIELD -- 15% - RUNOFF. SOIL ORDER = VERTISOL (HIGH SHRINK/SWELL MONTMORILLINITIC CLAY) BUNDS @ FIELD BOUNDARIES LITTLE EFFECT MOVEMENT OR RETENTION OF WATER. CROPS MAY SUFFER FROM WATER STAGNATION, BUND BREACHES = FLASH FLOODING. SOLUTION = DRAINS TO WATERWAYS & GRADED BUNDS (DEPEND. ON SOIL TEXT. AND PERMEABILITY)
			DRAINS AND WATERWAYS	300 km	US$ 15-21/ha			
			GRADED BUNDS/TERRACES	140,000 ha	US$ 41-51/ha			
			LAND SHAPING	10,500 ha	US$ 41-51/ha			
			LAND SMOOTHING	60,000 ha	US$ 15-26/ha			
			REHAB. EXISTING SOIL CONSER. STRUCTURES	30,000 ha	N/A			
			BRUSHWOOD & STONE CHECK DAMS	10,000	N/A			
			WIRE CRATE DAMS	400	N/A			
			DROP STRUCTURES	100	N/A			
			SOWING FODDER LEGUMES	45,000 ha	US$ 16/ha			
			DISTRIBUTE SEEDLINGS TO INDIVIDUALS	20,000,000	N/A			

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REPORT #	COUNTRY	PROJECT	TECHNOLOGY	AREA \ QUANTITY	UNIT COST	ASSUMED IMPACTS OF TECHNOLOGIES	ERR	REMARKS
			FARM FORESTRY	30% OF FALLOWED LANDS	US$ 115/ha			REPORT IS PRELIMINARY REPORT AND CONTAINS NO USEFUL QUANTITATIVE INFO ON IMPACTS OF PROPOSED TECHNOLOGIES
			REFORESTATION	30 % OF EXISTING FOREST RESERVE	US$ 344/ha			
6443-CHA	CHINA	GANSU PROVINCIAL DEVELOPMENT PROJ. AGRI. COMPONENT						
			BENCH TERRACES	13,500 ha	US$ 594/ha			REPORT CONTAINS NO QUANTITATIVE INFO
			TERRACES	21,000 ha	US$ 216/ha			
			LAND SMOOTHING (man.)	40,000 ha	US$ 27/ha			
			LAND SMOOTHING (mech.)	10,000 ha	US$ 270/ha			
			PLANT GRASS/LEGUMES	40,000 ha	US$ 54/ha			
			GULLY PLUGS	2,400 km	US$ 810/km			
3316a-TUN 1981	TUNISIA	NORTHWEST RURAL DEVELOPMENT - PHASE I						APPRAISAL BASED ON PILOT PROJECT (SEDJENANE RANGE MGMT.) AND SOIL CONS./FORESTRY PROJECT (B[illegible]JA PROJECT) ONLY INFO GIVEN IS THAT PROJECTS ARE "SUCCESSFUL"
			REFORESTATION/WOODLOTS	22,080 ha	US$ 1,857/ha	-FORESTRY PRODUCTION INCL. RURAL ENERGY SUPPLY - US$ 5.9M/YR @ FULL DEVELOPMENT -SOIL CONSERVATION TO REDUCE OR ARREST EROSION & DECLINE IN AGRICULTURAL PRODUCTION -REDUCE SEDIMENTATION IN RESERVOIRS	16%	
			PASTURE(IMPROVE./EST.)	72,648 ha	US$ 59,500,000 (TOTAL FOR ALL PASTURE & SOIL CONSERVATION)			
			CONTOUR BUNDS	3,300 ha				
			CONTOUR GUIDELINES	21,580 ha				
			GULLY STRUCTURES	1,740 ha				
			INTRO. NEW AG. TECH.	41,550 ha	N/A			++ - REPORT DOES NOT CONSIDER ROAD REHAB.UNDER SOIL CONSERVATION. SHOULD BE CONSIDERED AS BENEFIT IF
			ROAD IMPROVEMENT ++	1,940 km	US$ 7,216/km			
4831-BHU 1984	BHUTAN	FORESTRY DEVELOPMENT						REPORT STATES THAT PROJECT AREA COMPRISES AREA OF : "EASILY ERODIBLE SOILS", "GENERALLY STEEP SLOPES", "HEAVY PRECIPITATION" (3,950 mm(13 ft) - 4,870 mm(16 ft) per year). SEVERE EROSION AND SEDIMENTATION HAZARD AS RESULT OF LAND CLEARING, LOGGING, AND PLANTATION ESTABLISHMENT AND MGMT. PRACTICES NOT CONSIDERED.
			CONSERVATION WORKS : CHECK DAMS,GULLY PLUGS	WHERE NECESSARY	EST. EXPENDITURE US$ 105,000			
			PROTECTION PLANTATIONS ON SLOPES > 60%; ROTATION = 60 YEARS	700 ha	N/A			REPORT CONTAINS NO QUANTITATIVE INFO
2336-IND	INDONESIA	YOGYAKARTA RURAL						

Table 2.1

SUMMARY OF WORLD BANK PROJECTS

REPORT #	COUNTRY	PROJECT	TECHNOLOGY	AREA \ QUANTITY	UNIT COST	ASSUMED IMPACTS OF TECHNOLOGIES	ERR	REMARKS
1979		DEVELOPMENT	GULLY PLUGGING,DRAINS, TERRACE IMPROVEMENT (HOMEGARDENS) DRYLAND TERRACES : ++ (BENCH-TYPE,RAINFED) NEW TERRRACES REHAB. EXISTING LOWLAND TERRACES : NEW TERRACES REFORESTATION SILVI-PASTURE SYSTEMS	 390 ha 740 ha 100 ha 350 ha 350 ha	US$ 48/ha US$ 355/ha US$ 192/ha US$ 82/ha US$ 149/ha ** US$ 262/ha ^	-REDUCE SILTATION RATES IN DOWNSTREAM IRRIGATION WORKS -ARREST SOIL EROSION, DECLINE IN SOIL FERTILITY, AND CHANGES IN STREAMFLOWS -90% PER CAPITA INCOME INCREASE FOR PARTICIPANTS IN SILVIPASTURE -20% PER CAPITA INCOME INCREASE FOR PARTICIPANTS IN TERRACING -INCREASES IN AGRICULTURAL PRODUCTION DUE TO TERRACING : CASSAVA - 56% SWEET POTATO - 400% MAIZE - 200% DRYLAND RICE - 300% GROUNDNUTS - 150%	14% + 13% *	++ - COSTS BASED ON MEAN SLOPE OF 25% FOR DRYLAND AND 15% FOR LOWLAND TERRACES. COST FIGURE INCLUDES CONSTRUCTION AND/OR REHABILITATION OF TERRACE DRAINS AND WATERWAYS ** - COSTS INCLUDE PLANTATION MAINTENANCE TILL YEAR 5. PLANTATION ESTABLISHMENT COST = Rp. 74,000/ha ^ - COSTS INCLUDE MAINTENANCE TILL YEAR 5. ESTABLISHMENT COST = Rp. 145,000/ha PROJECT CONTAINED RESEARCH AND DEMONSTRATION PLOT COMPONENT.
4773-PAK 1984	PAKISTAN	INTEGRATED HILL FARMING DEVELOPMENT	AFFORESTATION FUELWOOD PLANTATION DISTRIBUTE SEEDLINGS TO FARMERS CHECK DAMS	5,680 ha 3,800 ha 12,000,000 NOT SPECIFIED	++ - SEE REMARKS	-DOUBLE AGRICULTURAL PRODUCTION -FUELWOOD -- 50,000 m3 @ yr 10, 340,000 m3 @ yr 15	22%	++ - COSTS NOT ITEMIZED. TOTAL COSTS FOR ALL PLANTATIONS AND SOIL CONSERVATION WORK = US$ 2,600,000 REPORT GIVES NO QUANTITATIVE INF
P-2139-PAK 1977	PAKISTAN	HILL FARMING TECHNICAL DEVELOPMENT	NO PARTICULAR TECHNOLOGIES PROPOSED FOR SOIL CONSERVATION			-"DEVELOPMENT OF BOTH AN IMPROVED TECHNOLOGY IN FORESTRY AND A SYSTEM OF USER PARTICIPATION IN ESTABLISHING SUSTAINED FUELWOOD SUPPLIES,WILL PROVIDE A BASIS FUR FUTURE LARGE-SCALE REFORESTATION PROG. ...TO PREVENT FURTHER DEGRAD. OF STATE'S FORESTS,SOIL,WATER.."		PROJECT ACTIVITIES INCLUDED START UP OF 4 EXPERIMENTAL/DEMONSTRATION FARMS. RECOMMENBABLE TO CHECK FOR RESULTS REPORT CONTAINS NO QUANTITATIVE INFO
2174a-IN 1980	INDIA	KANDI WATERSHED AND AREA DEVELOPMENT	VEGETATIVE & STONE CHECK DAMS/CHANNEL GRADE STABILIZERS/ DROP STRUCTURES/CRATE WIRE DAMS/DEBRIS BASIN SILVI-PASTURE	24,000 ha 18,250 ha	US$ 42/ha ++ US$ 188/ha	-INCREASED PRODUCTION OF FODDER -INCREASED INFILTRATION THUS INCREASED GROUNDWATER,DECREASED FLOODING,DECREASED SEDIMENT -TIMBER -- 320,000 m3 @ FULL DEVELOPMENT -FODDER -- 11,000 tons @ FULL DEVELOPMENT	12%	++ - COST IS DIRECT COST ONLY REPORT CONTAINS NO QUANTITATIVE INFO

Table 2.1

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REPORT #	COUNTRY	PROJECT	TECHNOLOGY	AREA \ QUANTITY	UNIT COST	ASSUMED IMPACTS OF TECHNOLOGIES	ERR	REMARKS
			LAND LEVELLING/ TERRACES/WATER HARVESTING STRUCTURES	3,700 ha	US$ 214/ha			
			BENCH TERRACES	500 ha	US$ 536/ha			
			LAND LEVELLING	3,000 ha	US$ 262/ha			
			GULLY RECLAMATION : CHECK DAMS/DEBRIS BASINS/CRATE WIRE DAMS/DROP STRUCTURES/ TREE & SHRUB PLANTING PROGRAM	1,100 ha	US$ 357/ha			
2269-TH 1979	THAILAND	NORTHERN AGRICULTURAL DEVELOPMENT	VILLAGE WOODLOTS	7,150 ha	US$ 252/ha	-REDUCE AREA USED FOR SHIFTING CULTIVATION BY 26,000 ha -PROTECT 138,000 ha OF WATERSHED FROM BURNING & DESTRUCTIVE CUTTING. -SLOW DEGRADATION OF SOIL,WATER, AND FOREST RESOURCES -SOIL CONSERVATION -FUELWOOD--112,000 m3/yr @ yr 10 -POLES--7,000 m3/yr @ yr 10 -SAWLOGS--6,100 m3/yr @ yr 10	13%	REPORT CONTAINS NO QUANTITATIVE INFO
			BENCH TERRACES	2,600 ha	NOT SPECIFIED			
			ROAD IMPROVEMENT	500 km	US$ 12,350/km			
			FOREST PLANTATION	7,600 ha	US$ 193/ha			
6096-ET 1986	ETHIOPIA	FORESTRY	FOREST PLANTATION	11,000 ha	US$ 1,909/ha ++	-INCREMENTAL PRODUCTION OF 881,000 m3 BIOMASS MAX PROD. @ YR 12, MEAN ANNUAL PROD. OF 577,000 m3 BIOMASS IN YEARS FOLLOWING. FUELWOOD COMPONENT OF BIOMASS HARVEST = 16-24% OF FUELWOOD DEMAND OF PROJECT AREA, ALLEVIATING SOME PRESSURE FROM REMAINING FOREST LANDS. -SOIL CONSERVATION,SLOPE STABILIZATION,MICRO-CLIMATIC, RESTORATION OF SOIL FERTILITY, -PROTECTION FROM GRAZING & TRAMPLING WILL RESULT IN INCREASED INFILTRATION THUS IMPROVING WATER SUPPLY & AGRICULTURAL PRODUCTION.	16%	++ - INCLUDES COSTS OF CONSTRUCTING 210 KM OF ACCESS AND FEEDER ROADS ** - INCLUDES COSTS OF CONSTRUCTING 90 KM OF ACCESS AND FEEDER ROADS REPORT CONTAINS NO QUANTITATIVE INFO
			UPGRADE EXISTING FOREST PLANTATION	13,000 ha	US$ 1,107/ha **			
			COMMUNITY FORESTRY PLANTATIONS	1,600 ha				
			UPGRADE EXISTING COMMUNITY FORESTRY PLANTATIONS	1,000 ha				
			SELF-HELP FORESTRY PLANTATIONS	8,500 ha	US$ 400/ha			
			UPGRADE EXISTING SELF-HELP FORESTRY PLANTATIONS	2,700 ha				
			FARM/HOMESTEAD PLANTINGS	210 ha				

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REPORT #	COUNTRY	PROJECT	TECHNOLOGY	AREA \ QUANTITY	UNIT COST	ASSUMED IMPACTS OF TECHNOLOGIES	ERR	REMARKS
			INSTITUTIONAL PLANTINGS	15 ha				
6072-CHA 1986	CHINA	RED SOILS AREA DEVELOPMENT	TERRACING - BROAD & BENCH CONTOUR PLANTING AFFORESTATION DROP STRUCTURES CHECK DAMS DRAINS	27,000/ha	US$ 804/ha	-600,000 m3 TIMBER. -IMPROVE ENVIRONMENTAL CONDITIONS -REDUCE SURFACE RUNOFF -FUELWOOD SUPPLY -DEVELOP SOIL CONSERVATION APPROACHES	29%	REPORT CONTAINS NO QUANTITATIVE INFO
P-4286-LSO 1986	LESOTHO	LESOTHO HIGHLANDS WATER ENGINEERING	SEE REMARKS			N/A	N/A	REPORT CONCERNED ONLY WITH DAM CONSTRUCTION WORKS; DOES NOT CONTAIN SOIL CONSERVATION COMPONENT DESPITE OBVIOUS CAUSE/EFFECT NATURE OF EROSION/SEDIMENTATION & RESERVOIR LIFE, CHANNEL AGGRADATION & HEAVY CONSTRUCTION IN FLOOD PLAIN.
P-3106-CO 1981	COLOMBIA	UPPER MAGDALENA PILOT WATERSHED MGNT.	SEE REMARKS			-PROJECT WILL SELECT AND REFINE TECHNICAL MEANS AND MANAGEMENT SKILLS FOR FUTURE WATERSHED PROTECTION PROGRAMS	N/A	REPORT CONCERNED WITH SETTING UP RESEARCH AND DEVELOPMENT PROGRAM TO IDENTIFY APPROPRIATE REFORESTATION SPECIES, SOIL CONSERVATION AND SUSTAINABLE AGRICULTURAL TECHNIQUES FOR UPPER MAGDALENA RIVER BASIN. PROJECT TO BE CARRIED OUT BY INDERENA OVER 4 YEARS. PROJECT SHOULD HAVE COMPLETED, CHECK FOR RESULTS.
4501A:6/13/84 5291-IND 1984	INDONESIA	UPLAND AGRICULTURE AND CONSERVATION	REMOVAL OF SILT FROM SEDIMENT TRAPS		US$ 1.40/m3 SILT	-INCREASED PRODUCTION OF AG, FOREST AND GRASS DUE TO SOIL/WATER COSERVATION IMPACTS ON : 1. PREVENTING LOSS OF SOIL NUTRIENTS AND DEGRADATION OF SOIL, 2. PREVENTING LOSS OF SOIL MOISTURE HOLDING CAPACITY, 3. BETTER MGMT. PRACTICES	(IRR) 12%	CILUTUNG WATERSHED, WEST JAVA - SEDIMENT LOSS INCREASED FROM 1mm/yr IN 1911 > 2mm 1935 > 6mm 1980's (EL SWAIFY et al in "Nat. Sys. for Develop., R. Carpenter,ed., 1983) EST. OF SOIL LOSS ON 16 SITES (see table 4, pg.16 of report) RANGE FROM

Table 2.1

SUMMARY OF WORLD BANK PROJECTS

REPORT #	COUNTRY	PROJECT	TECHNOLOGY	AREA \ QUANTITY	UNIT COST	ASSUMED IMPACTS OF TECHNOLOGIES	ERR	REMARKS
						(e.g. terraces). -REDUCED EXTERNAL COSTS OF DOWNSTREAM SEDIMENTATION & FLOODING. -PRESERVATION OF OPTIONS FOR AN UNCERTAIN FUTURE.		0.24 - 10.6 mm/yr. SOIL FORMATION RATE EST. @ 2.4 mm/yr. (note : this is an exceedingly high rate). SEE TABLE 1,2,3 pg.4-5,ANNEX I FOR USLE FACTORS. REF = HAMER,W.I., SOIL CONSERVATION CONSULTANT REPORT, for the SOIL RESEARCH INST. OF INDO., 1980,1981,1982 REPORT CONCERNED WITH SETTING UP R&D PROGRAM. CHECK WITH USAID PROJECT OFFICER FOR RESULTS.
4353-NEP 1983	NEPAL	SECOND FORESTRY	COMMUNITY REFOREST.	2,000 ha	US$ 277/ha	-OVER 40 YEARS -- FUELWOOD - 6.4 M m3, POLES - 1 M m3, TIMBER - 1.4 M m3, FODDER - 1.7 M mt, FRUIT - .3 M mt. -SAVE 6,900 m3/yr FUELWOOD WITH STOVES -SOIL CONSERVATION,PROTECTION RURAL WATER SUPPLY,MICRO-CLIMATIC,SOIL FERTILITY BENEFITS	27%	REPORT CONTAINS NO QUANTITATIVE INFO
			PRIVATE REFOREST.	12,500 ha	US$ 104/ha			
			STRIP PLANTATIONS - (roadcuts,river/canal banks)	2,550 ha	US$ 250/ha			
			DEMONSTRATION WOODLOTS	2,200 ha				
			AGRO-FORESTRY PLOTS	5,900 ha	US$ 954/ha			
			FUEL EFFICIENT WOOD BURNING STOVES	20,000	US$ 12/stove			
3628-MOR 1981	MOROCCO	MIDDLE ATLAS/CENTRAL AREA AGRI. DEVELOP.	SYLVI-PASTURE (range mgmt,forage plantings, fertilization,tree thinnings)	45,100 ha	US$ 69/ha	-OVER 5 YR -- 300,000 m3 CEDAR SAWLOGS, 900,000 m3 FUELWOOD. -OVER 30 YR -- SAVE 77,000 m3 CEDAR, 18,000 m3 FUELWOOD. -YEARS 30-34 -- PRODUCE 56,000 m PINE TIMBER. -INCREASE FORAGE YIELDS FOREST/RANGE THUS DECREASING LIVESTOCK DAMAGE	24%	REPORT CONTAINS NO QUANTITATIVE INFO
3676-MOR 1982	MOROCCO	FORESTRY	REHAB. EXISTING FOREST PLANTATIONS	20,000 ha		-US$ 190 M/30 yr FROM PULPWOOD PRODUCTION. 470,000 m3 SOFTWOOD FOR INDUSTRY - VALUE = US$ 55 M SUPPLY 1% (72,000 m3) ANNUAL FUELWOOD NEEEDS OF COUNTRY.	20%	REPORT CONTAINS NO QUANTITATIVE INFO
			REFORESTATION	10,000 ha	US$ 410/ha			
			PASTURE IMPROVEMENTS	2,600 ha	US$ 339/ha			

Table 2.1

SUMMARY OF WORLD BANK PROJECTS

REPORT #	COUNTRY	PROJECT	TECHNOLOGY	AREA \ QUANTITY	UNIT COST	ASSUMED IMPACTS OF TECHNOLOGIES	ERR	REMARKS
2871a-MOR 1980	MOROCCO	LOUKKOS RURAL DEVELOPMENT				-DOUBLE CROP PRODUCTION LEVELS -Pinus pinaster -- MAI = 5 m3/yr @ 35 yr rotation, -Pinus canariensis -- MAI = 10 m3/yr @ 30 yr rotation. -PIT PROPS -- 58,000 m3 -SAWLOGS -- 960,000 m3 -MOVE 25% OF FARMERS CURRENTLY BELOW POVERTY LINE TO ABOVE POVERTY LINE.	15%	FOREST DEPT. INITIATED A STUDY ON EFFECTS OF DIFFERENT SOIL CONSER. MEASURES ON EROSION & SEDIMENTATION LOCATED UPPER LOUKKOS. CHECK FOR RESULTS
			CONTOUR FARMING	N/A				
			PASTURE ESTABLISHMENT	300 ha				
			STONE TERRACES	1,500 ha				
			CHECK DAMS	3,500	US$ 330/ha			BREAKDOWN OF SOIL CONSERVATION WORKS
			FORAGE BANDS	1,850 ha				REPORT CONTAINS NO QUANTITATIVE INFO
			REFORESTATION/ WOODLOTS/FORAGE TREES/ FRUIT TREES	7,750 ha				
3840-IN 1982	INDIA	JAMMU/KASHMIR SOCIAL FORESTRY				-SUPPLY FUELWOOD NEEDS OF .45 M PEOPLE (1 m3/person/yr) ANNUALLY. PRODUCE 465,000 m3/yr -PRODUCE 465,000 m3/yr SMALL TIMBER & 2.0 M BAMBOO POLES/yr. -SOIL CONSERVATION,HILL/SAND DUNE STABILIZATION,MICRO-CLIMATE AND SOIL FERTILITY BENEFITS	27%	REPORT CONTAINS NO QUANTITATIVE INFO
			VILLAGE WOODLOTS	5,000 ha	US$ 447 - 471/ha			
			REHAB./REFORESTATION	17,000 ha	US$ 494 - 529/ha			
			FARM FORESTRY	19,000 ha	US$ 71 - 106/ha			
			WETLAND PLANTINGS	2,000 ha	US$ 471/ha			
			STRIP PLANTINGS	1,000 ha	US$ 588/ha			
		HARYANA SOCIAL FORESTRY						
			VILLAGE WOODLOTS	12,000 ha	US$ 489 - 527/ha			
			AFFORESTATION : ALKALI LANDS SAND DUNES	 500 ha 15,000 ha	 US$ 682/ha US$ 376/ha			
			FARM FORESTRY	30,000 ha	US$ 105 - 108/ha			
			STRIP PLANTINGS	9,500 ha	US$ 612 - 624/ha			
5591b-IN 1985	INDIA	NATIONAL SOCIAL FORESTRY				-REDUCE SOIL EROSION -INCREASE TIMBER SUPPLY.	21%	++ - COST DOES NOT INCLUDE NURSERY DEVELOPMENT. AVERAGE COST/HECTARE WITHOUT NURSERY DEVELOPMENT COST = US$ 186/ha; WITH NURSERY COST = US$ 253/ha.
			FARM FORESTRY	467,000 ha	US$ 16/ha ++			** - TOTAL COST
			TREE TENURE PLANTING	4,000 ha	US$ 3,121/ha			
			COMMUNITY FOREST	95,000 ha	US$ 515/ha			
			WASTELAND PLANTATIONS	77,940 ha	US$ 650/ha			

Table 2.1

SUMMARY OF WORLD BANK PROJECTS

REPORT #	COUNTRY	PROJECT	TECHNOLOGY	AREA \ QUANTITY	UNIT COST	ASSUMED IMPACTS OF TECHNOLOGIES	ERR	REMARKS
			FUELWOOD EFFICIENT STOVES/CREMATORIA	N/A	US$ 553,700 **			REPORT CONTAINS NO QUANTITATIVE INFO
6424 1986	NEPAL	REVIEW OF RURAL DEVELOPMENT	SEE REMARKS	N/A	N/A	N/A	N/A	REPORT IS A FINAL PROJECT PERFORMANCE REPORT. 3 PERTINENT PIECES OF INFO IN REPORT : 1. EROSION CONTROL WORKS TOO *IN FACE OF MAGNITUDE OF PROBLEM* 2. POORLY CONSTRUCTED PROJECT ROADS CREATED LANDSLIDES 3. LACK OF UNDERSTANDING OF FARMER'S DECISION-MAKING PROCESS RESULTED IN NO POSITIVE IMPACTS FROM EROSION CONTROL & FORESTRY DEVELOPMENT COMPONENT OF PROJECT
4662-YAR 1984	YEMEN	CENTRAL HIGHLANDS AGRICULTURAL DEVELOP.	SEE REMARKS	N/A	N/A	N/A	N/A	REPORT HAS NO SOIL CONSERVATION COMPONENT. NOTE THAT PROJECT WISHES TO CHANGE TRADITIONAL AGRICULTURAL METHODOLOGY W/O INCLUDING SOIL CONSERVATION EXTENSION COMPONENT. PROJECT IS AN UPLAND PROJECT.
2920-PH 1980	PHILIPPINES	WATERSHED MGMT. AND *EROSION CONTROL*	REFORESTATION (agro-forestry/timber crops)	32,100 ha	US$ 729/ha	*-REDUCTION OF EROSION* -LIMITING UNCONTROLLED BURNING -MINIMIZE FLASH FLOODS -ENHANCE PRODUCTIVITY -REDUCTION OF SEDIMENTATION -LEAFMEAL -- 15 tons/ha/yr FROM YEAR 5 ON -FUELWOOD -- LEAUCAENA - 301 m3/ha YEAR 10 ON CASUARINA - 186 m3/ha YEAR 10 ON CHARCOAL - 100% INCREASE -PULP/TIMBER YEMANE - 687 m3/ha TOTAL FROM YEARS 7-15 BENGUET PINE - 1,132 m3/ha TOTAL FROM YEARS 13-25 NARRA & MAHOGANY - 787 m3/ha TOTAL YEARS 20-40	18%	EROSION CONTROL STUDY INCL. LOAN # 1227-PH, 1976. - CHECK FOR RESULTS REPORT CONTAINS NO QUANTITATIVE INFO
			FOREST PROTECTION/ FIRE PREVENTION (veg. rehab.,soil *erosion control*)	155,000 ha	US$ 28/ha			
			FOREST ROAD MAINT.	410 km	US$ 3,170/km			
4369b-HA 1983	HAITI	SECOND RURAL DEVELOP. PROJECT IN THE NORTH				-BENEFITS CONCEIVED OF IN TERMS	23%	TECHNOLOGIES UNDER "AG EXTENSION/SOIL

Table 2.1

SUMMARY OF WORLD BANK PROJECTS

REPORT #	COUNTRY	PROJECT	TECHNOLOGY	AREA \ QUANTITY	UNIT COST	ASSUMED IMPACTS OF TECHNOLOGIES	ERR	REMARKS
			AG. EXTENSION/SOIL CONSERVATION (contour strips,hedges,strip crops,contour bunds, mulching)	9,000 ha	US$ 166/ha	OF INCREASED FAMILY INCOME WITH INCREASE IN CROP YIELDS OF 33% TO 150%		CONSERVATION" ARE THOSE WHICH PREVIOUS EXPERIENCE FOUND TO BE MOST PALATABLE TO SMALL FARMERS. SOIL CONSERVATION STRUCTURES (e.g. terraces) WERE THE LEAST ACCEPTABLE.
			ROAD MAINTENANCE	201 km	N/A			REPORT CONTAINS NO QUANTITATIVE INFO
3590-PA 1982	PARAGUAY	CAAZAPA AREA DEVELOP.	SOIL CONSERVATION (contour tillage,grass strips/waterways, protection plantings)	6,750 ha	US$ 89/ha	-BENEFITS CONCEIVED OF IN TERMS OF INCREASED FAMILY/TAX INCOME TO STATE AND A 20% (tobacco) TO 60% (sugarcane) INCREASE IN CROP YIELDS	20%	REPORT CONTAINS NO QUANTITATIVE INFO
			FOREST MANAGEMENT	130,000 ha	US$ 15/ha			
			ROADS/MAINTENANCE	270 km	US$ 62,592/ha			
3776a-HA 1982	HAITI	FORESTRY	SPECIES TRIALS/PILOT FUELWOOD PLANTATIONS	200 ha	US$ 2,775/ha	-WOOD -- 600,000 m3 = CHARCOAL, POLES,LUMBER DURING 4 YEAR IMPLEMENTATION PHASE, SUSTAINABLE TIMBER YIELD FROM YEAR 10 VALUED @ US$ 18.5 MILLION/YEAR. FUELWOOD VALUED @ US$ 250 OF KEROSENE/HA. -"SOIL CONSERVATION AND EROSION CONTROL WILL IMPROVE WITH THE PROJECT AND DETERIORATE SIGNIFICANTLY WITHOUT IT"	N/A	REPORT CONTAINS NO QUANTITATIVE INFO
			FOREST MANAGEMENT	32,000 ha	US$ 30/ha			
			DEVELOP FUEL EFFICIENT COOK STOVES	N/A	US$ 117,000			
2475-BO 1979	BOLIVIA	OMASUYOS-LOS ANDES RURAL DEVELOPMENT	FORESTRY	600 ha	US$ 497/ha	-"REFORESTATION OF PUBLIC AND PRIVATE LANDS (WILL) CONTRIBUTE TO BETTER SOIL CONSERVATION AND REDUCE THE PRACTICE OF BURNING DUNG THEREBY FACILITATING NATURAL NITROGEN FERTILIZATION"	(ROR) 36%	REPORT CONTAINS NO QUANTITATIVE INFO
			ROADS : IMPROVEMENT MAINTENANCE	 50 km 50 km	 US$ 3,628 km US$ 3,628 km			
2663a-NEP 1980	NEPAL	COMMUNITY FORESTRY DEVELOPMENT/TRAINING	VILLAGE FORESTRY : COMMUNITY FORESTS COMMUNITY PROTECTION FORESTS PRIVATE PLANTINGS	 11,750 ha 39,100 ha 900,000 trees	 US$ 69/ha US$ 10/ha US$ 0.01/tree	-FUELWOOD -- PROVIDE REQUIREMENTS (1 m3/person/year) OF 190,000 PEOPLE (1/3 of target area). -FODDER -- FOR 132,000 CATTLE (330,000 tons/year). INCREASE	16%	REPORT CONTAINS NO QUANTITATIVE INFO

Table 2.1

SUMMARY OF WORLD BANK PROJECTS

REPORT #	COUNTRY	PROJECT	TECHNOLOGY	AREA \ QUANTITY	UNIT COST	ASSUMED IMPACTS OF TECHNOLOGIES	ERR	REMARKS
			NURSERY/FORESTRY DEVELOPMENT IMPROVED STOVES	 15,000	US$ 3,280,000 US$ 16/stove	FOOD PRODUCTION BY SUBSTITUTING FUELWOOD FOR DUNG/CROP RESIDUES (equivalent 156,000 tons maize at peak year). SAVE 25,000 - SAVE 25,000 tons/year FUELWOOD WITH STOVES -SOIL AND MOISTURE CONSERVATION BENEFITS.		
2695-PH 1980	PHILIPPINES	RAINFED AGRICULTURAL DEVELOPMENT (ILOILO)	SOIL CONSERVATION : ++ REFORESTATION COVER CROPPING CONTOUR HEDGES DIVERSION DITCHES SODDING FIRELINES	400/ha	US$ 135/ha	N/A	N/A	++ - SOIL CONSERVATION PORTION OF PROJECT IS A PILOT PROGRAM REPORT CONTAINS NO QUANTITATIVE INFO
6197 1986	KOREA	REVIEW OF THE MIHO WATERSHED AREA DEVELOPMENT/YONG SAN GANG IRRIGATION PROJECT STAGE II	UPLAND RECLAMATION :++ BENCH TERRACES	1,200/ha	US$ 2,417/ha **	N/A	N/A	++ - WORKS TO BE PRIMARILY BENCH TERRACES, WHAT OTHER TECHNOLOGIES WILL BE USED IS NOT SPECIFIED ** - 1976 DOLLARS, REPORT IS A 1986 PROJECT COMPLETION REPORT. FUNDS ALLOCATED 1976. UPLAND RECLAMATION COMPONENT WAS NOT CARRIED OUT. REPORT CONTAINS NO QUANTITATIVE INFO
3925 1982	KOREA	REVIEW OF RURAL INFRASTRUCTURE	FUELWOOD UPLAND RECLAMATION	127,000 ha 4,400 ha	US$ 714/ha++ US$ 3,233/ha	-MEAN ANNUAL FUELWOOD YIELD OF 5 tons/ha/yr = 635,000 tons/yr FOR 10 - 15 YEARS. -REBUILDING SOIL FERTILITY -REDUCED EROSION -REDUCED FLASH FLOODS THUS GREATER AG. PRODUCTION -AMENITY VALUE OF FORESTLAND	16% ^ 19% ^	++ - COST INCLUDES : ESTABLISHMENT, AND MAINTENANCE/HARVESTING UNTIL YEAR 21 16% = FUELWOOD, 19% = UPLAND REC. REPORT CONTAINS NO QUANTITATIVE INFO
958a-NEP 1976	NEPAL	RURAL DEVELOPMENT	FODDER TREES REGENERATE VEGETATION	1,050 ha 1,000 ha		-REDUCE EROSION/SEDIMENTATION -REDUCE PRESSURE ON EXISTING FOREST -REDUCE AGRICULTURAL USAGE OF	22% +	+ - FOR EROSION CONTROL REPORT CONTAINS NO QUANTITATIVE INFO

Table 2.1

SUMMARY OF WORLD BANK PROJECTS

REPORT #	COUNTRY	PROJECT	TECHNOLOGY	AREA \ QUANTITY	UNIT COST	ASSUMED IMPACTS OF TECHNOLOGIES	ERR	REMARKS
			FOREST PROTECTION	5,000 ha	US$ 49/ha	MARGINAL LANDS		
			FUELWOOD	1,050 ha				
			SLOPE STABILIZATION TREE PLANTINGS	450 ha				
			EROSION CONTROL	UNSPECIFIED	US$ 846,000			
			TRACK/TRAIL DEVELOP & PROTECT	214 km	US$ 5,140/km			
7002-IND 1987	INDONESIA	FORESTRY INSTITUTIONS AND CONSERVATION				-INCREASE CROPPING INTENSITY 27% -INCREASE YIELDS OF UPLAND RICE, MAIZE,& CASSAVA 70 - 80%; MAIZE/GROUNDNUT 90 - 130% -SILT ENTRAPMENT BY CHECK DAMS WILL PROVIDE CULTIVATABLE TERRACE IN 3-7 YRS., NPV = US$ 1.3 M -REDUCED SILTATION OF RESERVOIR 1. PRODUCTION OF ELECTRICITY FOR LONGER PERIOD,NPV=US$ .2 M 2. DOWNSTEAM IRRIGATION FOR LONGER PERIOD,NPV=US$ 5.7 M -LIMITED HARVESTING OF FORESTRY PLANTINGS, NPV = US$ .79 M	22% *	* - WATERSHED CONSERVATION
			SOIL CONSERVATION : REHABILITATION OF EXISTING TERRACES	22,000 ha				
			GULLY HEAD WORKS	250				
			GULLY PLUGS (EARTHEN)	1,300				
			CHECK DAMS	160				
			SLOPING/GRASSING GULLY SIDES	5 ha	US$ 9,896,400			
			STREAM BANK PROTECTION (GABIONS)	10 km				
			ROADSIDE PROTECTION (RESHAPE EXISTING DRAINAGE CHANNELS, GRASSING BANKS,DROP STRUCTURES)	50 km				
			REFORESTAION : COMMUNITY FOREST	5,500 ha	US$ 2,675,500			
			CONSERVATION FOREST	3,500 ha				
			MANAGEMENT OF EXISTING CONSERVATION AREAS		US$ 6,388,700			

Table 2.2

On-farm soil conservation technologies, costs and expected benefits from selected World Bank Staff Appraisal Reports

TECHNOLOGY	PROJECT	COST PER HA	EXPECTED BENEFITS
		STRUCTURAL TECHNOLOGIES	
Terraces	China - rural development (1987)	US$ 216	None stated
Bench terraces	China - rural development (1987)	US$ 594	None stated
Terrace rehabilitation	Indonesia - soil conservation (1987)	not specified	Conserve soil, reduce sediment, increase crop productivity 100%
Bench and broad-base terraces	China - area development (1986)	not specified	Conserve soil, reduce surface runoff
Terraces	India - watershed management (1983)	US$ 526	Conserve soil, reduce sediment
Terraces/graded bunds	India - watershed development (1983)	US$ 41 - 51	Conserve soil and moisture
Contour bunds	Haiti - rural development (1983)	not specified	Increase crop productivity, increase farm family income
Contour bunds	Tunisia - rural development (1981)	not specified	Conserve soil, reduce sediment, arrest decline in productivity
Bench terraces and lowland terraces	India - watershed development (1980)	US$ 536 (bench) US$ 214 (lowland)	Conserve soil and moisture, reduce sediment
Stone terraces	Morocco - rural development (1980)	not specified	Increase crop production, increase farm family income
Bench terraces and lowland terraces	Indonesia - rural development (1979)	US$ 355 (bench) US$ 82 (lowland)	Conserve soil, reduce sediment, increase crop productivity by > 200% increase income 20%
Bench terraces	Thailand - agri. development (1979)	not specified	Conserve soil, slow degradation of soil and water resource
Bench terraces	Korea - watershed development (1976)	US$ 2,417	Upland reclamation
Land smoothing	China - rural development (1987)	US$ 27 (manual) US$ 270 (mechanical)	None stated
Land shaping and smoothing	India - watershed development (1983)	US$ 46 (shaping) US$ 21 (smoothing)	Conserve soil and moisture
Land leveling	India - watershed development (1980)	US$ 262	Conserve soil, reduce sediment, increase infiltration, increase groundwater, increase productivity
Drains	China - area develoment (1986)	not specified	Conserve soil
Drains and waterways	India - watershed development (1983)	US$ 15 - 21	Conserve soil
Waterways	Paraguay - area development (1982)	not specified	None stated
Diversion ditches	Phillipines - agri. development (1980)	not specified	None stated
Drains	Indonesia - rural development (1979)	not specified	Conserve soil

(Continued)

On-farm soil conservation technologies, costs and expected benefits from selected World Bank Staff Appraisal Reports

Table 2.2

TECHNOLOGY	PROJECT	COST PER HA	EXPECTED BENEFITS
	VEGETATIVE TECHNOLOGIES		
Contour planting	China - area development (1986)	not specified	Conserve soil, reduce surface runoff
Contour strips and hedges, strip crops	Haiti - rural development (1983)	not specified	Increase crop productivity, increase farm family income
Contour tillage	Paraguay - area development (1982)	not specified	Increase crop productivity, increase family income, increase tax income
Contour guidelines and contour farming	Tunisia - rural development (1981)	not specified	Conserve soil, reduce sediment, arrest decline in productivity
Contour farming	Morocco - rural development (1980)	not specified	Increase crop productivity, increase farm family income
Contour hedges	Phillipines - agri. development (1980)	not specified	None stated
Plant grass and legumes	China - rural development (1987)	not specified	None stated
Mulching	Haiti - rural development (1983)	not specified	Increase crop productivity, increase farm family income
Grass strips, protection plantings	Paraguay - area development (1982)	not specified	Conserve soil
Vegetative and crop cover management	Tunisia - rural development (1981)	not specified	Conserve soil, reduce sediment, arrest decline in productivity
Cover cropping and sodding	Phillipines - agri. development (1980)	not specified	None stated

Table 2.3

Off-farm soil conservation technologies, costs and expected benefits from selected World Bank Staff Appraisal Reports

TECHNOLOGY	PROJECT	COST PER HA	EXPECTED BENEFITS
	STRUCTURAL TECHNOLOGIES		
Gully head works, gully plugs, check dams, gully shaping/planting, gabions, drop strucs.	Indonesia - soil conservation (1987)	not specified	Reduce sediment, increase reservoir life, increase life of irrigation works, increase life of electricity producing dams, silt entrapment providing arable land
Gully plugs	China - rural development (1987)	US$ 810/km of gullies	None stated
Check dams/drop strucs.	China - area development (1986)	not specified	Conserve soil
Check dams, gully plugs	Bhutan - forestry development (1984)	not specified	None stated
Check dams	Pakistan - hill farming develop. (1984)	not specified	None stated
Brush/stone check dams, wire crate dams, drop structures	India - watershed management (1983)	US$ 11/check dam US$ 316/wire dam US$ 1,053/drop struc.	Conserve soil, reduce sediment
Brush/stone check dams, wire crate dams, drop structures	India - watershed development (1983)	not specified	Conserve soil
Gully structures	Tunisia - rural development (1981)	not specified	Conserve soil, reduce sediment
Vegetative/stone check dams, wire crate dams, drop structures, debris basins, check dams	India - watershed development (1980)	US$ 357	Reduce sediment
Check dams	Morocco - rural development (1980)	US$ 330	None stated
Gully plugs	Indonesia - rural development (1979)	not specified	Conserve soil, reduce sediment
	FORESTRY		
Community forest and conservation forest	Indonesia - forestry institution and conservation (1987)	US$ 297	Reduce silt, provide wood products
Forest plantation,	Ethiopia - forestry (1986)	US$ 1,909	Conserve soil, restore fertility, improve water supply, alleviate pressure on remaining forest lands
Upgrade existing plantations,		US$ 1,707	
Community and farm forestry plantations		US$ 400	provide fuelwood and sawlogs
Farm forestry,	India - social forestry (1985)	US$ 16	Conserve soil, increase timber supply
Tree tenure planting,		US$ 3,121	
Community forest,		US$ 515	
Wasteland plantations		US$ 650	
Afforestation,	Pakistan - hill farming development (1984)	not specified	Provide fuelwood
Fuelwood plantation		not specified	
Distribute seedlings to farmers		not specified	

(Continued)

Table 2.3

Off-farm soil conservation technologies, costs and expected benefits from selected World Bank Staff Appraisal Reports

TECHNOLOGY	PROJECT	COST PER HA	EXPECTED BENEFITS
		FORESTRY	
Protection plantations on slopes > 60%	Bhutan - forestry development (1984)	not specified	none stated
Fuelwood/timber plantation, Fodder tree plantation	India - watershed management (1983)	US$ 274 (Govt.) US$ 379 (Civil) US$ 158 (Civil) US$ 12 (Private)	Conserve soil, reduce sediment, provide fuelwood,timber,fodder
Farm forestry, Reforestation	India - watershed management (1983)	US$ 115 US$ 344	Conserve soil, provide fuelwood and fodder
Community reforestation, Private reforestation, Agro-forestry plots, Strip plantings	Nepal - forestry (1983)	US$ 277 US$ 104 US$ 954 US$ 250	Conserve soil, protect rural water supply, improve soil fertility, benefit microclimate, provide timber, sawlogs, and fuelwood, stabilize roadcuts, river and canal banks
Rehabilitate existing forest plantations, Reforestation	Morocco - forestry (1982)	US$ 410 not specified	Provide pulpwood for industry and 1% of annual fuelwood needs
Village woodlots, Reforestation/plantation rehabilitation, Farm forestry, Village woodlots, Strip plantings, Sand dune plantings	India - social forestry (1982)	US$ 447 - 471 US$ 494 - 529 US$ 71 - 108 US$ 489 - 527 US$ 588 - 618 US$ 376	Conserve soil, stabilize hillsides, and sand dunes, improve soil fertility, benefit microclimate
Forest management	Paraguay - area development (1982)	US$ 15	Not stated
Species trials/pilot fuelwood plantations, Forest management	Haiti - forestry (1982)	US$ 2,775 US$ 30	Conserve soil, provide sustainable yield of wood products, offset cost imported kerosene for fuel
Fuelwood plantations	Korea - rural infrastructure (1982)	US$ 714	Conserve soil, improve soil fertility, reduce flash flooding, amenity value of forest
Silvi-pasture	Morocco - agricultural development (1981)	US$ 69	Increase forage yields, decrease livestock damage, provide timber and fuelwood
Reforestation/woodlots	Tunisia - rural development (1981)	US$ 331	Conserve soil, reduce sediment, provide fuelwood and timber
Reforestation/woodlots/ forage trees/fruit trees	Morocco - rural development (1980)	not specified	Provide wood products, forage, fruit
Reforestation, Forest protection/ fire prevention	Phillipines - watershed management (1980)	US$ 729 US$ 28	Conserve soil, limit forest fires, minimize flash floods, reduce sediment, provide wood products
Community forests, Community protection forests,	Nepal - community forestry (1980)	US$ 69 US$ 10	Conserve soil and moisture, increase soil fertility by substituting fuelwood for dung, provide wood

(Continued)

Table 2.3

Off-farm soil conservation technologies, costs and expected benefits from selected World Bank Staff Appraisal Reports

TECHNOLOGY	PROJECT	COST PER HA	EXPECTED BENEFITS
	FORESTRY		
Private plantings, Nursery/forestry development	Nepal - community forestry (1980) (continued)	US$ 0.01/Tree US$ 3,280,000 Total	products and fodder
Reforestation,	*Phillipines - agri. development (1980)*	*not specified*	*Not stated*
Forest fire prevention		not specified	
Forest protection/ fire prevention	Phillipines - watershed management (1980)	US$ 28	Conserve soil, reduce sediment, minimize flash flooding
Reforestation,	Indonesia - rural development (1979)	US$ 149	Conserve soil, reduce sediment, regulate streamflow
Silvi-pasture		US$ 262	
Village woodlots,	Thailand - agricultural development (1979)	US$ 252	Conserve soil, watershed protection, slow degradation of soil,water, and forest resource, provide poles,timber,fuelwood
Forest plantation		US$ 193	
Forestry	Bolivia - rural development (1979)	US$ 497	Conserve soil, reduce burning of forests
Fodder/fuelwood trees, forest protection, slope stabilization tree plantings, regenerate vegetation	Nepal - rural development (1976)	US$ 49	Conserve soil, reduce sediment, reduce pressure on existing forest, reduce agri. use of marginal lands
	PASTURE		
Pasture improvements	Morocco - forestry (1982)	US$ 339	Not stated
Pasture establishment	Tunisia - rural development (1981)	US$ 90	Conserve soil, reduce sediment
Pasture establishment	Morocco - rural development (1980)	US$ 330	Increase farmer income

3. ECONOMIC ANALYSIS OF SOIL CONSERVATION TECHNOLOGIES

William B. Magrath

Comparing recent vegetative techniques for soil and water conservation using vetiver grass (Vetiveria zizanioides) and the standard practice of employing earthen bunds, this chapter explores the economic aspects of these alternative techniques. In addition to indicating the relative economic advantages of a conservation system based on vetiver grass, the exercise also helps set the agenda for the collection of additional physical and economic data. The paper consists of four parts: discussion of conceptual issues in the economics of soil conservation investments and the model used to implement this analysis; description of data used; discussion of the results of the basic analysis and, due to its speculative nature, modeling of a range of plausible combinations of parameters; and conclusions and recommendations for further research and development.

CONCEPTUAL ISSUES

It is widely accepted that erosion lowers agricultural productivity (see Chapter 2) and that soil conservation raises and preserves it. However, there is little agreement on exactly how productivity is related to erosion or on the quantitative impact of erosion on yields. In part, the uncertainty arises from the difficulty of defining fertility, as well as of conducting controlled experiments to identify and measure erosion-related yield changes. Erosion involves changes in soil structure that influence root growth and water availability and in the availability and relative concentration of plant nutrients. Soil conservation practices minimize the occurrence of these changes and often induce other reactions that directly improve conditions for crop growth, such as improved response to fertilizer or a delayed wilting point.

Nor is there widespread agreement on how erosion influences the economics of agricultural production. A decline in the underlying productivity of the resource base does, presumably, lower the profitability of farming but not necessarily in a simple or direct way. Erosion-induced losses involve declines in both current and future incomes, but their effects can be masked and at least partially overcome by the use of different or additional inputs. And, like all aspects of agricultural production, they interact with forces of nature largely or totally beyond farmers' control. Similarly, conservation measures often have hidden costs and may generate benefits only over long periods of time.

MODELING THE IMPACT OF EROSION AND SOIL CONSERVATION

Four Types of Data

In view of these difficulties, the most practical approach to developing an understanding of the potential role of soil conservation measures in a farming system is to employ an engineering economics approach: the impacts of erosion and conservation are applied to an economic model of crop production and the value of conservation is calculated on the basis of a with-without comparison. The basic data required for the analysis are crop production budgets, an understanding of local cropping patterns, evidence on the effects of erosion on yields, and evidence of the impact of specific soil conservation measures on crop yield.

The model developed for this analysis consists of two series of linked crop budgets that represent the consequences of erosion, on the one hand, and conservation, on the other, over a 30-year horizon. Cost and revenue items included in the budgets are shown in Table 3.1 and include all purchased and farmer-supplied inputs which can be valued at market or economic prices. Provision is made for outputs of crops and by-products as well as output (if any) produced from soil conservation practices.

Assumptions

The case being developed assumes that erosion affects farm income by reducing yields and costs, directly in the case of those which are harvest-related and less directly by making it unattractive for the farmer to add inputs such as the seed of improved varieties or to apply optimal amounts of fertilizer. Conservation treatment is assumed to change costs--by reducing cultivation costs and permitting cultivation and planting to be timely and by increasing costs related to harvesting a higher yield. Direct conservation costs are entered as separate items where applicable. Table 3.1 summarizes the structure of the crop budgets and the assumed impacts of erosion and conservation. These are restrictive assumptions and do not fully account for the range of impacts and cost-averting opportunities available to farmers. They do, however, probably account for the most direct impacts of erosion, at least in the early years of the planning horizon. The model makes provisions for two crops per year or the rotation of two crops.

Output

The basic outputs of the model are projections of the flow of net farm income (returns to land and management) without and with the project. The incremental flow can be cast in present value at any interest rate or summarized in an internal rate of return. A variety of extensions are possible, among them: evaluating the impact of cost and benefit sharing, alternative planning horizons and, in the case of vetiver grass, assessing the incentive to abandon soil conservation for oil-root harvesting.

There is considerable question as to the magnitude of the physical dimensions of the problem, and important parameters will vary from case to case. Therefore, results can be presented to show the impact of changes in key assumptions or the range or combination of parameters that favor one conclusion or another.

Table 3.1: IMPACT OF EROSION AND CONSERVATION ON THE MODEL CROP BUDGET

Item	Impact of Erosion	Impact of Conservation
Costs		
Seed	0	These inputs decrease in proportion to land taken out of production
Fertilizer	0	
Manure	0	
Bullock Rental	0	
Pesticides	0	
Labor		
Land Preparation	0	
Fertilizing	0	
Cultivating	0	
Harvesting	Decrease in proportion to productivity loss	Increase in proportion to productivity increase
Revenues		
Harvest (Product and By-Product)	Decrease in proportion to productivity loss	Increase in proportion to productivity; decrease in proportion to area taken out of production

DATA

Crop Budgets and Two Conservation Techniques

The model is used to compare the relative economics of the proposed vetiver grass-based technology with the more conventional approach of constructing earthen bunds. To the extent possible, data were assembled to reflect conditions on Alfisols in the semi-arid zones of India. Cost, yield and input data for the initial budgets are based on estimates provided by World Bank field staff, which in turn are based on research by state agricultural universities. The budget represents a rotation of sorghum intercropped with red gram (*Cajanus cajan*) and castor (*Ricinus communis*). Initial crop budgets are given in Annex 3.1.

The principles behind the two conservation techniques considered here are similar.1/ By interrupting the length of the field, both techniques are intended to slow movement of water down the slope, which reduces the movement of soil particles and allows for greater absorption of moisture into the soil and hence increased yields. Vetiver grass hedges are said to be more effective in slowing water and eventually form terraces as soil accumulates along their upslope side.2/ Earthen bunds promote some additional absorption of water but are also designed to channel surplus water into drains and waterways. Loss of water from the root zone via waterways probably accounts for the smaller increases in yield obtained under bund technology. Inadequate provision for disposal of excess water can cause failure of bunds during intense storms and damage to crops in the downslope vicinity. Even so, farmers are reluctant to allocate scarce land for water disposal. Table 3.2 summarizes data on the impact of selected soil and moisture conservation technologies on soil loss and runoff.

Table 3.2: IMPACT OF SOIL AND MOISTURE CONSERVATION TECHNOLOGIES ON EROSION AND RUNOFF

Technology	Erosion or Sedimentation --- (% Reduction)	Runoff ----	Location	Reference
Contour Cultivation	10-50		USA	Wischmeier and Smith (1978)
Contour Cultivation	30-60	10-70	India	Gupta, *et al.* (1971)
		25	India	Dhruva Narayana (1986)
Grass Strips	93		Indonesia	Abujamin, *et al.* (1985)
Grass Strips	40-60		USA	Carter (1983)
Contour Bunds	43	-70/a	Thailand	Sheng *et al.* (1981)
Contour Bunds	62		Sierra Leone	Millington (1984)

/a Runoff increased 70%.

1/ Data reported in this section on the effects of conservation technology are largely based on literature reviewed in Chapter 2 and Tejwani (1989).

2/ This effect has been noted with other grass used in soil conservation work in India. See Sud *et al.*, 1975, as discussed by Tejwani (1989).

Erosion and Productivity Decline

Despite scientific uncertainty over the impact of erosion on productivity and crop yields, as noted, data from a variety of experiments provide some indication of the magnitude of productivity declines. Experiments on Alfisols in Africa showed that mechanical removal of the top 10 cm of soil resulted in yield declines of 73% for maize. Similar experiments at Dehra Dun, India showed more modest impacts (Table 3.3). Actual levels of erosion on cropland, as reported by El-Swaify, et al. (1984), which appear conservative, are only a fraction of the amounts experimentally removed. Results reported by Lal (1987, and personal communication) argue strongly that the damage from naturally occurring erosion is much more severe than that produced in artificial experiments, largely because natural erosion tends to remove preferentially the most productive constituents of the soil. In this analysis, data from Dehra Dun were used to represent the without-conservation case. These are highly conservative and almost certainly serve to understate both actual damage from erosion and benefits from conservation.

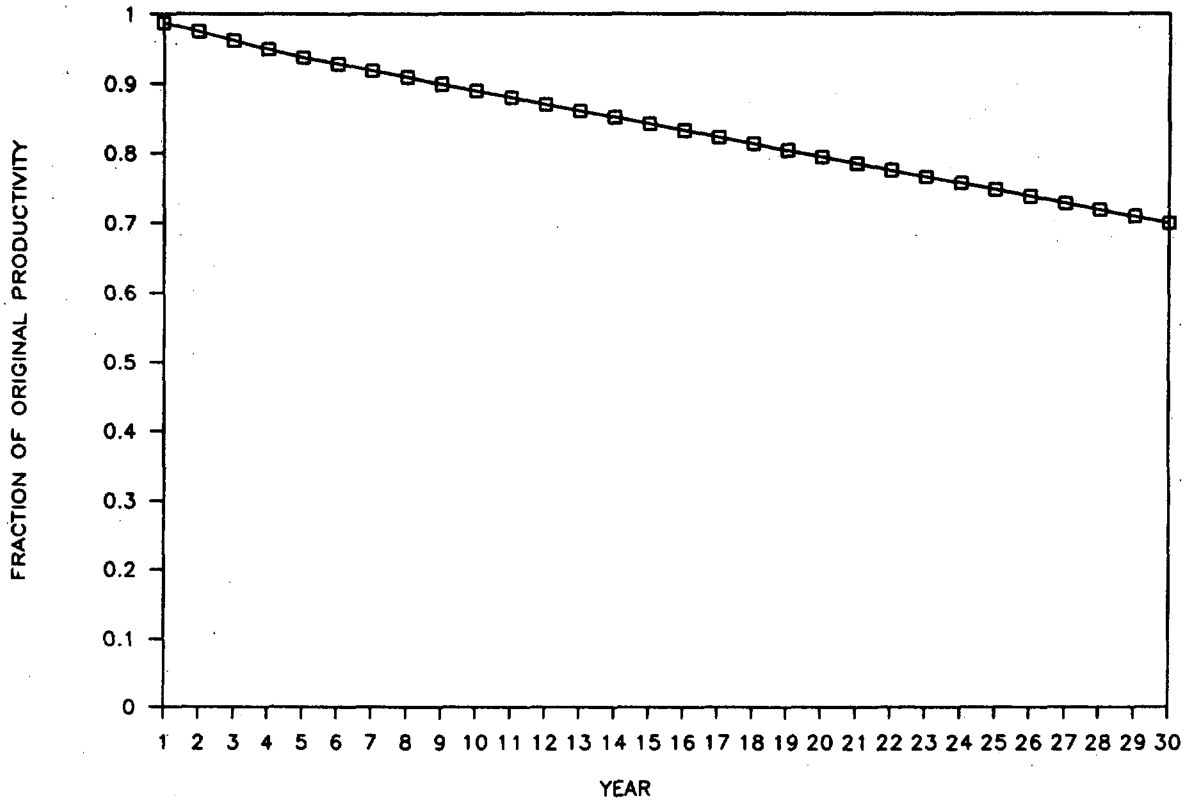
Table 3.3: EFFECT OF SOIL REMOVAL ON MAIZE YIELDS ON ALFISOLS

Depth of Soil Removal (cm)	Nigeria	India
	(% Decrease in Yield)	
5.0	30.5	12.5
10.0	73.6	25.1
15.0		33.3
22.5	93.5	39.1
30.0		45.0

Source: Lal (1987) for Nigeria; Hegde (1988) for India.

El-Swaify, et al. (1984) estimate that Alfisols on relatively mild topographies at ICRISAT (Hyderabad, India) have a mean annual erosion hazard exceeding 40 tons/ha or approximately 5 mm. Applied to the data from Dehra Dun, India, this implies yield declines of 1.25%/year for five years, decreasing to 0.95%/year thereafter (see Figure 3.1). In all likelihood, yield declines would become more severe in the absence of soil conservation as sheet erosion gives way to rill erosion leading to larger soil losses. On actual farmers' fields, it could be expected that some effort would be devoted to soil conservation but, at this point, there are no data to indicate what adjustments might be made.

Figure 3.1 EFFECT OF EROSION ON PRODUCTIVITY



Soil Conservation Treatment and Crop Yields

Vetiver Grass. The effects of alternative soil conservation technologies on crop yields have been studied in a number of experiments in India and elsewhere. Despite the apparent simplicity of the questions being asked, there are as yet no definitive answers. Experimental designs are weak and researchers have often focused on questions that are peripheral to impact on yields. Table 3.4 summarizes available data on the impact of alternative soil conservation technologies. In the case of soil and moisture conservation using vetiver grass hedges, the quality of the crop cutting experiments that have been conducted is questionable. There are, however, other data from trials with other grass barriers that provide some indication of likely benefits. In addition, it is likely that a significant proportion of the yield increase attributed to the vetiver grass system results from the accompanying practice of contour cultivation.3/ Using Greenfield (1987) as a base case, a 50% yield increase from vetiver grass technology has been assumed.

Table 3.4: IMPACT OF SELECTED SOIL AND MOISTURE CONSERVATION TECHNIQUES

Technique Employed	Impact on Crop Yield (% increase)	Crop	Location	Reference
Contour Cultivation	35	Sorghum	India	Dhruva Narayana (1986)
"	12	Sugarcane	Taiwan	Liao (1972)
"	60	Cotton	USA	Unger (1984)
"	6	Potatoes	India	"
"	46	Maize	India	"
"	25	Sorghum	Kanpur, India	Bhatia and Chaudhary*
"	15	Barley	Kanpur, India	"
Sloping Agricultural Land Technology	107	Maize	Philippines	Watson and Laquihon (n.d.)
Earthen Bunds	10	Maize	Chandigarh, India	Sud, et al.*
"	35	Maize	Uttar Pradesh, India	Khan*
"	18	Setaria	Tamil Nadu, India	Kanitkar*
"	11	Cotton	Tamil Nadu, India	"
"	17	Sorghum	Tamil Nadu, India	"
"	24.5	Sorghum	Maharastra, India	Tamhane*
"	25.2	Pearl Millet	Maharastra, India	"
"	35.6	Sorghum	Tamil Nadu, India	"
"	25.4	Pearl Millet	Tamil Nadu, India	"
"	21.4	Wheat	Punjab, India	"
	15	Grain	Punjab, India	"
"	19.7	Maize	Punjab, India	"
"	13.9	Pearl Millet	Punjab, India	"

* In Tejwani (1989).

Constructing Bunds. Similarly, experiments with bunding treatments provide only limited evidence of their efficacy. It is even possible that the standard practice of field bunding may have no positive impact on yields. However, in the calculations discussed, as a base case using Tejwani (1989), it has been assumed that bunds will increase yields 30% over the without-project case. For both bunding and vetiver grass treatments, the percentage

3/ Because the vetiver grass system essentially forces the adoption of contour cultivation, no effort has been made to separate these effects.

of yield increase has also been treated as a parameter and results have been presented for yield increases ranging from 0% to 140%.4/

Comparative Cost of Alternative Treatments

Investment costs for vetiver grass and bund treatments have been taken from estimates made by World Bank staff in preparing the Integrated Watershed Development Project--Plains (1989) in India. Costs for vetiver grass include labor in man-days (Md), bullock power (Bprs), fertilizer, and contingencies. Planting material is valued at full cost, including transportation, 25% contingencies, plus a 50% markup. Costs are detailed in Tables 3.5 and 3.6. These cost estimates are now considered generous. If vetiver grass technology is widely adapted, the cost of planting material will eventually fall to be only the labor cost associated with harvesting, and planting slips from existing hedges.

For the purposes of costing, a hectare of cropland is assumed to require 250 linear meters of contour hedge. At a width of 0.5 m, the hedge would occupy 125 sq m.5/ In addition to initial planting costs, allowance has been made for hedge maintenance in the second and third years, after which it is assumed that hedges would be fully established.

Costs for bunds are intended to reflect the same parameters. Costs are based on earth work on light soils and assume a bund cross-sectional area of 0.5 sq m, which appears to be the current standard. Land estimated to be taken out of cultivation by bunds consists of the width of the bund (1.7 m) and berm (0.3 m) plus one half of the borrow pit (1.7 m) and a provision for drains and waterways (0.3 m). These costs are detailed in Table 3.7, and total Rs 863/ha.

The cost of grassing and maintaining bunds has been excluded from the analysis. Poor maintenance is one of the main causes of bund failure and necessitates their frequent replacement; the base case assumption is that bunds require replacement every five years.

The use of vetiver grass strips as a source of fodder has been observed in southern India, but there are currently no data on its value as fodder or on sustainable yield. Fodder yields have not been incorporated into the benefit flows but this could easily be done as additional data become available.6/

4/ There is considerable doubt as to whether these yield increases can actually be reached. Percentage of yield increases, of course, depends on the base, which in the case of the semi-arid zone, can be highly variable. It is clear that yield increase due to moisture conservation can, in percentage terms, be very high in drought years, but in good years that the same absolute increase would be small in percentage terms.

5/ A square, one-hectare plot with a slope of 2.5%, would require approximately this much material.

6/ Potentially significant, especially regarding adoption, given the frequent importance of livestock to small farmers.

Table 3.5: COSTS OF PRODUCING VETIVER SLIPS IN A NURSERY

Cost items	Units	Cost/ Units (Rupees)	Per Ha No. of Units	Per Ha Total Costs (Rupees)
Labor and Machinery				
Plowing	Bprs	45	10	450
Breaking Clods	Md	12	50	600
Spreading Manure	Md	12	10	120
Forming Ridges & Furrows	Bprs	45	5	225
Transport Planting Material	Md	12	10	120
Treatment Dressings	Md	12	15	180
Pruning and Sorting	Md	12	20	240
Planting of Slips	Md	12	75	900
Weeding	Bprs	45	15	675
Weeding & Topping	Md	12	150	1,800
Uprooting Clumps	Md	12	25	300
Subtotal				5,610
Inputs				
Planting Material	'000	10	62.5	625
Manure	Ton	50	25	1,250
Diammonium Phosphate (DAP)	Kg	3.5	250	875
Urea	Kg	2.6	375	975
Atrazine (ai)	Kg	167	1.5	250
BHC (10%)	Kg	2	25	50
Irrigation	Total			250
Subtotal				4,275
Base Costs				9,885
Contingencies, Losses, etc.	%	25		2,471
Total Costs				12,356
Outputs	slips* '000		1,875	
Average Cost per Slip*	Paisa			0.66
Sales Price**	Paisa			1.00

* Basis for costing purposes is 30 slips/clump.
** Assumes 50% markup.

Bprs = bullock pair-days.
Md = labor in man-days.

Table 3.6: COST OF ESTABLISHING VETIVER GRASS HEDGES (1989 COSTS)

	Units	Unit Cost (Rs)	No. of Units Yr 1	No. of Units Yr 2	No. of Units Yr 3	Yr of Establishment Yr 1	Yr of Establishment Yr 2	Yr of Establishment Yr 3	Total Cost (Rs)
LABOR/INPUTS									
Labor									
Opening Furrows /a	Bprs	45	0.5			22.5	0.0	0.0	22.5
Forming Bunds	Md	12	5			60.0	0.0	0.0	60.0
Pruning, separating, loading & unloading	Md	12	2	0.4		24.0	4.8	0.0	28.8
Planting & dressing	Md	12	4	0.8		48.0	9.6	0.0	57.6
Weeding	Md	12	2			24.0	0.0	0.0	24.0
Subtotal						178.5	14.4	0.0	192.9
Inputs									
Purchase Cost of Slips /b	'000	10	40	8		400.0	80.0	0.0	480.0
Transport of Slips /c	%		10			40.0	0.0	0.0	40.0
DAP	Kg	3.5	20			70.0	0.0	0.0	70.0
Urea (3 split dressings)	Kg	2.5	60			150.0	0.0	0.0	150.0
BHC (10%)	Kg	2	40	4		80.0	8.0	0.0	88.0
Contingencies	%		10	10		74.0	8.8	0.0	82.8
Subtotal						814.0	96.8	0.0	910.8
TOTAL COST						992.5	111.2	0.0	1,103.7
Rounded Cost						990	110		1,100
TREATMENT COST PER HECTARE /d									
Labor						44.6	3.6	0.0	48.2
Inputs						203.5	24.2	0.0	227.7
TOTAL COST						248.1	27.8	0.0	275.9
Rounded Cost						250	25		275
PROJECT COST PER HECTARE									
Labor	% of above		100	100		44.6	3.6	0.0	48.2
Inputs	% of above		100	100		203.5	24.2	0.0	227.7
TOTAL COST						248.1	27.8	0.0	275.9
Rounded Cost						250	25		275

/a Costs entered as bullock pair days.
/b See nursery costs, Table 3.5.
/c From nursery to field site.
/d Based on 40 m horizontal interval, equivalent to 250 m per hectare (1 m vertical interval).

Table 3.7: COST OF CONSTRUCTING EARTHEN BUNDS (1989 COSTS)

	Unit	Slope (%) 1	2.5	4
Construction Costs				
Average bund length	per ha	100	250	400
Average earth works	sq m/ha	50	125	200
Field bunding costs	Rs	300	750	1,200
Associated Costs*	Rs	45	113	180
Cost per gross hectare	Rs	345	863	1,380
Loss of Arable Land				
Affected width	sq m of bund	4.00	4.00	4.00
Adjusted width	sq m of bund	3.00	3.00	3.00
Area affected	sq m	400	1,000	1,600
Net loss	sq m	300	750	1,200
Proportion affected	%	4.0	10.0	16.0
Net Loss	%	3.0	7.5	12.0
Cost per net hectare	Rs	356	932	1,368

* For associated diversion channels and waterways--15% of direct costs.

Assumptions: Bunds established at one meter vertical interval, bund cross-section equals 0.5 sq m and labor rate is equal to Rs 6/sq m for earth work.

RESULTS

Comparative Viability

The results of calculations are summarized in Table 3.8, and illustrated in Figures 3.2 and 3.3 for vetiver grass and earthen bunds, respectively. Using the base case assumptions, both systems appear economically viable. However, vetiver grass with a net present value (NPV) of Rs 8,543/ha (IRR=95%) is clearly superior to bunding (NPV=Rs 3,436/ha, IRR=28%).

The dominance of the vetiver grass technology, of course, is essentially complete for any plausible combination of parameters, mainly due to the cost advantage of vetiver grass. Figure 3.4 illustrates the impact of alternative productivity assumptions. Even if it is assumed that the impact of vetiver is only to prevent erosion, a yield increase from bunds of nearly 40% (higher than the optimistic base-case assumption) would be required before bunding would become the more desirable option.

Figure 3.2 DISCOUNTED IMPACT OF VETIVER GRASS

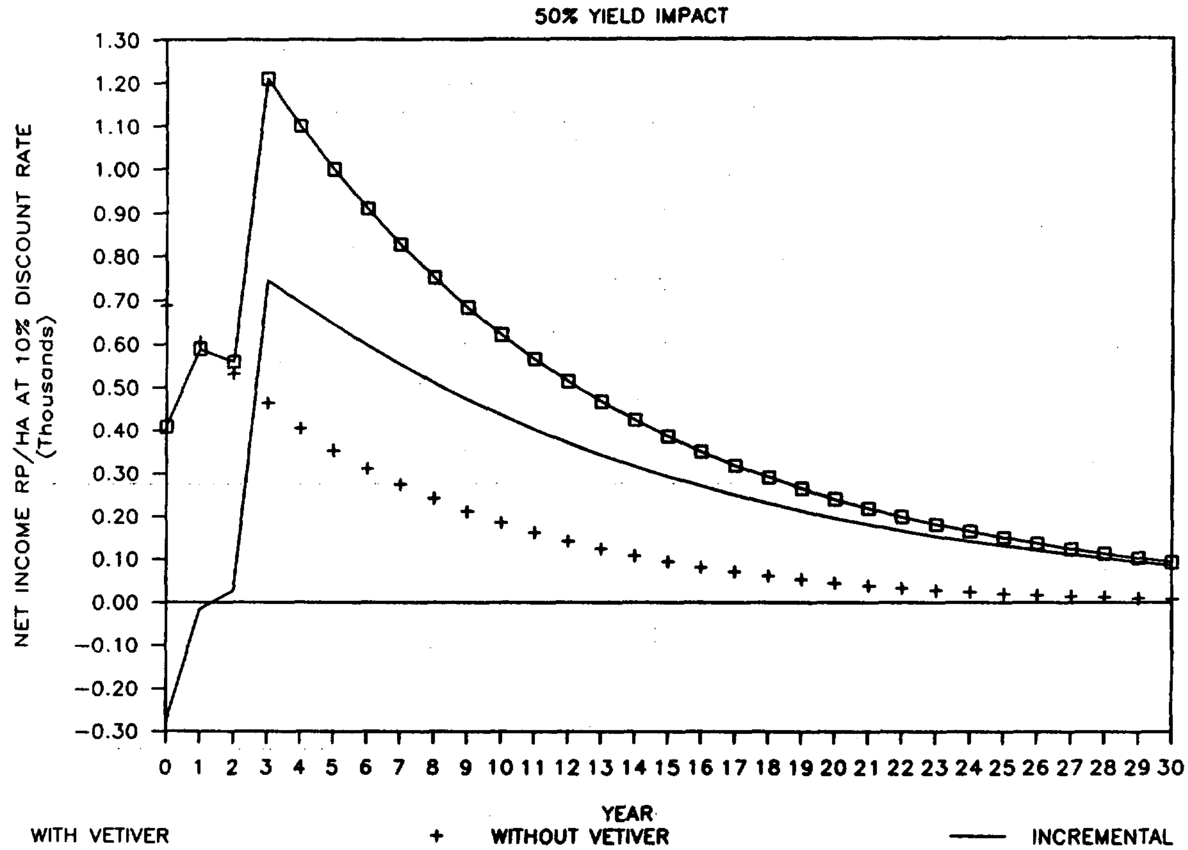


Figure 3.3 DISCOUNTED IMPACT OF FIELD BUNDS

30% YIELD IMPACT

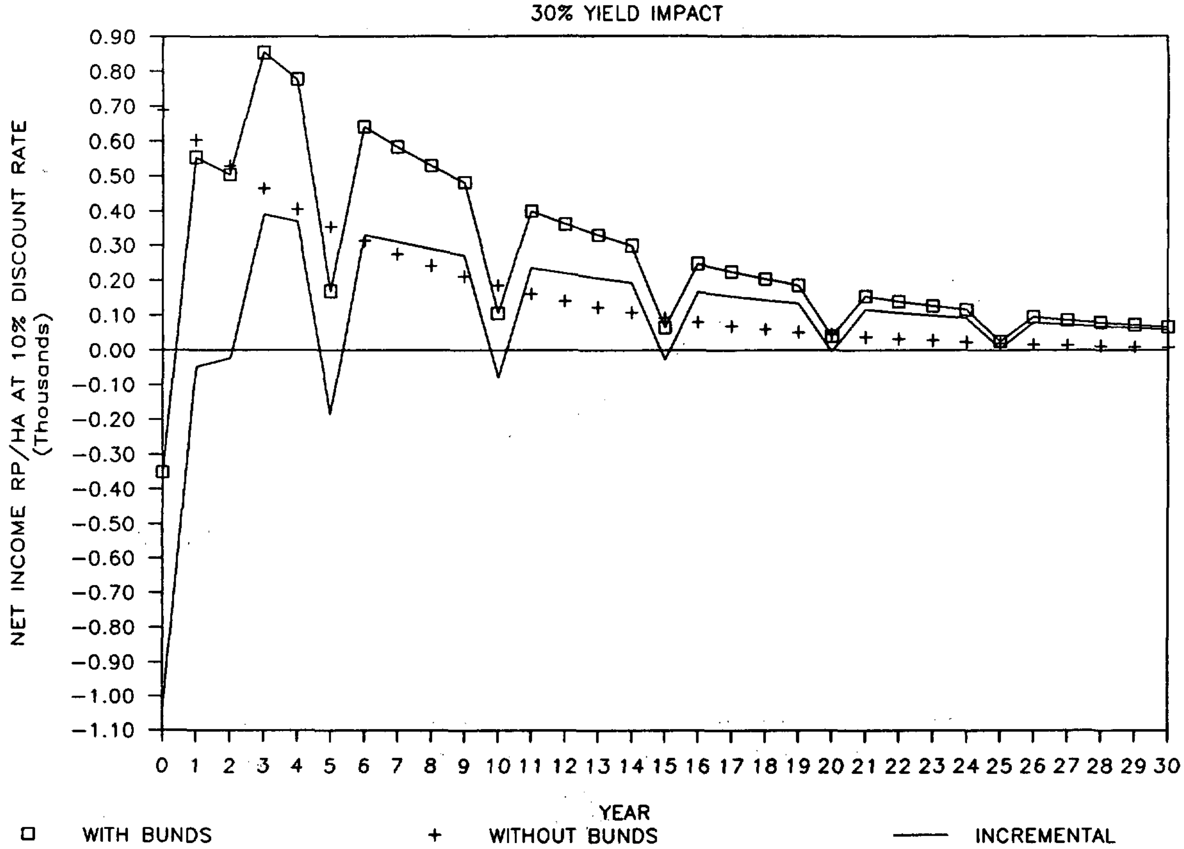


Figure 3.4 IMPACT OF ALTERNATIVE PRODUCTIVITY

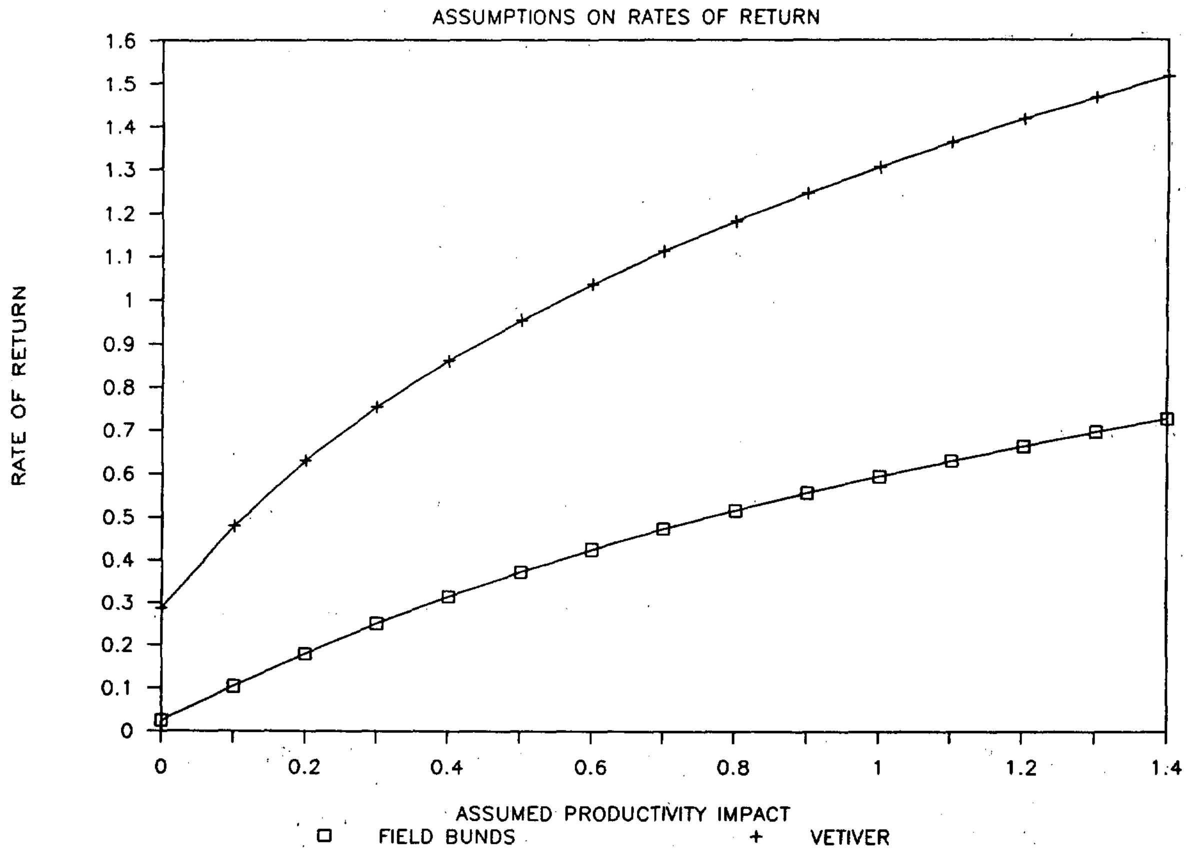


Table 3.8: RESULTS OF ECONOMIC ANALYSIS OF ALTERNATIVE SOIL CONSERVATION TECHNOLOGIES

Technology	Yield Increase (%)	Erosion Loss Prevented (%)	NPV /a (Rs/ha)	ERR (%)
Vetiver Grass	50%	0.95-1.25	8,543	95%
Earthen Bunds	35%	0.95-1.25	3,436	28%
Vetiver Grass	50%	0	6,765	87%
Earthen Bunds	35%	0	1,659	22%
Earthen Bunds (no replacement required)	35%	0.95-1.25	4,719	34%

/a At 10% discount rate.

If damage from erosion is ignored, the impact of a 50% yield increase from the vetiver grass treatment still shows a return of 87%. On the other hand, under the same assumption, a 35% yield benefit from bunding returns only 22%. Since, in fact, neither conservation technology will completely stop erosion, the actual rate of return would lie somewhere between these two estimates.

The assumption that field bunds need to be replaced every five years has relatively minor impact on the profitability of the technology. From the base-case rate of return of 28% with replacement, the rate of return rises only 6% to 34% if bunds are assumed to last the 30 years. The present value of future costs of replacement are so small as to have little impact at that high an implicit rate of discount. At a more modest discount rate of 10%, the impact and the present value rise from Rs 3,436/ha to Rs 4,719/ha. Nonetheless, even if bunds are maintenance-free, vetiver grass technology is more cost-effective.

Land Tenure Issues

Regarding land tenure issues in watershed development, two issues are relevant here: the importance of farmers' time horizon and the role of cost and benefit distribution as incentives for adoption of soil conservation (Chapter 6). Presumably, cultivators with less secure tenure will be more reluctant to invest in conservation techniques because of the longer time required to reap benefits from their investment. Conceptually, of course, this implies a high rate of time preference and can be expressed as a high discount rate. Alternatively, and perhaps more intuitively, this insecurity can be modeled by imposing a shorter time horizon. Figure 3.5 illustrates the rate of return to the two technologies as a function of planning horizon. For any planning horizon long enough to motivate adoption of either technology (>3 years), vetiver grass technology will yield higher returns.

Benefit and Cost Distribution

In addition, the impact of benefit and cost distribution on the incentive to adopt is relevant to government cost-sharing policies. From the point of view of land tenure, assuming that a small share of benefits accrues to the cultivator is comparable to assuming that profits from conservation are fully capitalized into land rent. Assuming that costs are shared between cultivator and landlord is conceptually the same as some form of government cost-sharing. To illustrate these issues, the basic model was extended to separate the costs and benefits of conservation in order to analyze alternative combinations of cost/benefit sharing. The internal rate of return for various combinations was calculated and "iso-return" curves (the locus of points representing equal rates of return) are plotted in Figure 3.6. Figure 3.6 can be used to distinguish the combinations that would lead a profit-oriented cultivator to adopt from those combinations which would be considered most attractive. The lower curve represents the vetiver grass technology and a 40% rate of discount. It essentially implies that cultivators operating under a discount rate as high as 40% would be willing to adopt vetiver grass technology if they expect to receive only 20% of the benefit, even if they bore the entire cost. The higher curve attempts to represent the decision calculus of a more patient cultivator (discount rate = 20%) considering earthen bunds. The higher curve indicates more stringent requirements and the greater slope more sensitivity to cost/benefit sharing. In order to adopt bunds, a farmer would require 30% of the benefits before shouldering 50% of the costs and would require nearly 70% of benefits before investing the entire cost of bunding.7/

Concern about Vetiver Root Harvesting

One aspect of vetiver grass technology that raises concern is the occasional occurrence of a lucrative cash market for vetiver grass root (see Annex 3.2). The harvesting of vetiver grass lines that are intended for soil conservation purposes can have quite the opposite effect. Uprooting vetiver grass can create deep furrows that are especially subject to erosion. This has been observed in areas of commercial vetiver grass production in Indonesia, as well as in a soil conservation project in Haiti. A farmer's decision to pull out the soil conservation lines in this fashion would presumably be related to his failure to understand their purpose, special needs for cash that the family might have, or a host of other considerations. More generally, however, even with full knowledge about consequences, combinations of prices and discount rates do exist that would lead a profit-maximizing farmer to adopt such an environmentally harmful practice.

7/ The choice of different discount rates appears awkward but is due to the fact that at a 20% discount rate, vetiver grass technology is accepted at essentially any combination, while at the 40% discount rate earthern bunds are refused at all but the most generous combinations. The curves shown are relatively favorable to bund and unfavorable to vetiver grass technologies.

Figure 3.5 TIME HORIZON AND CONSERVATION

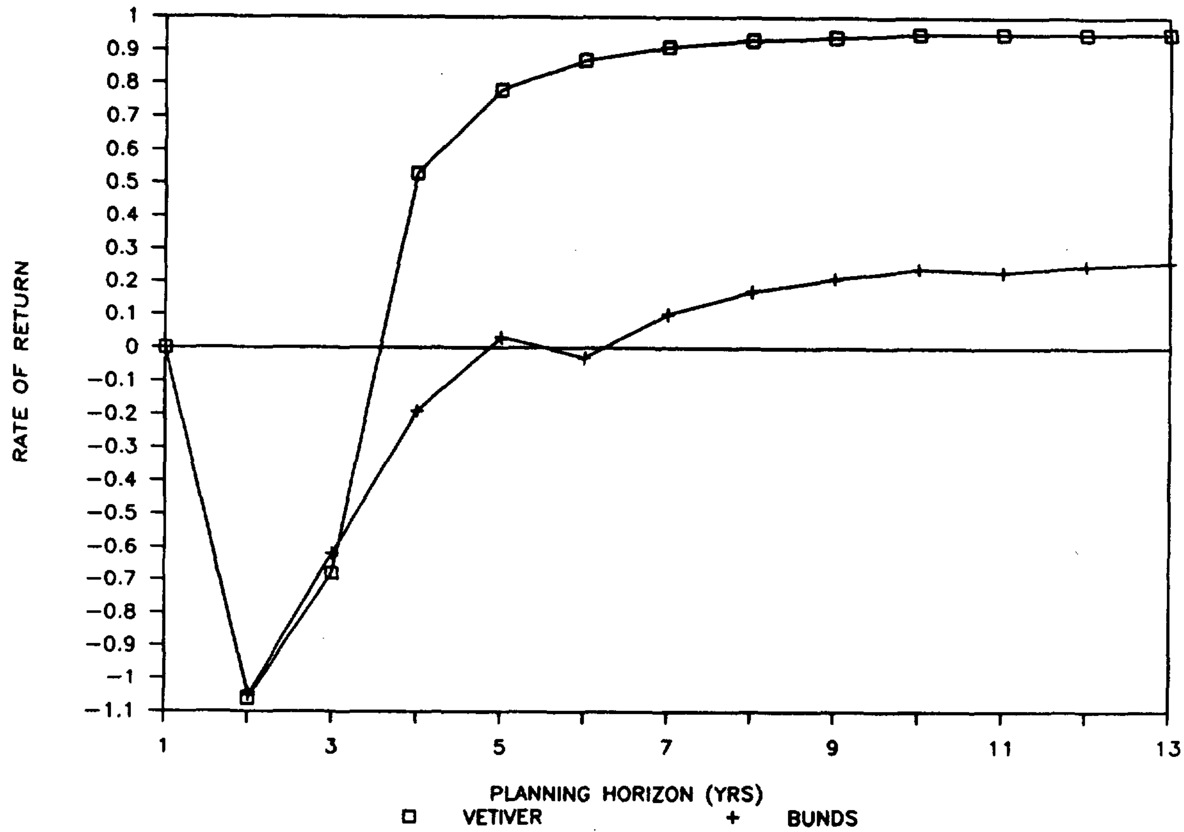
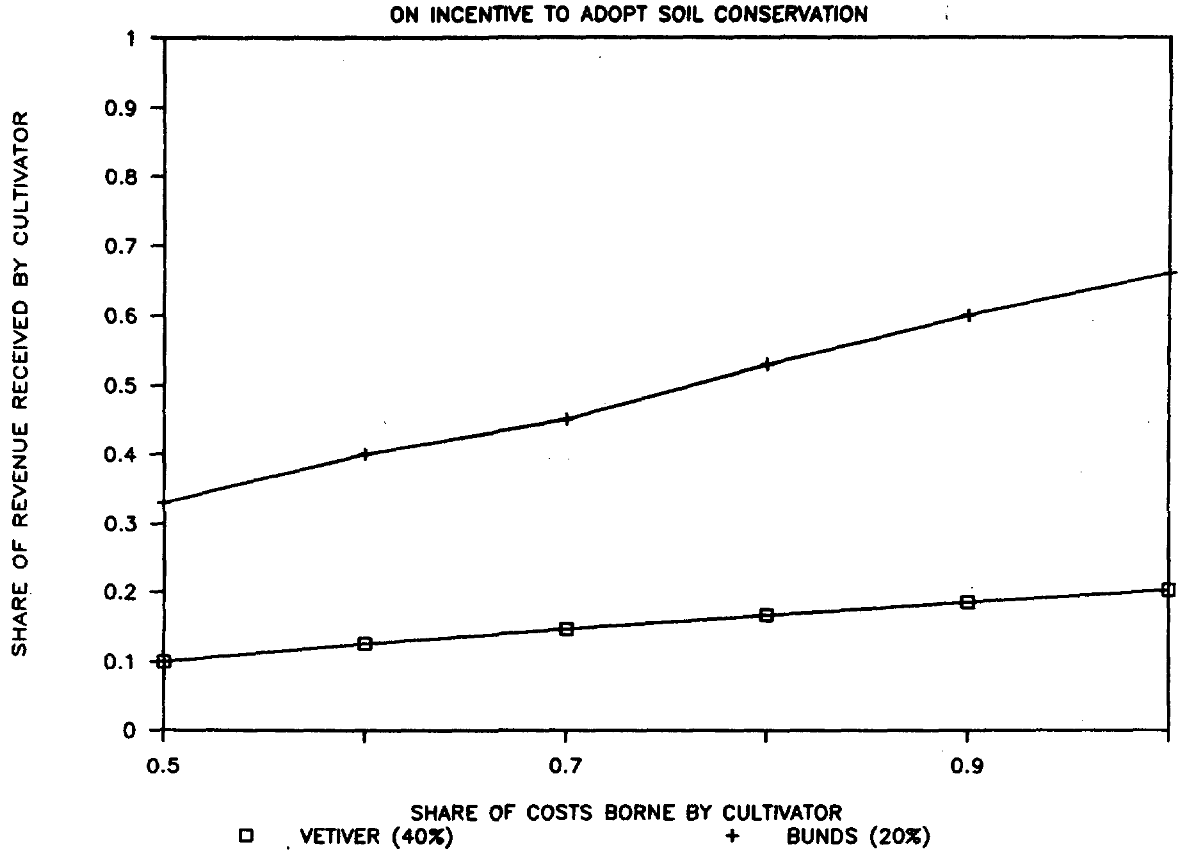


Figure 3.6 EFFECT OF COST AND BENEFIT DISTRIBUTION



This problem can be modeled by defining the keeping of vetiver grass lines in the ground as the without-project situation and harvesting for oil production as the project. There are three key parameters that need to be estimated for this calculation--the cost of harvest, the value of the root and the impact of harvest on erosion and yield. Harvest cost and root price have been treated as parameters and solely for the purpose of calculation, it has been assumed that root harvest will lead to an erosion rate of approximately 2 cm/year, leading to productivity declines of 5% per year. The range for harvesting cost is suggested by the costs given in Table 3.4 for nursery operation but are expected to be higher for oil production because the roots will be larger and deeper. The range for root price is based on root prices reported in Indonesia (see Annex 3.2).

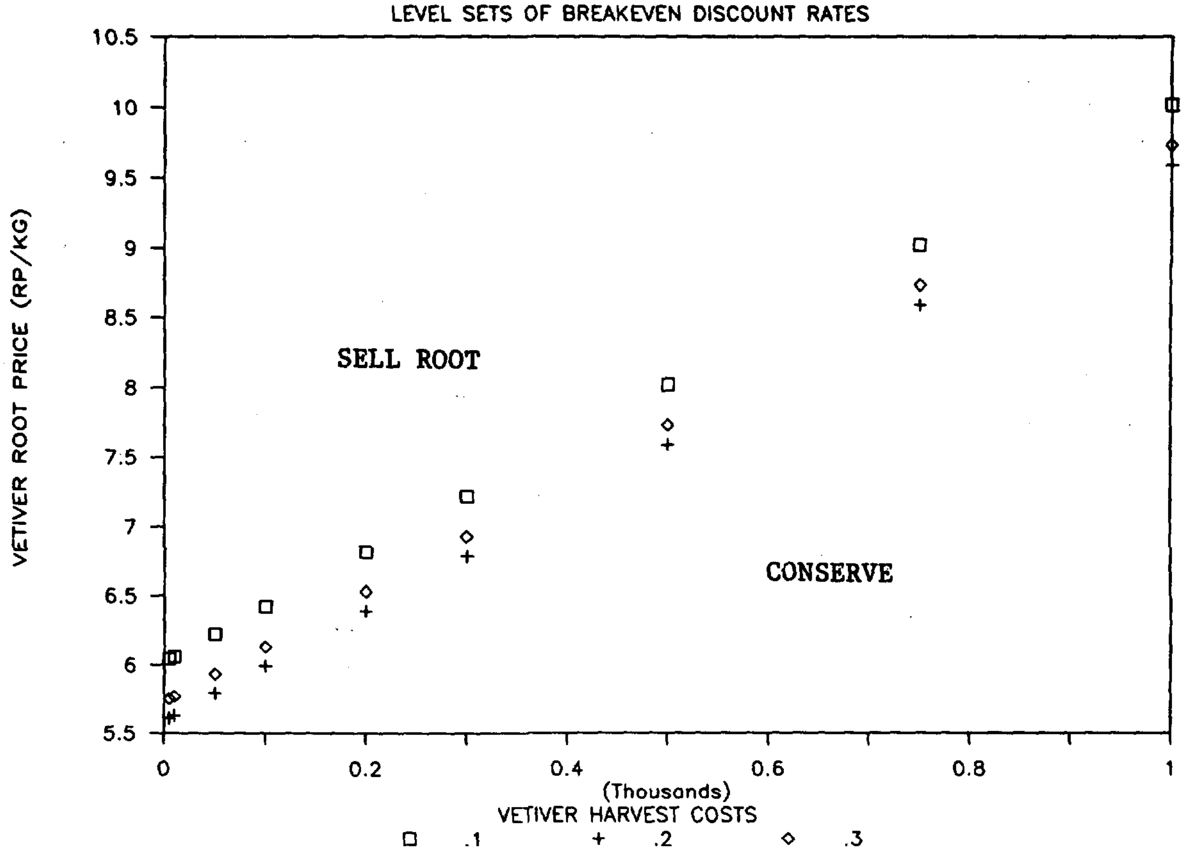
Figure 3.7 illustrates the results of this analysis showing the combinations of harvest cost and root price that will lead to either root harvest or conservation. The curves shown represent a discount rate of 10, 20 and 30%, respectively, and illustrate that results are quite insensitive to choice of discount rate. These results, together with experience in Haiti and Indonesia, suggest that the combination of parameters leading to abuse of vetiver grass is quite plausible and is an issue requiring attention during project preparation. It is important to realize that the model is severely limited in this respect and that harvesting vetiver grass roots will drastically alter the structure of the farm management problem in ways not envisioned here. Moreover, the world (let alone local) market for vetiver oil is presumably not perfectly elastic, and it is reasonable to think that appropriate measures could be designed to depress returns to oil production. Nevertheless this is one issue that seems to require additional consideration.

CONCLUSIONS

Value of Structured Economic Analysis

The foregoing discussion illustrates that despite obvious gaps in knowledge, a structured analysis of soil conservation investments can generate useful insights, and perhaps most usefully, can highlight specific issues on which additional research is necessary. Most notably, these are not questions of economic methodology. Rather they are largely technical questions about the impact of erosion and conservation on yields. In addition, there is the obvious need for more reliable cost data on crop production and a better understanding, both technical and economic, of farmers' responses to erosion. Economic analysis is not merely a device for project justification. Rather, it should be seen as a tool for decision-making and for understanding the resource allocation problems facing farmers and project planners. In this context, an important role of economic analysis is to identify and articulate areas of uncertainty and potential trade-offs. Consequently, an important aspect of this analysis is the manner in which uncertain results are presented.

Figure 3.7 TRADE-OFF OF CONSERVATION AND OIL SALES



Better Data Needed to Verify Assumptions

As a final point, the primary purpose of this analysis is normative: to assess whether a particular technology is profitable and should be promoted to farmers. The more positive issue, whether farmers will adopt a technology, depends on whether the assumptions on prices (including discount rates) and quantities are essentially correct and on the extent to which the assumption of present-value maximization holds true. The *ex ante* benefit/cost literature on soil conservation generally appears to have been overly optimistic about benefits and costs, has often failed to adequately address the subsidy component of conservation promotion schemes, seldom accounts for maintenance requirements and most importantly seems to be at odds with evidence on adoption rates. More careful attention to the dynamics of the adoption of soil conservation techniques is clearly needed.

DEVELOPMENT OF HECTARE CROP BUDGETS FOR TECHNOLOGY ANALYSIS

	Units	Red Gram Qty.	Red Gram Unit cost (Rs)	Red Gram Total cost (Rs)	Castor Qty.	Castor Unit cost (Rs)	Castor Total cost (Rs)
Crop Expenses							
Seeds							
Main crop	kg	10	1.5	15	25	3	75
Intercrop	kg	1	6	6			
Fertilizer							
Urea	kg	20	3	60	0	3	0
Phosphorus	kg	20	4	80	0	4	0
Potash	kg			0			0
Manure	ton	4	80	320	4	80	320
Bullock rental	Bprs	8	50	400	8	50	400
Pesticides	kg			0			0
Subtotal inputs				1,225			1,200
Labor							
Land preparation	Md	7	15	105	7	15	105
Fertilizing	Md	2	15	30	2	15	30
Cultivation	Md	5	15	75	5	15	75
Harvesting	Md	13	15	195	18	15	270
Threshing	Md	0	15	0	0	15	0
Subtotal labor	Md	27	15	405	32	15	480
Total Crop Expenses				1,660			1,680
Conservation Expenses							
Labor				0			0
Inputs				0			0
Total Conservation Expenses				0			0
Revenues							
Crop harvest							
Main product	kg	500	2	1,000	600	4	2,400
By-product	kg	2,000	0.16	320	300	0.16	48
Crop harvest							
Main product	kg	150	6	900			0
By-product	kg	600	0.08	50			0
Other harvest							
Main product	kg			0			0
By-product	kg			0			0
Total Revenue				2,270			2,448
Returns							
Net revenue return to land and management				610			768

Cost and Returns for Vetiver Oil Production in Indonesia

Background. Until recently, the economic use of vetiver grass was for the extraction of aromatic oil, for use in perfume manufacture, from the plant's roots. Other, relatively minor, uses are the manufacture of hand fans, screens for evaporative coolers and aromatic sachets from the plant's root. Harvesting the root can be environmentally destructive. For example, in Indonesia harvesting is carried out up and down the slope to take advantage of erosion that naturally loosens the root from the soil. As harvesting proceeds, bare soil is exposed to accelerated erosion. Although it is conceivable that a sustainable cultivation system could be developed for commercial vetiver production, to date none is available.

Cost and Returns. In the vicinity of Garut, West Java, a large area of vetiver grass is cultivated for oil extraction. Harvested roots are macerated by hand and distilled 12 hours with water in two-ton batches, producing 6 kg of oil. Each of several stills at a site is used for 7-10 batches per week. Costs and revenue estimates for vetiver distillation are given in Table A1.

Table A1: ESTIMATED COSTS AND RETURNS FOR VETIVER OIL DISTILLATION IN WEST JAVA

Item	Unit	Price (Rp)	Quantity	Total (Rp)
Root /a	kg	150	2,000	300,000
Kerosene	liter	200	300	60,000
Labor	Md	1,500	6	10,000
Returns				
Oil	kg	79,000	6-10	474,000-790,000
Return on variable costs per run				104,000-420,000
Return on variable costs per still per year /b				41.6 - 168.0 million

/a Cost to distillery based on yield of 20 tons/ha/yr and labor input of 60 man-days/ha. Vetiver is planted 80,000-100,000 slips/ha (spacing of 40-50 cm between rows.

/b Eight batches per week, 50 weeks.

Markets and Prices. Not much is known about the world market for vetiver oil. According to distillers, export markets have been growing rapidly. Prices rose in 1989 from Rp 46,000/kg to Rp 79,000/kg.

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4. ECONOMIC ANALYSIS OF OFF-FARM SOIL CONSERVATION STRUCTURES

William B. Magrath

Although off-farm structures such as checkdams and water-harvesting structures are often a substantial portion of costs in watershed projects, they are seldom subjected to benefit-cost analysis, due to their typically small size and dual objective of providing environmental and productive benefit. The benefit-cost analysis in this chapter, based on data collected in Indonesia, demonstrates that a rudimentary analysis can help distinguish viable investments from unprofitable ones, even when values for environmental benefits are uncertain. Furthermore, the effort required for benefit-cost analysis is minimal, compared to the engineering and construction input. Also noted are some strategic considerations involved in evaluating off-farm structures for watershed projects.

CONCEPTUAL ISSUES

Investment Objective

In most respects, checkdams and water-harvesting structures can be approached as conventional minor irrigation reservoirs. They are distinct in that one of their significant functions is to capture sediment, and consequently their life span is often quite short. While siltation is frequently considered cause for alarm, it is important to note that these structures are often built solely or primarily for the purpose of capturing silt and that if they were not eventually silted, the investment could be considered a failure.

In addition to determining the life span of a structure, siltation also influences the stream of irrigation benefits during the structure's life. In large reservoirs the ratio of capacity to sediment deposition is so large that, for practical purposes, reductions in service due to siltation can be ignored. In small structures, often associated with highly degraded catchments, benefit streams are more likely to be critically affected by sedimentation.

Dynamics of a Reservoir

This can be reflected in an economic analysis by explicitly relating benefit flow to the current status of the reservoir which needs in turn to be related to sediment delivery. The dynamics of the reservoir can be represented by the following difference equation:

$$C_{T+1} = C_T - S_T \qquad \text{(eq. 1)}$$

where C_{T+1} = Reservoir capacity at time T + 1
C_T = Reservoir capacity at time T
S_T = Sedimentation during period T

Initial storage capacity (C_o) is known from engineering and site studies. Current sedimentation can be estimated for small catchments through a variety of techniques. These include use of empirical soil loss equations (e.g., the universal soil loss equation (USLE), construction of sediment budgets, or monitoring data on stream-suspended sediment and bedloads.

Sediment Rates. Sediment rates are highly variable and dependent on both climatic variables and land use. In most cases, it will be necessary to use estimates of long-term average sedimentation rates. These, however, must be used with caution because there is seldom a sufficiently long time-series of data on which to calculate highly reliable estimates. If land-use changes or improvements are expected in the catchment, sedimentation can be treated as a variable dependent on other investments.1/ Projections of reductions in sedimentation need to be viewed skeptically. Significant improvements can probably only be reasonably expected in relatively small catchments and after some lag time.

Reservoir Capacity. The relationship between current reservoir capacity and benefit flows is dependent on a number of variables, including type of structure and operating rules. This can often be clarified by analysis of engineering studies. More typically, economic analysis of explicitly examined reservoir sedimentation has treated benefits as proportional to capacity. For example, an X% reduction in reservoir capacity can be assumed to produce an X% reduction in irrigated area. Provided that irrigation water is efficiently used in the first place and that there are limited opportunities for substituting less water-demanding crops, this is probably not an unreasonable first approximation.2/

Valuing Sediment Capture. Explicitly valuing sediment capture is another issue raised in the analysis of off-farm structures. This is often not strictly necessary when irrigation benefits can be shown to justify construction, but is relevant where irrigation benefits are insufficient or where the purpose of the analysis is to aid in project design.

The value of sediment capture is site-specific and dependent on the nature and value of the receiving downstream area. Deposition of silt in reservoirs and irrigation systems can, for example, raise operation and maintenance costs and/or reduce operating efficiencies. Deposition of gravelly and sandy material on agricultural land can reduce the value of this land or even take it entirely out of production. Yet, sediment deposit can be beneficial where sediment has desirable properties as a building material or for other uses.3/

1/ In which case the cost of land-use changes, including both direct costs and opportunity costs, need to be included in the analysis.

2/ See, for example, Southgate (1986).

3/ In the Kali Progo Irrigation Project, Indonesia, removal of 32,000 m^3 of sediment from silt traps costs Rp 23 million (Rp 718/m^3) per year. However, this material has a ready market and can be sold for Rp 2,000/m^3, yielding a net return of Rp 44 million/year.

Reasonable approaches to shadow prices for sediment capture can be based on costs of dredging (or other ameliorative measures), where practiced, or on the value of service reductions. It is useful to note that the costs of service reductions should not exceed the costs of dredging; otherwise, it would be in the interests of the downstream authority to institute such a program.

An alternative approach to shadow pricing, especially in the case of reservoirs, is to note that what is actually being valued is water storage. Reservoir capacity, once constructed, is a depletable resource. It is well established in the literature on depletable resources that their shadow price will rise at the rate of discount until reaching a backstop price.4/ The backstop price, in the case of reservoirs, could either be dredging (seldom practiced in developing countries) or the construction of additional storage by raising dam height or new dam construction.

A CASE STUDY: INDONESIAN REGREENING PROGRAM

Appraising Economic Efficiency of Checkdams

Checkdam construction is a major element of the Indonesian Regreening Program, accounting for as much as 60% of total annual expenditure (World Bank, 1989). The economic questions posed by this investment program are typical of those discussed in this chapter. The checkdams are intended to serve multiple functions, including provision of irrigation water, silt capture and land preservation and reclamation. To illustrate an approach to appraising the economic efficiency of these investments, data were collected on 23 checkdams constructed under the program in Central Java between 1983 and 1988.

Data. Costs and initial storage capacity data were available for all 23 dams.5/ Information on catchment size, erosion rate and command area were available for only seven dams planned for FY88/89. These data are summarized in Table 4.1.

4/ The classic treatment is Hotelling (1931); the ratio of a backstop price was popularized, in the context of energy resources, by Nordhaus (1969). For discussions of the application of this approach to reservoirs and watershed management, see Magrath and Grosh (1985) and Southgate (1986).

5/ All costs were converted to 1988 Rupiah using the IMF wholesale price deflator.

Table 4.1: DESCRIPTIVE DATA ON 23 INDONESIAN CHECKDAMS

	Units	Average	Minimum	Maximum
Catchment area	ha	140.5	70.5	285
Ponding area	ha	1.2	0.75	2.725
Storage	m^3	26,970	7,860	125,200
Erosion rate	mm/year	4.6	2.43	5.53
Expected life	year	3.6	1	7
Calculated life	year	4.2		
Dam length	m	74		
Dam height	m	8		
Dam base	m	4		
Command area	ha	3		
Cost	Rp million	33	19.7	49.2
Cost/m^3	Rp	1,668	392.7	3,539.0

Assumptions. Results presented here are based on an analysis of a representative checkdam, using average values and construction cost derived from a regression equation relating costs with initial storage capacity. The equation was of the form:

$$\text{Cost}/m^3 = \left[\frac{B}{\text{Storage Capacity } m^3}\right] \qquad \text{(eq. 2)}$$

where B is a parameter to be estimated. A relationship between storage capacity and command area was estimated based on the sample of seven dams. This relationship was assumed to be of the form:

$$\text{Command Area} = A \times [\text{Storage}] \qquad \text{(eq. 3)}$$

where A is another parameter to be estimated.

The form of equation 3 was chosen to reflect the economics of scale in dam construction. Equation 2 reflects the assumption that command area (irrigation benefit) is linearly related to capacity. Both equations are restricted to have a zero intercept on the basis that a reservoir of zero capacity has neither cost nor command area.

The results of ordinary least-squares estimation are shown in Table 4.2. In both cases, the estimates are statistically significant and of good fit.

Table 4.2: REGRESSION ESTIMATES

	A	B
Coefficient	0.000227	28484004
t-statistic	8.93	19.45
R^2	0.594	0.690

It is further assumed that after complete siltation the surface of the reservoir is salvaged as arable land.

Physical Benefits

Based on these assumptions it is possible to trace, using the logic of equation 1, the evolution of physical benefits from the representative checkdam, using the laws of motion given in Figure 4.1.

Figure 4.1: CHECKDAM SYSTEM EVOLUTION

$$\underset{(\text{ha})}{\text{Command area}} = 0.000227 * \underset{(\text{m}^3)}{\text{Current storage}}$$

$$\underset{(\text{m}^3)}{\text{Sediment capture}} = \underset{(\text{mm})}{\text{Erosion rate}} * \underset{(\text{ha})}{\text{catchment area}} * 10$$

$$\underset{(\text{m}^3)}{\text{Current storage}} = \underset{(\text{m}^3)}{\text{Lagged storage}} - (\underset{(\text{mm})}{\text{Erosion rate}} * \underset{(\text{ha})}{\text{catchment area}} * 10)$$

Together these assumptions generate projections of physical benefit flows from the representative dam. A base-case scenario is given in Table 4.3.

Table 4.3: PHYSICAL BENEFIT STREAMS FOR REPRESENTATIVE CHECKDAM

	Year								
	0	1	2	3	4	5	6	7	8
Command area (ha)		6.1	4.7	3.2	1.7	0.3	0.0	0.0	0.0
Sediment trapped (m^3)		6,463.0	6,463.0	6,463.0	6,463.0	1,118.2	0.0	0.0	0.0
Land reclaimed (ha)		0.0	0.0	0.0	0.0	1.2	1.2	1.2	1.2
Current storage (m^3)	26,970.173	20,507.2	14,044.2	7,581.2	1,118.2	0.0	0.0	0.0	0.0

Irrigation is valued at Rp 1,200 per hectare, based on calculations presented in the appraisal of the Forestry Institutions and Conservation Project (World Bank, 1988). Sediment capture is initially valued at Rp 60/m^3, based on the cost of constructing water storage in large reservoirs on Central Java.6/ Based on the assumption that reservoir storage is a nonrenewable resource, it is further assumed that this value will rise over time at the rate of interest. This is a low value of storage compared to the average cost of storage in checkdams (Rp 1,056). However, it reflects the fact that the cost of storage is subject to large economies of scale. Prevention of siltation in other applications, especially the protection of irrigation systems, can have considerably higher value. Mechanical silt removal from silt traps in Central Java costs roughly Rp 600/m^3. Accordingly, although the primary purpose of the sampled checkdams is to protect reservoirs, higher values were also tried to examine the viability of using dams to protect high-value installations. Lastly, land reclaimed is valued at an annual rental rate of Rp 2,225,000 per hectare, based on estimated returns to land and management.

Economic Benefits

Applying these values to the physical benefit flows in Table 4.3 yields the following profile of value flows:7/

Table 4.4: ECONOMIC COST AND BENEFIT FLOWS FOR REPRESENTATIVE CHECKDAM (Rp'000)

	Year								
	0	1	2	3	4	5	6	7	8
Costs (Rp'000)									
Construction	28,484								
Benefits									
Command area (ha)		7	5	4	2	0	0	0	0
Sediment trapped (m^3)		428	474	523	578	110	0	0	0
Land reclaimed (ha)		0	0	0	0	2,225	2,225	2,225	22,248
Total	-28,484	435	479	527	580	2,335	2,225	2,225	22,248

Under these conditions the investment has a net present value 8/ of Rp 12,672,000 and an internal rate of return of 1%. These results stem primarily from the high costs of storage and the low value of outputs. To explore the sensitivity of these results to alternative assumptions, several sensitivity analyses were conducted. In Table 4.5, the implications of higher sediment capture values and various values for irrigation services are shown.

6/ The Kedung Ombo Dam, Indonesia, was constructed at an average cost of Rp 55.8/m^3 of storage.

7/ Land returns accruing after the eighth year are capitalized at a 10% discount rate.

8/ All present values are based on a 10% discount rate.

Table 4.5: NET PRESENT VALUE OF REPRESENTATIVE CHECKDAM UNDER ALTERNATIVE IRRIGATION AND SILT CAPTURE PRICES

		Value of Irrigation (Rp'000/ha)					
		0.0	1.0	2.0	3.0	4.0	5.0
	0.00	-14,326	-14,313	-14,300	-14,287	-14,274	-14,260
	0.05	-12,961	-12,948	-12,935	-12,922	-12,909	-12,895
	0.10	-11,596	-11,583	-11,570	-11,557	-11,543	-11,530
	0.15	-10,231	-10,218	-10,205	-10,191	-10,178	-10,165
	0.20	-8,866	-8,853	-8,840	-8,826	-8,813	-8,800
Value of silt capture (Rp'000/m^3)	0.25	-7,501	-7,488	-7,474	-7,461	-7,448	-7,435
	0.30	-6,136	-6,122	-6,109	-6,096	-6,083	-6,070
	0.40	-3,405	-3,392	-3,379	-3,366	-3,353	-3,340
	0.50	-675	-662	-649	-636	-623	-609
	0.60	2,055	2,068	2,081	2,094	2,108	2,121
	0.70	4,785	4,798	4,811	4,825	4,838	4,851
	1.00	12,976	12,989	13,002	13,015	13,028	13,041

These show that considerably higher values for sediment capture, close to those associated with dredging of irrigation systems, are required to make the representative checkdam economically viable. This result is highly insensitive to irrigation values.

Table 4.6 gives net present values for alternative combinations of construction cost and silt capture. The sensitivity of NPV to construction cost illustrates its role in producing the negative estimate of profitability.

Table 4.6: NET PRESENT VALUE OF CHECKDAM UNDER ALTERNATIVE CONSTRUCTION COSTS AND SILT CAPTURE PRICES

		Cost of Construction (Rp'000)					
	0.00	15,000	20,000	25,000	30,000	35,000	40,000
	0.00	-826	-5,826	-10,826	-15,826	-20,826	-25,826
	0.05	539	-4,461	-9,461	-14,461	-19,461	-24,461
	0.10	1,904	-3,096	-8,096	-13,096	-18,096	-23,096
	0.15	3,269	-1,731	-6,731	-11,731	-16,731	-21,731
	0.20	4,634	-366	-5,366	-10,366	-15,366	-20,366
Value of silt capture (Rp'000/m^3)	0.25	5,999	999	-4,001	-9,001	-14,001	-19,001
	0.30	7,364	2,364	-2,636	-7,636	-12,636	-17,636
	0.40	10,094	5,094	94	-4,906	-9,906	-14,906
	0.50	12,825	7,825	2,825	-2,175	-7,175	-12,175
	0.60	15,555	10,555	5,555	555	-4,445	-9,445
	0.70	18,285	13,285	8,285	3,285	-1,715	-6,715
	1.00	26,476	21,476	16,476	11,476	6,476	1,476

An interesting aspect of the checkdam investment is its built-in obsolescence. Tables 4.7-4.9 show the results of different catchment erosion rates (and implicitly different reservoir life span), sediment capture and irrigation values. For all combinations, higher erosion rates (or shorter life spans) yield higher returns. This is due to the earlier onset of land reclamation benefits. This result is particularly interesting in that concern is often raised about the short life of these structures. Moreover, a standard recommendation is to require catchment stabilization prior to construction--a practice which, if followed, reduces the value of the representative checkdam.

Table 4.7: EROSION RATE (mm/yr)

		3	4	5	6	7
Value of silt capture (Rp'000/m³)	0.00	-16,943	-14,809	-12,792	-12,793	-11,123
	0.05	-15,571	-12,942	-11,428	-11,431	-9,762
	0.10	-14,199	-11,575	-10,064	-10,069	-8,402
	0.15	-12,827	-10,208	-8,700	-8,707	-7,041
	0.20	-11,454	-8,840	-7,336	-7,345	-5,681
	0.25	-10,082	-7,473	-5,972	-5,983	-4,320
	0.30	-8,710	-6,106	-4,608	-4,621	-2,959
	0.40	-5,965	-3,372	-1,879	-1,897	-238
	0.50	-3,221	-638	849	827	2,483
	0.60	-476	2,096	3,577	3,551	5,204
	0.70	2,268	4,831	6,305	6,275	7,926
	1.00	10,502	13,033	14,489	14,447	16,089
				(Reservoir Life) (year)		
		6.4	4.8	3.8	3.2	2.7

Table 4.8: EROSION RATE (mm/yr)
Silt Capture Valued at Rp 60/m³

		3	4	5	6	7
Value of irrigation (Rp'000/ha)	0.0	-15,316.7	-12,685.6	-11,169.8	-11,172.2	-9,502.36
	1.0	-15,300.0	-12,671.2	-11,157.3	-11,161.1	-9,492.32
	2.0	-15,283.4	-12,656.7	-11,144.9	-11,150.1	-9,482.29
	3.0	-15,266.7	-12,642.2	-11,132.5	-11,139.0	-9,462.23
	4.0	-15,250.1	-12,627.8	-11,120.0	-11,128.0	-9,462.23
	5.0	-15,233.4	-12,613.3	-11,107.6	-11,117.0	-9,452.20

Table 4.9: EROSION RATE (mm/yr)
Silt Capture Valued at Rp 600/m³

		3	4	5	6	7
Value of irrigation (Rp'000/ha)	0.0	-496.103	2,079.077	3,561.702	3,537.664	5,192.401
	1.0	-479.449	2,093.541	3,574.136	3,548.700	5,202.433
	2.0	-462.795	2,108.005	3,586.569	3,559.736	5,212.466
	3.0	-446.141	2,122.469	3,599.003	3,570.773	5,222.498
	4.0	-429.487	2,136.934	3,611.437	3,581.809	5,232.530
	5.0	-412.833	2,151.398	3,623.870	3,592.845	5,242.562
				(Reservoir Life) (year)		
		6.4	4.8	3.8	3.2	2.7

STRATEGIC CONSIDERATIONS

The inclusion of off-farm structural works in watershed projects raises issues that are not solely economic and which need to be considered in the context of an overall approach. It may lead to either inclusion of works that are strictly speaking not economically viable or exclusion of viable ones. This chapter discusses approaches to valuing environmental benefits that are usually not considered. In many countries, off-farm structures have become ingrained in watershed investment and they offer costs and benefits of quite a different sort. For example, the ability of soil conservation agencies to provide upland areas with irrigation benefits, even on a costly and probably inequitable basis, may be of value in gaining the cooperation of local communities for the introduction of other conservation techniques (see, for example, Society for Promotion of Wastelands Development, 1990). On the other hand, structural works often provide an opportunity for rapid expenditure of project funds with little meaningful local participation. Further, the inclusion of off-farm works, even if economically desirable, may also serve to bias agency efforts away from on-farm and forestry measures.

Thus, while it is feasible to conduct benefit-cost analyses of checkdams and other small structures, there may be good reasons for overriding the results. At a minimum, however, it is reasonable for donors and planning agencies to require implementing agencies to include simple economic analysis in the planning of such structural works and to document the justification for proceeding with structures that do not appear viable. This requirement could be imposed on structures greater than a certain size or that require more than a minimum level of site surveying and engineering.

In general, it is clear that checkdams and other small structures are an expensive adjunct to downstream water/sediment storage capacity. Because of the considerable economies of scale present in reservoir construction, small structures need to offer significant directly productive benefits or be sited to provide protection to highly valued infrastructure which would otherwise require expensive maintenance.

Other off-farm conservation works, for example, gully plugs which are primarily intended to stabilize channels and prevent loss of adjacent land, can be analyzed in similar fashion. It would be imprudent here to consider detailed analysis of all the small, scattered structures typically included in a watershed management project. The practice of benefit-cost analysis is itself an exercise in benefit-cost analysis and judgments as to the value of incremental information to the decision-making process is an essential element.

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5. REVEGETATION TECHNOLOGIES

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Revegetation is a significant technology employed in the rehabilitation of upper watersheds in the Asia region. It traditionally encompasses both enrichment planting and forestation of bare areas. This chapter recognizes that much plantation work has been less successful than hoped and discusses the reasons, both technical and nontechnical, for the lack of success. Technical components covered are: local need-based planning, choice of species, nurseries, ground preparation, planting methods, planting designs, protection and management. For each topic, the issues and options are presented. Poor success rates are attributed, variously, to these components, but also to social factors, such as the critical need for active participation by local inhabitants in revegetation programs, which is now often lacking.

INTRODUCTION

The relationship between the upper watershed and the forest is important to appreciate. Prior to settlement, most watersheds, both lower and upper, were covered with mixed species forest. In a pristine state, the upland forest comprised multilayered vegetation with a fully covered forest floor that held erosion to a minimum. Now mostly cleared to accommodate agriculture, forests have become restricted to the steeper, higher-elevation shallow soils or droughtier regions less suited to agricultural production, and even so, are being degraded by fuel-gathering and grazing. The degradation has reduced the vegetative cover and litter to various extents, often down to bare surface, inducing runoff and erosion and changing soil moisture status. With some exceptions, forests today provide marginal economic returns to government; yet, they are of considerable importance to villagers who exploit them for timber, firewood, minor forest products, food, and sometimes game and feed for their animals.

Revegetation, a significant technology in the rehabilitation of upper watersheds in the Asia region, encompasses enrichment planting (supplementing standing forest crops) and forestation (planting on bare land). Given the effect of degradation on soil and moisture loss, on-site soil and moisture conservation is an integral part of revegetation. Engineering structures for soil and moisture conservation are expensive to construct and maintain and are short-lived; therefore, they are not considered here, although it is acknowledged that under uncertain circumstances, especially in gully rehabilitation, such structures may be required to allow vegetation to establish. Rather, the focus is on vegetative conservation measures.

TECHNICAL COMPONENTS OF REVEGETATION

Local Need-Based Planning

While technical factors (such as species, spacing, soil moisture) are vital, the success of revegetation programs is also dependent on benefits accruing in the short and long run to local users who have traditionally depended on vegetative resources on adjacent common or public property for fuel, fodder or income. Population pressure and the consequent rising demand for fuel and fodder from the same land resources cause upland degradation. For various reasons, including poverty and lack of fuel alternatives, rural families cannot forsake biomass fuel (Leach, 1987) and this dependence will persist for some time to come. Similarly, stall-feeding of animals to relieve pressure on forest vegetation, although feasible, is unlikely to be widely adopted in the near future because of the need to grow fodder and the investments needed. Also, in India for example, poorer villagers often subsist by illicitly collecting and selling fuelwood in towns (Fernandes, 1987). Generation of employment through revegetation programs could possibly break this ongoing poverty-land degradation-poverty cycle. Revegetation planning that does not take into account local needs is inadvisable, because new plantations cannot survive the pressure of fuel collection for consumption and commerce, nor can they survive unrestricted grazing. The correct approach to revegetative technology, therefore, would consider both the site and needs of the local population.

All common land is tied in some way to users, who may be individuals, groups, communities or villages, and although usage may not be recorded, it is traditionally accepted by all concerned. For practical reasons, the identity and size of the planning unit for revegetation are important. Furthermore, needs of subunits may differ and identifying those that can be addressed requires care: marginal farmers may own few cattle and need little fodder, while the intermediate-size farmers may need more; the landless may require employment from the program, while farmers would not. Discussion with representatives from various economic groups within the planning unit is therefore necessary to provide a full-bodied and accurate depiction of needs, and in this discussion, women as a social unit should be involved.

Once needs are assessed and land and financial resources of the unit analyzed, technology suitable for the site and aimed at meeting these needs can be developed. Continuous consultation within the client community and adaptation from one site to another regarding planning, execution and mechanisms for distributing benefits should, therefore, be major elements of revegetation programs (Banerjee, 1987). Forestation projects by nongovernmental organizations (NGOs) have succeeded in many countries (though on a small scale) due to project planning, execution and protection by local inhabitants (see Chipko in Garhwal Himalayas and Appiko in the Western Ghat mountains in Hegde, 1987). In contrast, many government projects, without local involvement and enthusiasm, have failed in spite of suitable technology.

<u>Issues of Participatory Planning</u>. Given the fact that local participation is essential for successful revegetation programs, some important questions emerge:

(a) What should be the geographical unit whose inhabitants relate to the project site: village, a cluster of villages, district or some other unit such as a users' group?

(b) Should an institution represent the people? If an institution is necessary, should it tap into an existing one or be newly formed or should a spontaneously created group be promoted?

(c) What should be the mechanism of participation?

Recent experience shows that the smaller the unit in relation to the revegetation site the more likely people will take a cooperative interest in the project and the more likely it is to succeed. A village, often encompassing a users' group, is usually a reasonable unit for participatory planning. Existing institutions, if genuinely representative, are sound choices. The mechanism for consultation may involve complexities best sorted out by specific circumstances. The point to keep in mind is that the views of a cross-section of a village, usually made up of heterogeneous elements, should be incorporated in the technical plan, designed to satisfy plural objectives. With any choice, coordination of local interests is necessary--whether it involves a community movement spawned by local initiative in ecological restoration; a community association, such as the village forestry associations in the Indo-German Dhaulader project in Himachal Pradesh, India, that assist in planning, protection and management of revegetation of degraded hills; or existing institutions such as the *panchayat* in India.

Choice of Species

Monoculture and Exotics. Over the past three decades of forestation programs, monoculture has become an regular practice. Only a few species have been used and often they are exotics: *Eucalyptus tereticornis*, *Casuarina equisetifolia*, *Prosopis juliflora*, *Cryptomeria japonica*, and *Pinus patula* in India; *Acacia mangium* and *Paraserianthes falcataria* (prev. *Albizzia falcataria*) in Bangladesh; *Pinus caribaea* in Malaysia; *Leucaena leucocephala* in the Philippines and Thailand; *Eucalyptus camaldulensis* and *Eucalyptus citriodora* in many of the South Asian and insular Southeast Asian countries.

Two important reasons for selecting exotics and monoculture are fast growth and easy management, which characteristics have obvious advantages in areas suffering from biomass shortage and a lack of technical manpower. However, the adverse effects of monoculture could outweigh its advantages. To ensure adequate stocking, close espacements are used, resulting in early canopy closure which discourages undergrowth, for example, in plantations of *Cryptomeria japonica*, *Eucalyptus tereticornis*, *Pinus roxburghii* and *Tectona grandis*. Some species, particularly *Eucalyptus*, are said to tap too much groundwater and nutrients. Fast-growing species must use these essential elements in absolute quantities, but often utilize each molecule of water and nutrient to produce more biomass than slower-growing species can. Some species may allocate more energy towards wood production at the expense of crown development, for example, *Casuarina equisetifolia*. This benefits fuel productivity but limits the supply of twigs and leaves for local people and reduces recycling of nutrients. Exotics may provide a new food source for pathogens and could be vulnerable to pests and diseases due to growth stresses related to poor site conditions. Corticium salmonicolor is a serious pest of Eucalyptus grandis in Kerala, India and Agrilus opulensis, a wood borer, severely attacks Eucalyptus deglupta in the Philippines (Evans, 1982).

Impact on Erosion. Lack of undergrowth in hill conditions is a serious deficiency which results in soil erosion. Care is needed to select species with relatively light crowns in order to encourage ground cover. Since fast-growing species require more water, special efforts are needed during planting to ensure maximum percolation of rainfall into the soil. When excessive nutrients are likely to be lost due to disproportionate wood/leaf production, green manure plants should be introduced. Rao (1967) reports a decline in yield of C. equisetifolia from 185 tons at the end of the first rotation to 140 tons at the end of the third, in Nellore, Andhra Pradesh, India. Since the C. equisetifolia had to be replanted, the seed source may have been the cause of yield decline, but possibly different crops should be used in alternate rotations.

Quite often exotic species are mistakenly introduced in enrichment planting also. Planting of Acacia auriculiformis in degraded forests of Shorea robusta in Bihar, Eucalyptus tereticornis in moist deciduous forests of West Bengal and Kydia calycina in tropical rain forests of Arunachal Pradesh, India, have been unrewarding.

Response to Site Conditions. Several issues need to be considered in selecting species for Asian uplands which are fragile ecosystems that deteriorate quickly. The process of deterioration is progressive: reduced protection of the soil surface by removal of cover permits increased runoff with a concomitant reduction in percolation and loss of soil, leading to a sequential reduction in available soil moisture and nutrients. Therefore, choice of species has to take into account, not only site and local needs, but also the degree of deterioration. Three categories of degeneration can be recognized. If the site is bare, degraded to the point that it cannot support trees, then grasses, legumes and local shrubs may be the only alternatives. On a partially degraded site with some scrub vegetation left, enrichment planting of aggressive indigenous shrubs and management by protection may be appropriate. But, if the site is just beginning to deteriorate so far as canopy cover is concerned, a mixture of trees and shrubs to establish a two- or three-tier forest should be introduced.

Bare sites are characterized by thin soil cover, low moisture-holding capacity, low fertility, and ongoing erosion. These areas may also be subjected to overgrazing and periodic burning of whatever surviving weeds or grasses remain. Attempting to revegetate them with tree species, even if indigenous, is bound to fail, based on experience in the western Himalayas of India, where Pinus roxburghii and Quercus incana, both indigenous, have been planted without adequate success. Both these species, which were respectively the pioneer and climax tree species, now stand as "relicts".1/ Due to biotic disturbance, the sites have retrograded ecologically and the appropriate vegetation required to reverse the situation has to be more akin to that found in newly

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1/ Persistent remnant of otherwise extinct flora.

exposed sites. Grasses, herbaceous weeds, hardy shrubs, and legumes are the early harbingers in natural succession and should be planted to begin revegetating such sites.

On degraded sites with scrub vegetation, the situation is quite different. Often they are occupied by unwanted shrubs such as Lantana spp. and Eupatorium spp. in Nepal and India, by single-stemmed bamboo Melocanna bambusioides in Burma, and Imperata cylindrica grass in many of the South Asian countries. While these species appear to stabilize the site and prevent erosion, they seldom allow other planted species to grow and are mostly unwanted by local people. However, their removal in order to replant with desirable species can induce erosion. In such cases, enrichment planting of desired species that will gradually suppress the weeds is the appropriate measure. The choice of species is difficult, because they have to be aggressive with the capability of competing with the shallow, matty root system of weeds which use soil moisture rapidly and, at the same time, withstand fire, cutting and grazing. Not many trees, except some belonging to the Leguminoseae family such as Acacia mangium and Robinia pseudoacacia, can satisfy these demands. On the other hand, many shrubs have the desired properties and are at the same time useful to local people.

On sites beginning to deteriorate--with poor tree stocking but reasonable soil depth--selected species should include all forms of vegetation: trees, shrubs, herbaceous legumes and grasses. They will be able to establish a multitier plantation crop. The tree species can be either local or proven exotics, while the shrubs preferably should be local ones. Some examples of indigenous tree species used in forestation programs are Pinus roxburghii in Indonesia, Eucalyptus deglupta in the Philippines and Papua New Guinea, Araucaria huntsteinii and A. cunninghamii, Tectona grandis, Dalbergia sissoo, P. roxburghii and Cedrus deodara in India. Exotic species used include Pinus caribaea in Malaysia, P. patula and Pseudotsuga menziesii in New Zealand, and Eucalyptus spp. in most countries. There have been very few attempts to combine tree and shrub species in plantations, which has led to a number of drawbacks. Unless the tree is a multipurpose species, the plantation cannot supply more than one category of need to local people. Secondly, tree species usually take a few years to produce a useful product unlike the shrubs which mature faster. Thirdly, the tree canopy generally fails to prevent erosion to the extent a multitiered forest can. The correct choice of species to establish multistoried plantations, however, can meet most of these deficiencies.

Issues Concerning Choice of Species. Species selection is related to the type of site being revegetated and preferences of the local population. On degraded sites with shallow soils, useful grasses, legumes and indigenous shrubs are likely to be better adapted than tree species. They will develop a root mat and surface cover to minimize runoff and soil moisture losses. When the site already has a cover of aggressive, nonusable species, locally available hardy shrub and tree species, particularly tree legumes like Acacia mangium and Robinia pseudoacacia, should be introduced to develop a multilevel canopy. On poorly stocked sites with adequate soil depth, exotic trees with indigenous shrubs are suggested, aimed again at a multistoried canopy. The propagation technology of indigenous shrub species is poorly understood and will require field research.

Nurseries

Seed Quality. Currently, the weakest aspect of nursery operations is the use of poor-quality seeds. Seedlings raised from them produce trees of poor form and growth rate. Such trees are found in large numbers in plantations of many afforestation projects in Asia. Since most countries are increasing their planting activities with inadequate attention to seed selection, unsatisfactory results are likely; in other words, the biomass potential of the ecotype will remain unrealized.

A few short-term measures can substantially improve seed quality. Most countries plant a large number of tree species, but only a few in large numbers. Initially, the most commonly used species in forestation programs should be selected for quality improvement. The first step would be to select a number of phenotype (candidate plus trees) of these species; the selected trees should be mature and have characteristics considered by their planters to be desirable when ready for harvesting. The number of trees to be selected would depend on the quantity of seeds produced by a tree, seed germination percentage and the total quantity of seed required for the program. The second step would be to mark, protect and maintain the selected trees to obtain the maximum yield of seeds. The third step would be to engage trained personnel for seed collection and to eliminate seeds from any other source. These selected seeds then should be supplied to all nurseries assigned to the project. Records of seed origin, at least by provenance, should be maintained.

Long-term measures also need to be taken. These measures would include provenance trials, selection of the best provenances, identification of their outstanding trees, etc. In addition, establishment of a seed and testing certification department that would act as the core department to control quality of seeds distributed would be necessary.

Root-Shoot Ratio. Another important aspect of nursery operations is the root-shoot ratio of the seedlings raised for planting. A commonly held notion among foresters is that larger seedlings have a better chance of survival and establish themselves faster than smaller ones. This is erroneous and needs to be strongly countered. Smaller seedlings with a bushy root system and a woody erect shoot should be the preferred product for planting. The ratio of root to shoot varies across species, but in all cases the root system should be sufficient to provide the seedling with required water and nutrients in the initial period of its life. Modern nurseries raise containerized plants in root trainers which prevent root coiling and ensure that growth commences quickly after transplanting.

Ground Preparation

Ground preparation consists of one or more of the following operations: removal of ground vegetation, windrowing, burning and soil cultivation. Depending on the objectives of the revegetation program, nature of the site and availability of resources, these operations are carried out in varying degrees. Each measure has the potential for increased erosion and must be carried out carefully if required.

Removal of Ground Vegetation. Ground vegetation on degrading uplands prevents soil erosion and conserves moisture but also competes for moisture, nutrients and light with planted species. It is a controversial matter as to whether the existing vegetation should be removed or left undisturbed. All sloping areas are vulnerable to erosion under certain circumstances.

There are few species which compete with undisturbed ground vegetation. Most Eucalyptus spp. prefer a completely cultivated and weed-free site for rapid early growth. In Papua New Guinea, a trial of eucalyptus failed completely because of competition from Imperata cylindrica. Similarly, growth of Araucaria cunninghamii and A. hunsteinii in Papua New Guinea is poor when there is lack of weed control (Evans, 1982). In contrast, many species of acacia such as Acacia auriculiformis, A. mangium and Faidherbia albida (prev. A. albida) grow well, albeit at a reduced growth rate, in competition with ground vegetation.

When deciding on the degree of ground clearance to be undertaken, the objectives need to be clear. If the objectives are mainly soil conservation and rehabilitation of the site, existing vegetation should not be disturbed and loss of growth of planted seedlings should be considered as a trade-off for the achievement of the objectives at hand. On the other hand, if increasing the cash value of the crop with marketable species is the intention, removal of existing vegetation becomes imperative, while soil and moisture conservation measures have to be undertaken as a part of the plantation operation. A compromise of the above two extremes is removal of alternate strips of vegetation at specified intervals and stacking them up against the undisturbed vegetation (Cassels, 1983).

Clearance of vegetation can be accomplished mechanically or manually. Removal of ground vegetation is a capital-intensive task if heavy tractors, bulldozers and other attachments are used. Manual operation is preferred on steep hills, as it disturbs the soil less, but is time-consuming and expensive. Sixty-five man-days were necessary to clear a light savannah area in Nigeria with 9-sq m basal area of wood, whereas two 180-hp tractors did a similar job in about 18 minutes. Bulldozers cannot operate beyond a certain slope, and in these situations, manual operation remains the only available option.

Windrowing and Burning. The cleared vegetation is heaped and should be windrowed across slopes by machines. However, as harvesting is usually done up and down slope, windrowing across slope is inconvenient. On most forestation sites, there is hardly any valuable harvestable product and windrowing on the contour is then possible, which reduces soil erosion. The heaped or windrowed vegetation is burned when dry and the ash provides a good nutrient-rich seedbed for seedlings. Several studies have shown that seedlings grow well in these ashbeds.

Soil Preparation. Soil preparation is one of the most important operations in the plantation operation as it affects soil erosion, moisture conservation, plant growth and plantation cost. Soil manipulation can range from no-till to intensive bulldozing, plowing and harrowing operations. The most common soil preparation methods now in practice in the uplands are:

(a) no-till;

(b) pitting;

(c) patch or strip soil working;

(d) herringbone or fish-scale plantations;

(e) tie ridging;

(f) contour stone walls;

(g) gradoni or banquettes;

(h) broken contour line ditches; and

(i) V-ditch and contour banks;

No-till. There is now a considerable body of opinion that soil should not be manipulated on any slope beyond 20% if the soils are loose. Vulnerability of such sites to erosion is most visible in Kandi Siwaliks, India. The rocks in this upland chain consist of fragile sandstone and siltstone which disintegrate to sand or silt on minimum disturbance. They then roll down the hills as slides or wash down with rain water to silt-up downstream agricultural land. Therefore, no-till is generally appropriate in such areas.

Pitting. Pits are usually cubes, each side being 30-45 cm, dug at 2-4 m intervals. The soil is heaped on the side of the pit for 1-3 months before being put back in the pit for planting. Pitting is a common practice all over India. In Fiji, small seedlings of *Pinus caribaea* are inserted in holes dug only with a crowbar (Evans, 1982). A popular misconception exists that a pit planting design on the contour is beneficial as an anti-erosion measure. In fact, except for initial assistance to the seedling by providing loose soil, pits whether on contour or not have little impact in reducing erosion, nor do they conserve any significant moisture.

Patch or Strip Soil Working. Sometimes small square patches, each side being 1-2 m, at a certain spacing are loosened by hand to prepare for sowing and planting. The main reason for such a simple soil operation is to reduce cost. This method does not significantly assist seedling growth. Some species, however, need shade initially to grow and patch sowing under the shade of other trees can be a successful practice. *Azadirachta indica* in semi-arid Vertisol soils in submontane and low hills of central India are sown successfully in this manner. *Eucalyptus pilularis* and *E. grandis* are grown by patch sowing in Australia. Strip working is more intensive; strips are plowed at intervals. In the hills, the method is not recommended on bare slopes as it accelerates erosion significantly. On slopes with some vegetation, however, the uprooted shrubs and tree stumps are often stacked along the lower edge (Chapman and Allan, 1978). Any dislodged soil is to a large extent trapped both by stacked material and the undisturbed strip.

Tie Ridging. This method covers the entire surface with basin-like furrows scooped out along the contour with special plows, and the soil is thus ridged. The contour ridges are then interconnected to create a number of basins for water accumulation. The method is very expensive and not suitable for areas with moderate to steep slopes.

Contour Stone Walls. Chapman and Allan (1978) describe contour stone walls with bases of 30-40 cm and height of 20 cm and cross ties every 5 m along the contour wall. Whatever soil is available is dragged back to seal gaps in the wall to make a reverse slope. Seedlings are planted on either side of the cross tie, thus using the low point of water concentration. This method is inexpensive if sufficient stone is available at the site and useful in arid and semi-arid uplands with shallow soil.

Herringbone or Fish-Scale Method. These methods direct water from a small surrounding area to the planted seedling. With the herringbone pattern (Dalwaulle, 1977), a crescent-shaped low ridge is raised on the downslope side of the tree and small channels are dug into the upslope side leading to the tree. In the fish-scale method, a low dike is raised on the downslope by soil collected from about 2-4 sq m from the upslope side to provide a depression for water collection against the dike where the seedling is planted. The method is an inexpensive moisture conservation method, but in the course of a few years, the depression is filled up by soil moving in from outside and the advantage of pooling is lost.

Gradoni or Banquettes. These are narrow terraces built along the contour on the hillside with the outside rim higher than the inner edge. The terraces are generally discontinuous and are staggered between rows. The runoff water not only loses velocity at the terrace, but also is collected in the terrace because of the negative slope. Erosion is thus reduced and seedlings planted in the gradoni receive additional water. In Morocco, *Eucalyptus gomphocephala* and *Pinus halepensis* are successfully raised on gradoni terraces (Chapman and Allan, 1978). In Gujarat, India, gradoni soil working is the standard practice to forest degraded stony areas of low hills.

Broken Contour Line Ditches. This method is practiced in arid and semi-arid hill slopes of parts of India. The ditches dug on the contour are of different sizes (usually 30 cm x 30 cm x 60 cm), done either by hand or by heavy tractor-bulldozers, spaced 3 m apart center to center in the row and 3-6 m between rows, in a staggered fashion. The soil dug out from the ditches is heaped on the downslope side of the ditch. The trenches collect the water which benefits the seedlings planted either in the ditch or on the mound. Unless the ditches are at close intervals, which is expensive, this method is inadequate as the ditch fills quickly with soil washing down from the upslope side. The seedling bed in the trench is also not a suitable microsite for root development, because on degraded hill slopes the subsoil is rocky. Broken contour line ditches, however, are better for soil and moisture conservation than simple patch soil working or pitting, the two most commonly practiced methods.

V-Ditch and Contour Banks. This is a totally mechanized operation executed by heavy crawler tractors provided with rippers and angle dozer-blades. Contour subsoiling is possible on up to 30% slope but is most satisfactory on slopes below 22-25% (Shepherd, 1986). The latest available machines with new ripper designs shatter a total width of 3 m to a depth of 50 cm. In order for the subsoiling to be effective, it is carried out when the soil is dry. The rip lines are usually 5-6 m apart. After subsoiling is complete, the tractor's angle blade makes a V-ditch in the ripped line and simultaneously forms a ridge on the downhill side of the ditch. Seedlings are planted in the ditch 1-2 m apart in holes dug with a spade. This pattern of earthwork is most suitable where the soil is shallow and is underlain by hard pan. The ripper, by shattering the pan, improves water percolation and enhances root development. The V-ditch on the contour combined with subsoiling is an effective way to conserve moisture in-situ and to reduce soil erosion. In the Pilot Project for Watershed Development in Andhra Pradesh, India, this method has been used to obtain uniform and significantly better growth of Eucalyptus tereticornis, Dalbergia sissoo and several other tree species planted in degraded Alfisols.

Issues Concerning Ground Preparation. Several issues relate to preparation methods:

(a) ground vegetation removal may contribute to erosion, but nonremoval leads to competition with the planted species for light, moisture and nutrients, so careful site reconnaissance is needed before vegetation removal;

(b) burning releases nutrients locked up in waste biomass. This may have a beneficial "ashbed" effect, but also may kill harmful pathogens and beneficial symbiotic bacteria, insects, etc.; may seal the soil pores on the surface leading to faster runoff; and boost weed growth, thus affecting planted seedlings. On the other hand, controlled early burning, having a cooler burn and being easier to supervise, may be beneficial. The pros and cons of burning during site preparation need to be evaluated;

(c) manual soil manipulation is labor-intensive, while machines are capital-intensive, have adverse effects on soil by compaction and are difficult to operate in steep rocky sites. However, tractors equipped with rippers can shatter rocks, makes trenches, terraces, and ditches economically which assists moisture infiltration and in-situ moisture retention. In some instances, soil manipulation increases land productivity, while in others it may contribute to accelerated erosion; hence, the situation on each site needs review.

Decisions regarding the above questions require an understanding of context: (a) these operations are generally in hills and vulnerable to erosion; (b) highly degraded lands are frequently in areas with acute shortages of fuelwood and fodder; and (c) where there is a high level of unemployment and poverty. Technologies which promote soil and moisture conservation, increase productivity of biomass, provide conditions for reducing poverty and generate employment are obviously more appropriate. However, there cannot be one model to cater for the plurality of requirements. Each site, with its individual micro- and macro-environment comprising geographic, historical, social, political and ecological aspects, needs a customized model.

Planting Methods

Alternative planting methods involve direct sowing of seed, planting of bare root or containerized seedlings. Other methods such as stumping, grafting, and root suckering are rarely used in large-scale plantation operations and are not discussed.

Direct Sowing. Sowing of seeds has not been used to its maximum potential in enrichment planting and forestation. The high mortality of seedlings emerging from direct sown seeds compared to those raised by planting seedlings have made it unpopular. The mortality is caused principally by a combination of post-emergence drought and weed competition. Many of the commonly planted exotics have tiny seeds (for example, *Eucalyptus* spp.) and emergent seedlings are small, needing special care and attention which are seldom provided. The unpopularity of direct sowing is unfortunate, because it is a low-cost method of regenerating indigenous species, seeds of which are seasonally plentiful and locally available. Extensive areas can be vegetated by direct sowing with less manpower and infrastructure than formalized transplanting if some special precautions are taken. Firstly, selection of species is important. Seeds should have low dormancy and high germination percentage, and the emerging seedlings should have the capability to survive weed competition. Secondly, more attention than hitherto should be given to breaking dormancy and reducing germinating time by proper seed treatment. Thirdly, where insect or fungal damage, erratic rain, or low soil fertility are expected, seeds should be pelletted with a poly-layered coating which may contain pesticides, anti-drying chemicals and fertilizers. In addition, seed should be coated with mycorrhizae or bacteria, as may be necessary if the species belong to the families *Pinaceae*, *Casuarinaceae* or *Leguminoseae*.

Broadcast sowing, patch and line sowing or aerial seeding may be used. Planting *Eucalyptus* spp. by direct seed sowing has been successful in Australia. *Acacia auriculiformis* is successfully grown by line sowing in plantations in West Bengal, India, as is *Dipterocarpus turbinatus* in Bangladesh. *Aesculus indica* and *Juglans* spp. are grown by direct sowing in the Kashmir Himalayas, India. *Shorea robusta* and *Dipterocarpus macrocarpus* also grow well from direct sowing. *Prosopis juliflora* has been grown very successfully by direct sowing in some arid states of India. All these examples show the potential of sowing as a method of plantation establishment. Aerial sowing of pelletted seed is an interesting option, which has been successfully utilized in New Zealand, Canada and Indonesia. The technique may be valuable in arid and semi-arid wastes and is a possibility that should be explored.

Bare-Root Planting. Bare-root planting is less expensive than container seedling planting, due to lower nursery and transporting costs, and should be adapted wherever possible. While some species are very sensitive and cannot stand bare root transplanting (e.g. *Acacia catechu*, *A. nilotica*), others are amenable, provided the seedlings are carefully handled. *Eucalyptus tereticornis*, *E. camaldulensis*, *Casuarina equisetifolia*, *Pinus roxburghii* are some of the species which have been successfully raised with bare-root stock.

Container Seedlings. The use of container seedlings is the most common planting system used today in revegetation programs. Two types of containers are used: semipervious and impervious containers, with the latter used more extensively. Semipervious (and pervious) containers were extensively used before polyethylene bags were introduced. These were made up of leaves (*Shorea robusta*, *Butea frondosa*, *Bauhinia villosa* in India), waste veneers (by Picop in the Philippines), or bamboo pots (by Nalco in the Philippines), all locally available and low-cost. One of the disadvantages of semipervious containers is that roots penetrate the container and form a mat with the roots of adjacent containers, making it difficult to separate them during transplanting. This type of planting stock has less mortality than bare-root stock. The semipervious containers are not used widely anymore, but renewed attention to this method and evaluation of its potential would be useful.

Two types of impervious container, the flexible polyethylene bag or sleeve and the more rigid root-trainers, have been developed over the past decade. In tropical countries, flexible polybags or tubes are most commonly used: they are frequently 4-mm thick black or transparent polyethylene and of varying diameter and length. Disadvantages are that they are not biodegradable, add to seedling production costs and may constrict root development. However, advantages are many: seedlings have a better chance of survival, planting stock size can be controlled and there is little damage during transportation. To prevent root-constriction, root-trainers have been developed. They are normally hung slightly above the ground, causing air pruning of roots and have the additional benefit that seedlings do not significantly deteriorate if held back in the nursery due to erratic rains or other delays in planting schedules.

Issues Concerning Planting Methods. The following issues are important regarding planting methods:

(a) direct sowing as a method of revegetation is unpopular. As the method is low-cost and has a lot of potential, provided the seeds are pretested and pelletted, a fresh look at this method for extensive use is recommended;

(b) bare-root seedling planting is successful for many species, provided seedlings are planted during good climatic conditions. Containerizing them to ensure success is not necessary under such circumstances. It would be worthwhile to list species that do well by this method of propagation and standardize the procedure of growing bare-root seedlings in nurseries;

(c) semipervious containers, particularly of leaves, once popular have been practically discarded. Yet the method has potential. Not only are they low-cost but also biodegradable. Species which can withstand some root disturbances during transfer can be successfully grown in these containers; and

(d) containerized seedlings often have abnormal shoot/root ratios and coiled root systems. Controlling size of shoot and shoot/root ratio through the use of the best container size needs to be introduced as a standard nursery practice. For species requiring containerization, root trainers should be used where possible.

Planting Design

Planting design involves the pattern and spacing between trees. The pattern commonly used is the square or rectangular. In the square pattern, the distances between plants in the row and between rows are the same. In the rectangular pattern, distances between rows exceed those in the row. Examples are: Eucalyptus deglupta is spaced at 4 m x 4 m, Paraserianthes falcataria at 4 m x 2 m in the Philippines and Araucaria cunninghamii 3 m x 2.50 m in Papua New Guinea.

Planting pattern and spacing are determined by the silvicultural requirements of the species, the objectives for which the trees are being raised, plantation management methods and cost considerations. Species with spherical crown shape (for example, Mangifera indica) are appropriate for the square pattern, but those with a cylindrical form are better suited for rectangular planting. Some species are raised very close in a square pattern for self-pruning in the early period of life to obtain knot-free timber. Larger rectangular spacing, on the other hand, can provide open space between rows for agroforestry. If management aims at getting intermediate yield, closer planting initially allows mechanical thinning at a young stage. This allows for recovering some of the higher investment cost due to the greater number planted.

These planting patterns and spacing are suitable for industrial plantations but inappropriate for revegetation where soil and moisture conservation and production of fuel and fodder are more important. In this latter case, planting on the contour in V-ditches or the equivalent, with contour barriers of suitable shrubs or vetiver grass is the preferred option. The pattern and spacing of trees would be approximately 1 m apart in the rows and about 3.5 m between rows, depending on the slope. The steeper the slope, the lesser the distance with contour hedges of grass or shrub grown between tree rows.

Issues Concerning Planting Methods. Planting design for watershed revegetation should avoid the usual square or rectangular pattern and spacing followed in plantation forestry. The dual objective of providing benefits to people and of soil and moisture conservation is best served if trees are planted close in rows in contour V-ditches, or in pits, and between rows a contour hedge of useful shrubs or grass. The hedge will assist in soil and moisture conservation, provide twigs and leaves for low-quality fuel, and the trees can supply most of the other products needed by people, including fodder, poles, small timber, etc.

Protection

Protection of revegetated sites during the establishment period may be done by fencing, watch and ward, social consent or by a combination of these methods. Fencing types used include cattle-proof ditches, stone walls, barbed wire fences, electric fences and hedges. Watch and ward employs persons to guard the plantation. Social consent infers that the people voluntarily desist from using the plantations for a certain period. Protection by social consent is the most appropriate and inexpensive method but also the most difficult to execute. A minority group or even one person in a village may damage the plantation. An unconcerned man may accidentally burn the young crop. Stray cattle, by browsing among the seedlings, may put back the growth of trees by several months. Fencing becomes ineffective if local people do not accept it. Protection by watch and ward is effective if people cooperate with the guard. Hence, low-cost fencing, such as a vegetative hedge, and watch and ward with community cooperation perhaps would be the ideal combination.

Fencing. Several options in terms of efficacy, cost, material, and level of technology and maintenance pertain to the use of barriers to protect plantations in upland Asia.

Cattle-proof ditch is a common method of fencing in many parts of India. They are dug around the plantation, having vertical side walls, variable sizes (generally 60-90 cm wide, 100 cm deep) with the soil heaped as a ridge on the plantation side. The trenches are interrupted by half-cut transverse walls at intervals to ensure that the trench does not form a running gully. The trenches are not desirable for a number of reasons. They are expensive, costing about 25% of the total plantation cost, hard to dig where there are rock outcrops on the surface or at shallow depths, promote severe erosion where ditches run along the slope, and are ineffective if any part is breached or filled with soil washing down the ridge or collapsed side walls.

Stone walls are convenient if sufficient stone is available on site. The walls should be at least 1.5 m high and 0.3 m wide. Often in the hills, irregular shape and hence lengthy boundaries make walls very expensive.

Barbed wire fencing is very effective against men and animals and can be recommended, even if expensive. Wire is often stolen as it has resale value and continuous repair makes it even more costly.

Electric fences have been introduced recently in parts of India and Southeast Asia, particularly to protect crops from cattle and wild animals. Their use can be totally negated by human interference as damage to one portion makes a large part inoperative. In addition, forest workers in many developing countries are not trained to keep them under repair.

Live hedge is the least-cost and most appropriate form of fencing. Selection of species for the hedge can be made from a large number of shrubs in each site. In India, some common hedge plants are *Agave* spp., *Ipomea* spp., *Euphorbia* spp., *Duranta* spp., *Cactus* spp., *Vitex* spp., *Barberis* spp. Such hedges not only protect the plantation, but can provide fuelwood and other products if properly managed. The difficulty with the hedge as a fence is that it has to be raised at least two years in advance of plantation planting, unlike other fences which can be built in the year of plantation.

Watch and ward is the most common method of protection in Bangladesh, Burma, India, Nepal, Pakistan, and Sri Lanka. Guards selected from the local village are effective if villagers cooperate. A guard can look after an area of 10 hectares in the plains and about 6 hectares in the hills. Employment is a recurrent cost and can be prohibitively expensive if a guard has to be employed beyond the first 1-2 years.

Social Consent. People will normally agree to protect the plantation voluntarily if they are involved in planning, execution, management and are recipients of the benefits that may accrue from it. But rarely in the past have villagers been consulted in revegetation projects in the uplands. Aguilar (1982) reports indifferent success of four forestry projects in upland Philippines due to noninvolvement of people. Many community woodlands raised under social forestry projects in India have been destroyed by the people themselves. On the other hand, there are examples of forest protection by social consent. Villagers of Chamoli district in the Western Himalayas of India, who initiated the Chipko movement to ban Government tree felling in 1972/73, have now focused their attention on raising plantations and protecting forests (Agarwal, 1986). In West Bengal, villagers on their own initiative protected about 120,000 ha of *Shorea robusta* forest by 1973 (Banerjee, 1978) and 150,000 ha by 1988. Eckholm (1979) reports successful planting of over 643,000 ha of village woodlot by village forestry associations in South Korea.

Issues Concerning Protection. Protection by social consent is the most inexpensive and desirable method of protection. But a minority of one uncooperative person may damage the revegetation effort. Hence, social consent combined with some form of fencing or watch and ward is necessary for protective fencing. Among fencing options, the live hedge seems to be the ideal method. Not only does it protect the area from stray cattle, but the hedge can be managed to provide fuelwood and other useful products for distribution to people. The difficulty with the hedge method is that it should be established at least two years in advance to be effective by the year of plantation. Other forms of fencing using materials such as barbed wire or stones, though commonly used, are generally ineffective, expensive, and should be discontinued wherever feasible. Cattle-proof trenches, as used in India, are a source of erosion and should be discontinued.

Management

For this discussion, the term management refers, narrowly, to only silvicultural practices that exploit a revegetated area for sustained yield. As mentioned earlier, soil and moisture conservation and meeting local needs for fuel, fodder and food are the primary objectives of revegetation. Management practices, therefore, have to be oriented towards these objectives, yet few examples of managing upland revegetation can be cited that have attempted to attain these objectives simultaneously.

Current management practices can be broadly divided into two categories: protection and fixed-rotation harvesting. The first involves a hands-off approach that uses vegetation as a protective cover and induces indirect yields through water and soil conservation. Such areas are fenced and looked after by intensive watch and ward for a few years to keep local people and cattle out. Hardly any silvicultural treatments are carried out, except for weeding, fire protection and climber cutting in the initial 2-3 years. The second involves exploitation in short rotations. Usually such areas are coppiced (5-15 year rotation) if the species are suitable, or they are clearfelled and the area replanted. *Eucalyptus* spp., *Leucaena leucocephala*, *Prosopis juliflora* are examples of species having coppicing ability. Those clearfelled include *Acacia nilotica*, *A. auriculiformis*, *Cassia siamea*, *Faidherbia albida* and *Pinus roxburghii*. Before harvest by coppicing or clearfelling, there is no other operation except grass cutting or weeding. Both are, to a large extent, adversely affected by local disturbance through illicit grazing, hacking and intentional burning.

The objectives of soil and moisture conservation, on one hand, and fixed-rotation harvesting for supply of products to upland villagers, on the other, can be in conflict unless management methods are substantially changed. Disturbance of the understory and forest floor (litter, humus layer, root mat) during the removal of trees in upland areas exposes the soil and accelerates erosion. At the same time, harvesting trees is essential to provide round wood for people. The supply of forestry products only at the rotation age (say at 5th, 10th, 15th, 20th years if the rotation age is 5 years) is unsatisfactory, as the community needs small amounts of products such as fuelwood and fodder regularly.

Silvicultural operations such as annual brashing, low and high pruning, pollarding, coppicing, selective thinning every year are some of the management methods most applicable for arranging regular supply. For example, on a plantation of *Prosopis juliflora* and *Acacia nilotica* in Karnataka, India, the rotation of *A. nilotica* is fixed at 15 years, while *P. juliflora* is regularly lopped and the harvest supplied to people after it has reached the age of three years. *P. juliflora* continues to develop leafy shoots which act as a soil cover in spite of annual lopping. Another interesting example of dual-purpose management is that of *Leucaena leucocephala* regenerating profusely under its own shade in Haryana, India. The overhead canopy is retained with a long rotation, while cattle are allowed to graze the vegetation daily.

Annual silvicultural operations such as brashing, pruning, thinning and coppicing are expensive and ought not to be done by regular employees. Under the technical guidance of the responsible line department, beneficiaries should take over the management and benefit distribution of such plantations. Social forestry projects in India have community land and roadside plantation components that aim at local management. Dani and Campbell (1986) report that one third of the villages in Nepal have at least one local forest under local management and the number is increasing.

Issues Concerning Management. Very few examples are available in upland revegetation programs of successful management to attain soil and moisture conservation and regular production of goods for local people. Either they are managed as protection forests, or else they are cut at fixed-rotation intervals to produce fuel and other products. The dual-purpose technology for soil and moisture conservation and production of goods in the same area has to be designed. Raising of shrubs and grasses, such as vetiver grass, on contours as hedges under the overhead tree canopy is an appropriate design for this dual purpose. The hedge can act as the soil and moisture trap and supplier of twigs and branches for fuel, and the tree the major supplier of other products. Regular supply can be arranged only if annual silvicultural operations such as brashing, low and high pruning, topping of the hedge and thinning the top canopy when possible are introduced. The hedge should be a species that can withstand annual cutting and topping and yet develop enough shoots to protect against soil loss and continue as a hedge. All these operations are expensive and cannot be repeated unless the management is carried out by local beneficiaries who voluntarily execute the job for their own consumption.

CONCLUSION

Upland revegetation efforts in Asia have seldom been successful. Although failure is generally attributed to techniques, in many instances biotic factors such as cutting, unrestricted grazing, and intentional burning by the local population have dominated. The introduction of technology without the active participation of local inhabitants in the revegetative program is ineffective. Their participation can be assured only if they are involved in different stages of the revegetation program including benefit-sharing. The technology should aim not only at producing fuelwood, fodder, and employment opportunities and at promoting soil and moisture conservation, but also at involving them in its adaptation and use. A review of available technology reveals a number of shortcomings. Choice of species has overemphasized trees, exotics and monoculture. It is argued that the introduction of shrubs, indigenous legumes and grasses, on the contour as a hedge, should find a place in land stabilization and the regeneration of vegetation.

Ground preparation includes removal of ground vegetation, windrowing, burning, and soil manipulation. Removal of ground vegetation, an established practice, may have serious erosion implications, although planted seedlings cannot compete otherwise with existing vegetation. Burning supposedly releases nutrients from biomass waste, but may also increase erosion. In soil manipulation, pitting is the common practice in Asia, often done manually and rarely by machines. In planting methods, reintroduction of direct sowing and more use of bare-root planting and biodegradable containers to reduce cost are proposed. In planting design, it is suggested that planting with a shrub hedge on the contour in between the tree rows should replace the present method of square planting. Regarding protection, social consent with watch and ward or with a live hedge raised at least two years in advance is preferable to other forms of fencing. Management of revegetated areas presently comprises two methods: complete protection without any harvesting and regular harvesting at the rotation age. Both methods fail to consider the needs of local villagers for a continuous supply of products. This can be satisfied by introducing silvicultural practices such as annual brashing, low and high pruning and topping of the hedge and thinning of the top canopy of trees.

Table 5.1: TREE SPECIES CITED

Genus	Species	Common Name
Acacia	auriculiformis	Northern black wattle, ear podwattle
Acacia	catechu	Khair (Nepal)
Acacia	mangium	Mangium, brownalwood, hickory wattle
Acacia	nilotica	Egyptian thorn; red-heat, kudupod, "sweet smell," babul (India); kiker, babar (Pakistan); sunt, ruikperul (Arabic)
Aesculus	indica	Lekh-pangar, Nark (Nepal)
Araucaria	cunninghamii	Hoop pine
Araucaria	huntsteinii	Klinki pine
Azadirachta	indica	Neem, nim
Bauhinia	villosa	Orchid tree
Butea	frondosa	Flame-of-the-Forest, dhak (India), Palans (Nepal)
Cassia	siamea	Yellow cassia, minjri, moung, angkanh, kasof-tree, Bombay blackwood, cassia (French)
Castanea	spp.	Chestnut
Casuarina	equisetifolia	Casuarina, Australian pine, agoho (Philippines), ru, aru (Malaysia), nokonoko (Fiji)
Cedrus	deodara	Deodar; Diar, Devadaru (Nepal)
Cryptomeria	japonica	Sugi (Japan); Dhupi salla (Nepal)
Dalbergia	sissoo	Sisso, sarsou, shisham, nelkar, karra, tanach, tali, yette
Dipterocarpus	macrocarpus	Hollong (India)
Dipterocarpus	turbinatus	Garjan
Eucalyptus	camaldulensis	Red gum, river gum
Eucalyptus	citriodora	Spotted gum, lemon-scented gum
Eucalyptus	deglupta	Kamarere (Papua New Guinea), bagras (Philippines), leda (Indonesia)
Eucalyptus	gomphocephala	Tuart
Eucalyptus	grandis	Flooded gum, rose gum
Eucalyptus	pilularis	Blackbutt
Eucalyptus	tereticornis	Blue gum, mountain gum, red gum; Mysore gum (India)
Faidherbia	albida (Acacia albida)	Apple ring acacia, Haraz
Juglans	spp.	Walnut
Kydia	calycina	Kubindeh (Nepal)
Leucaena	leucocephala	Leucaena, ipil-ipil (Philippines), subabul (India)
Mangifera	indica	Mango, amp (Nepal)
Paraserianthes	falcataria (Albizzia falcataria)	Batai, Molucca albizzia, sengon, falcata, vaivai, puah, white albizzia, tamalini, marfa, placata, djeungjing
Pinus	caribaea	Caribbean pine, putch pine, pino de la costa, pino clorado
Pinus	halepensis	Aleppo pine, pino carrasco, sanaoubar halabi
Pinus	patula	Patula, Mexican weeping pine
Pinus	roxburghii	Chir pine
Prosopsis	juliflora	Mesquite, algarroba
Pseudotsuga	menziesii	Douglas fir
Quercus	incana	Bluejack oak, sano banjh (Nepal)
Robinia	pseudoacacia	Black locust, robinia
Shorea	robusta	Sal
Tectona	grandis	Teak, sagwan, sengon,

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6. LAND TENURE ISSUES IN WATERSHED DEVELOPMENT

Augusta Molnar

Intended to document why tenure is relevant to watershed projects and to provide a conceptual framework for making decisions related to tenurial issues during project design, this chapter is grounded in a review of the literature on land tenure and conservation and a review of relevant projects in China, India, Indonesia, Nepal, the Philippines, and Thailand. It begins with an overview of the importance of land tenure in watershed projects, describes some general principles of land tenure and categories of tenure systems found in the Asian uplands, discusses why the relationship between conservation and tenure has not been clearly understood, presents a conceptual framework for analyzing that relationship based on case studies, identifies measures for addressing tenurial issues in watershed projects, and, finally, suggests studies that should be undertaken to further the World Bank's operational understanding of this issue.

INTRODUCTION

Basic Objectives of Watershed Projects

Watershed development projects aim at improving the overall productivity, sustainability and equity of land use in fragile, arable and nonarable lands. Land tenure can be an important factor in achieving these goals. Productivity is linked to tenure because tenurial arrangements can affect both the profitability of present and improved farming systems and the ability of the cultivator to make the transition to an improved technology. Sustainability is linked to tenure because tenure affects both the initial decision to adopt practices to slow land degradation and the ability to maintain land improvements over the longer term. Finally, equity concerns are linked to tenure because project investments can reduce people's access to resources, including land; and new technologies may induce changes in land tenure, displacing people from their land and their employment base without providing viable alternatives.

It is generally difficult to identify strategies that optimize all three of the above objectives. Choosing a strategy for addressing tenure issues will inevitably require some trade-offs in project goals. For example, in the Amazon region, titling programs to induce squatters to adopt a long-term view of their holdings also resulted in increased land speculation and the opening up of new areas for agriculture, ultimately leading to further land degradation (Cullins and Painter, 1986). In the Southeast Asian uplands, private agriculture on steep slopes is not the ideal use of the land, but because of population pressure, improving local agricultural practices is more sustainable and equitable than trying to eliminate such land use (World Bank FFARM Study, 1989). Thirdly, closing lands to open grazing in South Asia and inducing graziers to adopt stall-feeding may lead to more sustainable or productive land use, but land-poor herders without pasture who cannot afford to stall-feed may be forced out of animal husbandry. Each case involves difficult choices.

Tenurial Issues in Watershed Projects

Land tenure includes the formal (state-recognized) and informal (customary) rights of access to different kinds of land, the rights to control products of that land, obligations to maintain the land, the rights of transfer, and rights to determine changes in use of that land. Formally and informally held rights in land may be in harmony or there may be conflicting rules within the system. Land tenure is not unchanging, but responds to new economic, social, political, and cultural factors on a continuous basis. Often, changes occur in the system when different interpretations of rights--by other farmers, the village council, the state, the forestry bureaucracy, or the courts--gain precedence in the resolution of a tenure conflict.

There are several reasons why it is important to be concerned with land tenure issues in watershed projects, all of which can be illustrated by examples from recent, World Bank-assisted upland projects.

(a) the type of tenure may affect the profitability, adoption rates, and the impact of proposed measures;

(b) efforts to change land tenure patterns to provide land-users with better incentives for sound management may have unintended, negative consequences;

(c) introduction of specific soil and water conservation technologies may affect land tenure patterns and have an unanticipated impact on local smallholders; and

(d) the failure to understand existing tenure patterns may lead planners to overlook promising opportunities to develop lands under particular tenure arrangements, especially informal systems or systems of group-management.

Land Tenure Systems in the Asian Uplands

There are many systems of land tenure in the Asian uplands adapted to specific ecological/economic conditions, cultural/historical traditions, and population densities. A summary of the range of tenure types is presented in Table 6.1. Some of the most familiar systems in Asia are:

(a) watersheds with relatively stable land tenure systems, such as the island of Java or Taiwan. These have few communal lands, more or less clearly demarcated state-owned lands, and complex owner-cultivator and tenant-cultivated arrangements, many of which are not clearly reflected in the official land registers;

(b) watersheds with relatively ancient, state-recognized land tenure systems, such as Burma, China, India and Nepal, where collectively-managed resources, usually called common property resources (CPR), are an important part of the formal and customary (informal and de facto) tenure rights; and

(c) watersheds in "frontier" areas, such as the Philippines, north Thailand, Malaysia, or the Outer Islands of Indonesia, where a limited proportion of cultivators has state-recognized tenure rights, and a large portion of forested and unforested land is usually designated as state forest. Cultivators in such areas include indigenous ethnic minorities (including tribal groups) who have a long-standing land-use traditions and informal tenure based on ancestral rights; settlers, often belonging to majority ethnic groups whose actual tenurial arrangements tend to emulate those elsewhere in the country; and recent migrants on newly-cleared lands.

These tenurial differences are important because each system may lend itself to different forms of technical and social intervention.

Table 6.1: CHARACTERISTICS OF DIFFERENT TYPES OF TENURE ARRANGEMENTS IN THE ASIA REGION RELEVANT TO THE ADOPTION OF SOIL AND MOISTURE CONSERVATION

Tenure category	Guaranteed long-term access to land (security)	Access to credit/ capital	Ability of user to make development decisions	Ability to protect land from others	Percentage of returns to user of land	Ability to transfer rights of ownership
Privately-owned with title	High	High	High	High	High	High
Privately-owned without title	Medium	Medium	High	High	High	Medium
Leased from relative	Low	Medium	Medium	High	Medium	Low
Fixed renter from unrelated owner	Low	High if owner contributes	Low	Medium/high	Medium	Low
Sharecropper from resident owner	Low	Low (medium if owner contributes)	Low	High	Low to medium	Low
Sharecropper from absentee owner	Low	Low in general	Low	High	Low	Low
Private cultivator on public lands	Low	Low	High	Depends on management system	High if not paying rent to pseudo-landowner	Low
Perum Perhutani model of longer taungya leases (Java)	Medium	High	Medium/high	Low/medium	High	Low at present
Forest associations (FOSAs) (Philippines)	Medium	High	Low	Medium	High	Low at present
Local grazier on village common land	High	Low	Low	Depends on management system	Depends on management system	Depends on management
Local grazier on state revenue lands	Low	Low	Low	Low	Depends on management system	Depends on management
Tree tenure/leases on state revenue land (India)	Medium	Low	High	Low	High	Low
Cost-sharing of forests giving user protection duties (West Bengal, India)	High	High	Low	High	High (could be higher if products expanded)	High within village
Recognizing customary rights over forests	High	Low	Depends on Forestry Department/ village relations	High	Can be high	High within village

Population Pressure and Land Tenure

One characteristic that makes land tenure systems so distinctive in most of the Asian uplands is the high population pressure on scarce resources. While population densities in the lowlands are widely recognized as affecting socioeconomic conditions in Asian countries, their effect has not been as apparent for the uplands, because the high proportion of nonarable lands tends to make densities seem low. Statistics comparing lowland and upland population densities are misleading, because they do not usually factor in the limited amount of cultivable land in the upland areas. In Thailand, Cohen (1983) calculated the number of persons per km^2 of cultivated land and found that pressure exceeds 500 persons/km^2 in 58 out of 64 districts of seven northern provinces. Comparable figures for other upland areas are 560-1,000 persons/km^2 for upland Java, 530 persons/km^2 for upland Nepal and 215 persons/km^2 in the Philippines' uplands. If the lower productivity of upland soils is factored in, this is a striking picture.

Given the importance of population density in determining land use in much of Asia, this review has focused on case studies of tenure systems and projects in relatively populated watersheds; examples are also included from the relatively underpopulated Outer Islands of Indonesia, parts of Malaysia, Bhutan, and Papua New Guinea, where the tenure issues and trade-offs are less constrained by competing demands on scarce resources.

Factors Obscuring the Impact of Tenure in Watershed Projects

The data are ambiguous regarding the effect of tenure on adoption rates in ongoing or completed watershed projects and the analysis has been confused by a number of factors, such as quality of the technology packages, subsidies, and lack of knowledge about the land tenure situation in project areas.

(a) Many of the technologies promoted (gully plugs, bench terracing, vegetative contouring or afforestation) have not been as economically attractive as anticipated. Either they have been too expensive (in terms of labor and capital) for the cultivator to adopt, given the long time before benefits start to flow, or they have not led to the projected increases in yields and cash returns, with the result that neither owner-cultivators nor tenants had an incentive to adopt. Projects have also ignored variations in the availability of household labor and assumed profitability would be the same in differing households. In such cases, land tenure has often been cited as a problem, whereas the issue is related to poor choice of technology.

(b) Because of the high, initial cost of adoption, many technologies have been heavily subsidized. In such cases, it is impossible to separate the effects of land tenure on adoption rates from the incentives provided by the subsidy. In some projects, in sites with considerable differences between recorded tenure rights and actual tenurial arrangements, project staff have no idea whether subsidies were paid to owners or cultivators/ land managers, so separating their effects becomes doubly difficult.

(c) There has been little monitoring of the effect of tenure on adoption rates. Where data have been collected, project staff have often failed to understand the tenure system and either lumped a number of distinct tenurial types into one analytical category or failed to recognize the existence of a range of customary land tenure arrangements. In India or Nepal, common property resources (CPRs) have been falsely perceived either as open access or private lands, when in fact there were effective, informal systems for their management. Alternatively, truly open access lands have been lumped together with collectively-managed lands for purposes of analysis, leading to an overly pessimistic picture of the scope for CPR management. In both South and Southeast Asia, corporate-owned private lands have been mixed with individually-owned lands, with negative results when development programs attempt to interact only with individual landowners.

Improving Analysis of Land Tenure Factors

A significant problem with attempts to evaluate the effects of land tenure is that studies have been too simplistic. The commonly studied, predetermined sets of tenure categories--owner-operator versus tenant-operator on private lands and private land tenure versus public land tenure for the system as a whole--are largely meaningless for analyzing the relationship between tenure and adoption rates in most Asian settings. A sound study would first identify the full range of tenure types in the project area, the characteristics of tenure that affect the adoption of proposed technologies, and then select the tenure types that should be evaluated. In a dynamic tenure system, there are multiple rights and obligations, not just the rights of long-term access to the land commonly associated with the word "title." These other rights will affect adoption rates.

Another important point is that distinct tenure types represent points on a continuum in any tenure system and may not fall squarely in a preset category such as "privately-owned," "corporately-owned," "communally-owned," or "publicly-owned." This is not to say that the rights and obligations pertaining to a tenure type are ambiguous, but that these groupings obscure important tenure dynamics. For example, village grazing lands in northwest India include shamlat i deh, a tenure type which allocates a legally specified set of landowning households primary rights to that grazing land in proportion to the size of their private holdings in the village. Resident landless families have only secondary rights to grazing that land at the behest of village landowners. In addition, any trees planted in this "common" or "corporate" land belong to the person who planted them. This "tree right" is not found in village lands in other regions of the country. Shamlat i deh thus functions as a place to plant privately-owned trees, a corporately-owned grazing land, and through the concessional rights to landless, as communal land (Stewart, 1989). In addition, since anyone is entitled to right of way for this land, it functions as a public land. In the conceptual framework presented in Table 6.1, there has been no line drawn between public and private land tenure types. Some of the tenure types on the public end of the continuum have as many characteristics which support adoption of improved land practices as tenure systems on the private end of the continuum.

CHANGES IN LAND TENURE AND THEIR IMPACTS

Impact of Tenure on Adoption of New Technologies

In the current World Bank-assisted watershed development projects in the Asia region, a number of soil and moisture conservation technologies are being promoted, including:

(a) structural works, such as bench terraces, contour banks, gully plugs and water diversion channels and drainage channels, to manage surface runoff and sedimentation;

(b) vegetative barriers on the contour, such as vetiver grass, fodder grasses, or mixed conservation hedges of shrubs, grass, and trees to keep moisture and silt on the site;

(c) cultural treatments and improved cropping systems to improve farm production in a manner that protects soil and moisture status;

(d) agroforestry technologies that provide a long-rotation crop for steep, fragile soils; and

(e) silvipastoral or pastoral technologies that provide ground cover, fodder, and forest products.

A pertinent question in the Asian watersheds concerns the extent to which tenurial arrangements affect the adoption rates of these technologies. A logical assumption has been that cultivators will be less likely or unlikely to adopt technologies which have a long time-lag before they begin to generate benefits, or stated in a another way, which require a high level of investment without a commensurately high, short-term return. Following from this assumption, where tenure status is weak, the most appropriate technologies to promote should be those with quick returns and minimum levels of investment. These include the vegetative barriers and mixed silvipastoral models mentioned above.

Tenure has a significant impact on the profitability, adoption rates, equity, and long-term sustainability of interventions. The farmer's sense of long-term tenure security will affect his willingness to undertake land improvements. Private cultivators with secure title rights, tenants who are relatives of the owners, or corporate groups with secure land-use rights are more likely to take a long-range view of land productivity. Sharecroppers with short-term or indeterminate contracts, nonresident landowners who are more concerned with land as an investment than in its annual productivity, and village graziers with only concessionary rights to forest or grasslands are all unlikely to take a long-range view of the resource. Tenure may also affect a farmer's access to credit for land improvements where written title is a prerequisite of creditworthiness.

Effect of Tenancy on Improved Practices

Tenancy arrangements affect the profitability of an intervention differently, depending on the rent paid out, the terms of produce-sharing and the length of the contract. There is a wide range of tenancy arrangements in the Asian uplands, and when targeting technologies, it is useful to understand the particular range found in the project area. The case-study data from India and Java document many informal produce-sharing and rental arrangements that do not conform to the legal code, which makes it difficult to collect accurate data on their extensiveness (Mackie, 1989; Khasnabis and Chakravarty, 1982; Cohen, 1983). Arrangements differ depending upon the productivity of the land, the reason the owner is leasing out the land, the market orientation, and the relationship between owner and tenant. Studies indicate that as many as 50% of the cultivators who rent or sharecrop land may be friends or relatives of the owner, and that these tenants receive more favorable terms and more latitude in decision-making than other tenants. In Thailand, relatives avoid "key money" (right-to-lease payments made to the owner distinct from the regular terms of the actual contract) and in Java, produce shares are greater (Mackie, 1989; Cohen, 1983).

Different categories of landlords also respond differently to such technologies. Some poorer farmers temporarily rent out parcels of land to get short-term capital or to deal with scarce labor problems. They will not contribute to inputs or encourage tenants to develop the land, lest they lose claim upon it. Another consideration in adopting new practices is whether the tenant or owner is expected to provide the inputs. A disadvantage for tenants who have secure tenancy contracts is their lack of access to credit for inputs. Case studies from South India indicate situations in which owners provide sharecroppers with inputs, either when tenants are destitute and cannot even afford seed or when the owner's investments can clearly increase profitability to both owner and tenant. In this latter situation, there may be considerable scope to encourage landowners to help tenants invest in high-return, soil and moisture conservation measures. Absentee landowners are, however, a category of owners who are unlikely to encourage land improvement. As nonresidents of the village, they tend not to concern themselves as much with long-term land productivity and tend to discourage tenants from undertaking improvements lest they weaken the owner's claim to the land. One exception to this rule is in regions where land reform legislation is enforced, as in parts of South India, where tenants are often the main decisionmakers on the estate and absentee owners are afraid to set terms.

Impact of Land Titling

Recognizing the linkage between tenure and the incentives to undertake land improvements, a number of upland projects have included components to strengthen tenurial status. By far, the most common of these is land titling. Watershed projects have included titling components to provide incentives for farmer participation in programs, to enhance the farmer's tenure security, and to provide the farmer with access to formal sources of credit. A mixed picture emerges on the relationship between titling and land improvements. The only in-depth study for Asia was undertaken in northeast Thailand (Feder *et al.*, 1988). It compared the productivity of farmers with titles and those with certificates of occupancy and concluded that titles had a significant impact, mainly because of their value for obtaining loans with land as collateral. Since farmers had been resident in the area for some time, security did not seem to affect the decision to invest in the land. The Thailand study argues strongly for titling components in projects that promote soil and water conservation and other land improvements in order to give farmers access to capital and enable them to transfer title and improvements to their heirs.

Unfortunately, there are few comparative data to generalize to other regions or countries. The ongoing titling project in Thailand has been very successful, but no new data have been collected from it on the relationship of titling to agricultural productivity. In India, where rural credit is provided at subsidy, it has usually been monopolized by larger farmers and few marginal and small farmers have gotten formal credit, regardless of whether they had titles to the land they cultivated. Some analysts of the Thai case argue that once titling programs increase the number of farmers seeking credit, a similar problem of credit rationing will occur. Where technologies require formal credit, however, as in the case of fruit tree schemes in Java, providing certificate of title may be an important inducement for participation in the scheme.

Lack of tenure security seems to be more important where customary rights are not strong and farmers without title are worried about eviction. Unfortunately, the lack of data makes it difficult to evaluate perceptions of security. Titling has been carried out as part of the Yogyakarta Rural Development Project in Java where customary rights are recognized, but land records still pertain to surveys carried out when the province was a princely state. No formal study has been made of its effect on productivity, though a consultant's report indicates that some farmers with newly titled home gardens have used their new access to credit to invest in still-untitled drylands (Mackie, 1989).

Land Certificates or Land Leasing

In the "frontier" areas of Southeast Asia (Malaysia, Thailand, the Philippines, Outer Islands of Indonesia, Papua New Guinea), large tracts of steep land designated as state forest land have been converted (sometimes prior to their designation as state land) to shifting or permanent cultivation. As governments become more interested in preserving natural resources, there is an increasing controversy over whether to move such people out of designated forest areas or legitimize their land rights. In most areas, it has proven counterproductive to evict already-settled inhabitants of lands designated as forest. Programs to increase tenure security in such areas include formal titling of holdings, granting of limited-use certificates in state forest lands, and/or formalizing customary land rights.

In Thailand, limited-use certificates have not been very effective (Feder et al., 1988), because farmers already have customary security of tenure and would only change their agricultural strategy if they have more access to formal credit channels through titling. In contrast, in the Philippines or parts of the Outer Islands of Indonesia, where residents may not have the clout to protect their holdings from outsiders, certificates may serve an important function as an intermediate tenure step to prevent transfer of land (World Bank, FFARM, 1989). It is, therefore, important that limited-used certificates be carefully evaluated as to the rights they are intended to provide.

In some areas, limited-use certificates have been used to ensure that the farmers plant only specified crops, such as trees, on steeper slopes. However, this has not been very effective. The certificates of use issued in the Philippines for state forest lands specify that farmers must put 10% of their land under trees for conservation reasons. This rule is not complied with unless the farmer finds an economic as well as conservation reason for adopting such a practice. Programs encouraging tribal farmers in Thailand to change their swidden cultivation practices to more intensive agriculture have also had limited success due to the poor returns from recommended technologies (Hoare and Larchrojna, 1986). Unless an intervention is perceived as economic, no farmer will adopt it, regardless of tenure.

Land Consolidation and Land Redistribution

Other tenure changes have been promoted through land redistribution or land consolidation programs. In both instances, there is little evaluative information and what exists does not indicate a strong relationship between implementing these programs and increasing levels of productivity and sustainability. Two positive examples exist of land consolidation measures. One is a World Bank-assisted Moroccan project (Meknes Rural Development Project) in which land consolidation was carried out to create more viable holding sizes for agricultural development and land stabilization (World Bank, Meknes PCR, 1987; Adams and Seddon, 1983). The success of this initiative was linked to the identification of enough different soil types so that farmers could maintain a diverse farming strategy. The second example comes from Gujarat state in India, where the soil and water conservation service has reallocated some field boundaries along the contour in consultation with farmers to make adoption of conservation measures less cumbersome.

In general, land redistribution and land consolidation programs are tricky to implement and require political will and an efficient bureaucracy. The evidence collected so far (Herring, 1983) is that such programs are best implemented for their equity objectives, rather than to increase productivity. There are numerous instances in which reforms were not accompanied by adequate technological packages or support services, and many of the cultivators who were allocated land did not stay on that land over the long term or rented out the land due to economic need.

Special Issue: Tribal Land-Use Rights in Forest Areas

To date, inadequate attention has been paid to the scope for introducing improved agricultural practices that are based upon traditional systems in forest areas. Bank guidelines on indigenous peoples and development expressly state that "the Bank will not assist development projects that knowingly involve encroachment on traditional territories being used or occupied by tribal people unless adequate safeguards are being provided." Government and Bank policy on this point has been confused by the general lack of understanding of the dynamics of tenure and the resultant attempt to fit a variety of indigenous systems into tight categories of "private farms" and "public forest." Despite some progress, the issues of what land-use rights should be recognized is largely unresolved in traditional swidden cultivation areas and in those areas where indigenous people may have moved in response to pressure from more powerful migrants. A case in point is the situation in the Outer

Islands of Indonesia where tree crop schemes have provided outsiders with title over lands that indigenous groups perceive as theirs.

Where governments have been willing to recognize the rights of local people to forest lands, such as in Thailand under the Highland Agriculture Development Project, a mistake has been to try to adjust customary land rights to fit preexisting legal categories, rather than to adjust legal categories to traditionally viable systems. In the Thai case, applying the statutory land ceiling in the uplands resulted in uneconomic holding sizes, given the productivity of the land and potential household economic strategies. Even with the intensification of agriculture proposed in the project, farmers did not think they could support themselves and most farmers refused to participate in the land titling program. With a more flexible body of land legislation, ceilings could have been adjusted in the tribal area and made to conform more closely to customary systems. The same problem has been recognized in the Philippines. There, a proposal has been made to the government to formalize ancestral, communal rights to lands in areas with tribal residents, rather than titling these lands to individuals, and preserve the more sustainable, traditional system (World Bank FFARM Study, 1989; Lynch and Talbot, 1988).

THE SCOPE FOR COMMON PROPERTY RESOURCE (CPR) MANAGEMENT

Emerging Principles

In those Asian countries with long-standing tenure traditions, including lands designated as common property resources (Bangladesh, Burma, China, India, Nepal), watershed development has emphasized individual, owner-cultivated lands to the neglect of noncultivable lands held by corporate groups or public lands managed as a common property resource (CPR). This is an important issue for watershed stabilization, since nonagricultural lands make up a large proportion of land in the watershed and can be important sources of products within a farming system.

Under high population pressure, it is almost impossible to manage state lands by excluding local people. Projects are therefore exploring systems for management of public lands by corporate groups or surrounding communities. However, early evaluations of the World Bank's experience in South Asia in promoting common property resource management on village lands, state revenue lands, and forest lands were generally pessimistic (Naronha, 1985; World Bank, India National Social Forestry Project, 1985, Uttar Pradesh and Gujarat Social Forestry Projects, 1988; Blaikie, et al., 1985; Ljungman, McGuire, and Molnar, 1987). The conclusion has been that such strategies fail due to the heterogeneity of most communities and their control by a small group of elites, the breakdown of indigenous systems in the face of population pressure and market orientations, the privatization of many CPRs by industries and encroaching farmers, and the lack of equity in distribution systems established for products.

Recently, however, more positive experiences with CPR management are being documented on both communal and state-owned lands, and projects are becoming more sophisticated in their understanding and approach to the dynamics of CPRs (Stewart, 1989; Dani and Campbell, 1985; Arnold and Campbell, 1986; Guhathakurta, 1989; Brara, 1987). What is striking about the recent literature, however, is that the principles for effective common property resource management that are being discussed directly contradict the strategies promoted in earlier forestry and watershed development projects.

Addressing Problems in CPR Management

Under the World Bank-assisted social forestry project, which started in 1982, farmers in West Bengal were encouraged to plant trees on marginal lands that had been allocated to them on 99-year, unlimited-use leases as part of a land redistribution scheme. These lands had been considered too degraded to support crops, but tree planting proved to be a profitable, alternative land-use strategy. This program, locally dubbed "group farm forestry" because of the joint responsibility taken by blocks of farmers for protecting the trees, was successful (World Bank, 1985; Molnar, 1986; Shah, 1987). However, this system did not work in states which did not have active land reform programs, but tried to emulate the scheme in a more restrictive manner by giving landless cultivators plots of government land to be used solely for tree-planting. Unlike the West Bengal leases, which allowed individuals to do anything they wished with the land, in other states the lease was limited to tree planting and the lease period confined to the life of the plantation. These schemes failed to reach their targets, due to recipients' lack of capital and labor, lack of confidence in their long-term use rights, the power of local elites to co-opt some lands, and the fact that communities believed the government to be alienating lands for which they had informal rights. The schemes also created a legal precedent for further undermining common property rights.

More recent interventions in India and Nepal have found models for generating sustainable land management of common property resources; each shares the following characteristics:

(a) management resting with a locally constituted users' group, building on both customary and formal institutional arrangements (regulating long-term access, use and protection of the resource);

(b) publicly-acknowledged rights and duties of the users regarding the resources in question, and the ability of users to make decisions about development or utilization;

(c) a regular flow of outputs valued by the users, i.e., at least an annual flow of produce, not merely a one-time harvest;

(d) a distribution system that reaches diverse elements in the population without excluding the interests of power brokers in the community;

(e) a protection system that has clear, easily enforced rules of compliance; and

(f) a public authority (such as the forest department or district council) at a higher level that supports the local-level authority over the resource against outsiders.

These characteristics were missing from earlier social forestry models. Shortcomings were that management was given to an artificial, political body with no customary management responsibilities; rights and duties were not known to the majority of users (that is, formal agreements with the forest department were only shared among a few key village leaders); distribution was skewed away from local power brokers; and the protection system was alien to local customs and difficult to enforce by local people.

While the problems of sustained management of state lands in upper catchments are not solved, the basic principles and how to apply them are beginning to be clarified. Lessons learned from South Asia are, first, that traditional systems of CPR management rarely provide equal returns to all users, that is, distribution of benefits tends to be skewed toward the elite and vested power brokers. Effective systems are those that provide substantial benefits to both resource-rich and resource-poor individuals, not necessarily equal benefits to both. Second, approaches must be tailored to the sociopolitical context of the project location, rather than fit an ideal type of CPR management.

Legal Issues in CPR Management

In devising an effective intervention, three aspects of CPR management are essential: consideration of the resource's potential productivity including the range and kinds of products that can be generated for local or national needs; review of the formal and informal institutions that govern use, access, management, and development of that resource; and knowledge of the formal, legal status of rights in a particular resource and how the legal rights relate to customary rights or to the actual use of the resource. A common mistake in project planning for nonagricultural lands has been not to investigate the legal as well as customary tenure status of lands designated as common or public.

Few countries have a consistent set of rights and obligations for different users of common-property resources. There can be conflicting rights over a CPR that may each be valid from a different legal standpoint. Where customary rights pertain to a piece of land, these may be equal to or have precedence over the formal rights prescribed in written law. When designing measures to encourage CPR management, it is important to analyze correctly the interrelationship of conflicting tenurial claims to a piece of land. Where the desired intervention to strengthen management by a community of users is a legal one, the correct point of legal intervention must be well understood.

Tenurial rights governing the use of a piece of land can be legally present at any of five distinct levels (C. Singh, 1989). These include: (a) customary or traditional rights (e.g., village grazing rights, tribal forest rights); (b) administrative orders regarding use of lands (e.g., forest department rules concerning collection of headload fees or forest closure orders); (c) court rulings regarding existing legislation; (d) state and national legislative statutes regarding the rights over lands (e.g., the Indian Forest Conservation Act); and (e) constitutional law regarding citizens rights in land. Conflicts over use rights occur because there is a discrepancy in the rights at two or more different levels. (See Table 6.2.) To identify the proper measure to strengthen CPR management, it is often necessary to identify conflicting claims and take legal or policy steps to alleviate the conflict. At each level outlined above, the solution will be different. The solution to weak CPR management may rest upon the formal recognition of existing customary rights (local, level 1), or may require changing forest department regulations (administrative, level 2), or there may be need for a formal change in the state forest legislation (state law, level 4).

Table 6.2: A LEGAL TYPOLOGY OF TENURIAL RIGHTS

Level	
1. People	Customary Law
2. Administration	Govt. Orders
3. Courts	Legal Cases
4. Legislative Bodies	Statutes
5. Legislative Body - National	Constitution

For example, a study of village grazing patterns in central Rajasthan, India revealed conflict resulting from the claims of (a) traditional village users of the grazing lands, (b) panchayat (village government) officials entrusted with responsibility for these lands as the smallest unit of state administration, and (c) private individuals who had encroached upon these lands over time. When these disputes led to court cases, their resolution varied. While the common ruling was to give decision-making power to the panchayat, more recent rulings have upheld the traditional rights of villagers to retain control of these lands for grazing. Thus, villagers today may be gradually losing control of grazing lands to panchayats and private individuals, due to their lack of awareness that the courts might rule in their favor if they sued the panchayat.

The dilemma of community woodlots in the Indian social forestry programs stem in part from the differing perspectives of the government implementing the program and the local population regarding tenurial rights over the woodlot and the responsibilities stemming from those. When a panchayat gave permission to the forest department to establish a woodlot on village grazing land, with an agreement that the forest department would recover its costs at the time of harvesting, everyone saw the agreement differently. To the panchayat, it was much like renting the land out to the forest department on a 50/50 share basis, since cost recovery usually led to this division of profits. To the local village, it meant a loss of grazing land to the panchayat and forest department, with no assured returns to the village. To the villager admonished by the forester for grazing his cattle inside the enclosure, it was evidence of the forest department's assumption of tenure over the land, even if on behalf of the environmental needs of the villager. To the forester, it was panchayat and village land, and the people were responsible for protection. Thus, no local sense of responsibility for protection or plantation maintenance developed in the intended direction of sustained CPR management. Rather than reinforcing local village conceptions of common grazing land management, which had been undermined by population pressure, the woodlot model introduced a new arrangement for which no one had clear responsibility.

LAND USE MANAGEMENT IN STATE-OWNED FOREST LANDS

Forest lands subject to claims of state ownership and traditional common property resource rights fall into several different, state-created categories:

(a) undemarcated forest lands to which people often have traditional use rights for subsistence products;

(b) production forests, which are lands allocated for timber production, and generally more restricted to local people;

(c) reserve forests, including parks and reserves, which are closed to local people (although indigenous peoples may have customary and conflicting claims to these areas);

(d) forest lands of all categories which have been put under shifting or permanent agriculture; and

(e) forest lands allocated on concession or lease to industries, cooperatives, associations, etc. (pulp industries in India, forestry associations granted stewardship contracts in the Philippines, village resource societies with grass leases in Haryana, India).

For the ex-colonial countries, it is important to note that forest land demarcation tends to follow patterns set up during the colonial administration (Java, the Philippines, and India), with the result that many customary rights have been revoked in law and others remain ambiguous. The situation is complicated in India by the fact that some areas of India remained princely states up to independence and in these areas, customary rights were never legally overridden at independence.

In general, recommended measures to encourage sustained resource management on public lands include: (a) formally recognizing local people's rights of access to public lands, sometimes with written agreements (woodlot agreements in the Indian National Social Forestry Project, forestry management plans in the Hills Community Forestry Project in Nepal); (b) transferring control over resources to local groups of users or political authorities; (c) instituting systems of joint management and cost-sharing of final product between local users and government agencies; and (d) extending leases to cooperatives or associations for forest or pasture development (Forestry Stewardship Associations in the Philippines). These are also critical ingredients in the management of forested lands.

Transferring Control to Local Communities

In Nepal, where few forests have been demarcated or reserved, the policy for improved forest management in the hills, and more recently in the Terai, is to transfer control for local protection and management to communities over two categories of government forest lands: those rehabilitated through plantation and those already-forested lands near villages. In many areas of Nepal, this policy is simply legalizing an already existing, traditional system of common property management, and thereby providing more encouragement for its sustained continuance. The present policy reverses an earlier one (1957), which had transferred control over all forest areas to the state in an attempt to arrest deforestation resulting from rapid population growth. The first step in the change transferred management to the local administrative council, the panchayat, with a forest committee organized to handle the management of the forest area. It is now proposed to transfer management to a more natural unit, namely the village or villages with traditional rights of access to the forest for their subsistence needs. With this change the role of the forest department would shift from manager to advisor, assisting the local community to develop a sustainable management plan and providing technical guidance on silvicultural matters.

Cost-Sharing Model of Community/Forest Department Management

Transfer of resource control has been successfully implemented on a broad scale in West Bengal, India. The forest department on its own initiative has been experimenting with a cost-sharing model for producing timber in natural but degraded sal (Shorea robusta) forests. Villagers agree contractually that in exchange for protecting growing timber, they will be employed in operations to cut all but the main shoot from degraded sal stands, receiving concessional prices for the discarded stems. They are assured a fixed share (25%) of the final harvest, distributed in cash individually to each villager, and have access to the forest for fallen wood, grass, and sal leaves (which can be a major source of income when sold in local markets). This model has been so successful that about 150,000 hectares of regenerating sal forest is being managed in this fashion. Several other state forest departments, including Haryana, are planning to implement a similar model.

Increased Rights Over Produce from Forest Lands

Cost-sharing is matched by a general trend to increase substantially local rights over produce from forests established under social forestry. In all Indian states with these programs, government orders regarding the concessionary rights of local communities have been revised to provide increasing amounts of produce to surrounding areas--either through the panchayat on auction or by allowing more collection of intermediate produce. In addition, there is experimentation with new technologies that are directed toward improving the environment rather than timber production, and which also provide a range of forest products needed by the poor and marginal villagers. Emphasis is on silvipastoral plantation models that generate grass for stall-feeding of animals as well as trees. More use is being made of shrubs and hedges that stabilize the soil as well as provide a regular source of medium-quality, but continually accessible supply of household fuel (World Bank, 1988b).

Increased Tenure Rights in Taungya Models

In response to a very low success rate with afforestation of production forest lands in Java (under the jurisdiction of the forest corporation), the government in cooperation with the Ford Foundation has been experimenting with increasing tenure rights of laborers working in afforestation schemes under a taungya system. Individuals are allocated plots for a longer time period than the original three years and are allowed to plant intercrops of grasses and fruit-bearing trees between rows of timber and pulp species for their own profit, in addition to seasonal crops planted before closure of canopy (Peluso, 1988; Ford Foundation, 1988). From the cultivator's perspective, the model is somewhere between a stewardship contract and the West Bengal cost-sharing model.

This revised scheme is emulating principles emerging for successful CPR management in South Asia. There is a sustained flow of benefits from the initial planting of seasonal crops, rows of fodder grass, and eventual harvesting of fruit. On a pilot basis, the plots have been targeted to marginal villagers, but on a broad scale, considerable opposition from better-off villagers is likely if they are, de facto, excluded from access to plots. Rights and responsibilities are clearly defined for the plotholder and foresters. In some areas, foresters have stopped enforcing restrictions on the gathering of minor forest produce in villages where the new scheme is in effect (Sri Palupi, 1988); this appears to be a conscious effort to change the relationship between village and forest department and has strengthened villager faith in the program. The scheme raises the issue of what the villagers' rights of access should be to other forest lands. Should the government consider the income-generating potential of other forest lands, except for parks and reserves, or continue its present policy of exclusion, except under the limited taungya plots? Wells (1989) argues for rights of access in forest areas adjacent to parks and reserves, so that these areas can realistically serve as buffer zones. This is also a contention of the Dutch-assisted Kalikonto watershed project staff in East Java, which is tackling similar forest land-use issues (Jacques Beerns, personal communication).

Leases to Cooperatives and Associations

There are two models for extending leases to cooperatives and associations in the case studies examined. One is in the Central Visayas Regional Project in the Philippines, in which groups of upland residents who had been illegally exploiting forest lands for timber in areas of extensive in-migration have been given legal stewardship over these lands for forestation purposes. The residents of the area are organized into associations (FOSAs) under the project by the forestry extension staff and project staff. They establish nurseries for forestation and plant forest lands with timber and fuel species, over which they have exclusive rights of harvest within the terms of a 25-year, renewable lease. Initially, the associations are allowed to harvest the remaining timber on these lands in a controlled manner to generate income in the early stages. Since most FOSA members have some land under agriculture as well, the project also provides tree crop seedlings to members to encourage more sustainable agricultural practices, along with slopy area land (SALT) technologies promoted in less slopy agricultural sites.

Since FOSAs are quite new, there is not enough information to judge their viability. This model merits careful study, particularly of inputs and returns, as an alternative to private or village management of resources.

The second model comes from the state of Haryana in India. A Ford Foundation-assisted program for the degraded watershed catchment near the capital city, Chandighar, developed small-scale water-harvesting structures for irrigation and created village resource management societies to protect the upper catchment and the flow of water into the harvesting structure. The lands in the upper catchment are state forest lands that were formerly given on lease to contractors for grass harvesting. In some villages in the new model, these societies have purchased lease rights from the forest department for the grasses. These are used for rope-making and as fodder for local dairy cattle. Given the proximity of these watersheds to the capital city, there is a good market for milk and dairy products, and villagers have a strong incentive to protect the catchment for grass production. Analysis has shown that in many sites, the water-harvesting benefits are quite small, because of limited potential, and that the benefits from grass are more promising. Irrigation structures provide an initial, strong incentive for village participation and mobilization, while it is the grass management that offers the most sustained returns to the village population as a whole (Stewart, 1989; Arnold and Stewart, 1989).

Interestingly, even though the irrigation facilities created are limited and do not reach the majority of villagers, they serve as a strong incentive for protection of the catchment by all villagers, including those without irrigation facilities. This is the case even where the returns from grasses and resulting fodder production are actually greater than from the water. It would seem that small irrigation structures in hilly areas may provide a good reward for catchment protection in state watershed programs.

Potential for Small-Scale Forest-Based Enterprises

Recently, a growing interest has developed in the potential to increase the income-generating potential and thereby the sustainability of forest lands through support for small-scale, forest-based enterprises. In areas of natural forest, which traditionally supply a range of nontimber forest products, more attention to the income-generating potential of these forests for local people is recommended. Potential encompasses income from collection and sale of products and from better access to markets and greater participation in value-adding processing activities. In the villages participating in the cost-sharing model in West Bengal for sal forest rehabilitation, women earn substantial income from such nontimber products. Not yet recognizing this benefit, foresters have neither tried to increase nontimber productivity nor assisted villagers with processing for higher returns.

Attention to nontimber products is also being recommended for forest areas on Java in several projects. For the areas under taungya forestation schemes, Kalikonto project staff are promoting higher-value products such as oilseeds that can be locally processed by cultivators and are more difficult to steal than the fruits now grown on often-distant plots. Several social forestry projects in India have placed increasing attention on growing nontimber products, such as medicinal plants, but again have not explored the best channels for marketing or processing them in order to generate maximum income for local people. An innovative NGO in Delhi, India has started an experimental industrial estate which will support a small village from enterprises drawing on raw materials produced in a nearby plantation on government land.

CHOOSING EFFECTIVE PROJECT MEASURES

Measures that provide checks and balances in project design against the unintended consequences of introducing technological or institutional change include: (a) provision of appropriate support services, especially to those categories of farmers with inadequate resources for adoption; (b) choice of technological options that generate additional income to beneficiaries; (c) mechanisms for local institution-building; and (d) strategies for mediation at the local level.

Support Services. Farmers' groups are an excellent conduit for support services. The Central Visayas Regional Project in the Philippines and the Highland Agriculture Development Project in Thailand both attribute a large measure of their success to the strengthening of existing farmers' groups and providing extension services through them. In Thailand, such groups were a focus for offering alternatives to formal credit. Formation of farmers' groups for improved extension services has also proved important in relieving labor constraints to the adoption of soil and moisture conservation on arable lands in the Yogyakarta Rural Development Project in Indonesia. Where extension services are effective, a much wider range of farmers will be interested in the technologies offered.

Income-generating opportunities from projects also address tenure-related constraints. In Java, farmers traditionally invest much less in rainfed plots than in irrigated rice or home-and-mixed gardens, particularly when the distant rainfed plots are difficult to protect and time-consuming to reach. The Dutch-financed Kalikonto watershed project in eastern Java has increasingly put emphasis on identifying income-generating components. Research efforts have focused on cropping systems with high returns for home-and-mixed gardens on the premise that enough additional income from them would reorient marginal farmers towards heavier agricultural investment in their rainfed plots and make them less dependent on off-farm employment.

Mediation as a Form of Extension Support. In "frontier" areas, generating adequate information about tenure rights, mediating between cultivators and other land claimants, and informing landowners about conservation measures are all crucial to adoption of new practices (Feder, 1988; World Bank, FFARM Study, 1989; Hoare, 1986). Programs carried out by the Bureau of Forest Development in the Philippines relied upon mediation between individuals claiming rights to the same lands (Seymour, 1985). Mediation has led to informal guarantees by *de facto* owners that cultivators will benefit from land improvements. This mediation is less threatening to the existing power brokers, yet seems to be simultaneously increasing benefits to cultivators, who can now adopt more sustainable practices.

NGOs as Mediators. Some local NGOs have established group plantations on wastelands allocated to them. They are successful largely because of the social pressure that NGOs can place on local elites to protect the groups from power brokers competing for access to these newly productive lands. Yet

NGOs have not been able to help groups gain formal lease-certificates for these wastelands, since the legal procedures are formidable and not well understood by government personnel at different levels of the administration. There is potential to expand NGO programs under Bank-assisted projects through support to training of NGO personnel and encouraging policies that streamline government procedures and recognize customary rights.

CONCLUSIONS

Land tenure issues in watershed development are complex. Certain kinds of tenure changes can have a positive impact on adoption, and in some cases, titling or land consolidation on private land in areas with socially recognized tenure rights is effective. The most scope can be found in increasing tenure security in the "frontier" areas and in recognizing and strengthening systems of corporate and common property resource management, where they exist.

Some positive measures that can be included in projects to support land tenure changes or to broaden the range of adoption within existing tenure systems include: providing increased extension support, often through targeted groups; providing sources of credit; focusing on technologies with quicker and high returns; strengthening local institutions; and providing mediation or legal aid to participants.

It becomes clear from this review that the World Bank needs to continue to study the relationship between land tenure and the adoption of soil and water conservation technologies, so that clearer directives can be given to task managers as to what strategies are most productive, sustainable, and equitable in the different Asian settings. More testing is needed of these measures through controlled study of ongoing project experience. Monitoring and evaluation systems are already overburdened by information requirements and are in any event unlikely to yield the culturally sensitive data needed. With Bank guidance, studies could be carried out by host country institutions, providing value both to the borrower and the Bank task manager.

Project Cases Examined in This Review

1. Yogyakarta Rural Development Project, Indonesia, (WB/Government) which included a titling component for private, dryland plots to encourage farmers to adopt improved technologies.

2. Upland Agriculture and Conservation Project, Indonesia (USAID/WB/Government), which has selected demonstration plots on farms cultivated by the owners for the dissemination of bench terrace technology and agroforestry.

3. Social Forestry Project of the State Forest Corporation, Indonesia (Ford Foundation/Government), which has provided extended leases for taungya/tumpang sari cultivation and allowed farmers to plant perennial crops in between timber trees.

4. National Social Forestry Project, India (USAID/WB/Government), which is the most recent of the Bank's social forestry programs funded for individual states in India.

5. West Bengal Social Forestry Program, India (WB/State Government), which includes a Bank-assisted project with a component termed "group farm forestry" encouraging farmers with marginal holdings to undertake block tree planting with shared labor and shared protection systems.

6. West Bengal forest department experiment in regeneration of natural forest through allocation of forest land to local villages (WB/forest department program), which has provided villages with intermediate yields and a substantial share of the final timber harvest in rehabilitated sal forests.

7. Village Resource Management Societies, Haryana, India (originally Ford Foundation-assisted), which are a local-level society created for watershed management and maintenance of small, water-harvesting structures for irrigation.

8. Forest Panchayats, Himachal Pradesh and Uttar Pradesh, India (pre-independence institutions), established in the Himalayas and Siwaliks for community management and protection of forests on behalf of the forest department.

9. Central Visayas Regional Project (CVRP), Philippines (WB/Government), which is a watershed and coastal rehabilitation project extending the sloping area land technologies (SALT) for land improvement to upland farmers and providing stewardship leases to farmers cultivating state forest lands.

9b. Forestry Associations (FOSAs), CVRP, Philippines (WB/Government), which is a component of the above project for organizing upland migrants to exploit lands over 18% slope into associations (FOSAs) for the establishment and extraction of forest plantations on degraded forest lands and providing them with stewardship leases to these lands.

10. Highland Agriculture Development Project, Thailand (Australia/WB/Government), which is a project in north Thailand for rehabilitation of lands cultivated by tribals under an extensive (slash-and-burn) agricultural system.

11. Gansu Provincial Project, China, (WB/Government), which has allocated pasture lands to individuals for development on long-term leases (the period of the lease has steadily increased since the inception of this program).

12. Red Soils Provincial Project, China (WB/Government), which has allocated lands to individuals for development on long-term leases, and which includes a parastatal institution providing capital and marketing support for farmers developing these lands.

13. Kalikonto Project, Java, Indonesia (Dutch-assisted), which has experimented with arable and nonarable land watershed development, concentrating recently on increasing economic returns from home gardens to reduce farmer dependence on off-farm employment strategies.

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7. A FRAMEWORK FOR PLANNING, MONITORING, AND EVALUATING WATERSHED CONSERVATION PROJECTS

Glenn S. Morgan and Ronald C. Ng

This chapter reviews the World Bank's operational experience with planning, monitoring and evaluation (PME) of watershed development projects; develops a rationale for promoting and developing local competency in PME as part of watershed development projects; and describes the essential components of a PME program that should be established prior to, or as part of, project implementation. To be successful, PME components should be developed within a clearly articulated framework for organizing key functional tasks. The approach described herein recommends that these tasks be organizationally structured under three closely related administrative cells.

DEFINITION OF TERMS

The terms planning, monitoring and evaluation are used to refer to three mutually supportive, though discrete, project activities. Planning, used traditionally, refers to a systematic process of establishing watershed development objectives (spatial and nonspatial), formulating alternative development actions, and selecting technically sound and socially acceptable courses of action. Monitoring denotes continuous assessment of project activities in the context of implementation schedules, the use and allocation of project inputs by targeted beneficiaries, and the measurement of progress against stated goals. Evaluation refers to periodic assessment of the relevance, performance, efficiency and impact of the project in the context of its stated objectives.

WORLD BANK EXPERIENCE WITH WATERSHED PROJECTS

Careful planning, monitoring and evaluation of project activities have been cited as essential components of virtually every World Bank-assisted watershed development project. As reflected in project appraisal reports, the components' overall goals within watershed projects appear consistent with recommendations available in the technical literature. Financial allocations for such components have typically ranged from 1% to 6% of total project costs, with the average expenditure being about 2%.

Available project documentation reveals that the most often cited goals for planning, monitoring and evaluation procedures are to:

(a) establish baseline information;

(b) track and document physical progress and achievements;

(c) account for financial expenditures;

(d) develop an information system adequate for comparative analysis of project components;

(e) provide a mechanism for evaluating the need for project adjustments; and

(f) execute special-purpose studies to evaluate project performance.

Still, World Bank experience with implementation and execution of such tasks within watershed development projects seems to have varied considerably. Benefits of PME, though thought to be large in relation to expenditures, have proven difficult to quantify. The effort required to design and implement PME activities successfully has probably been underestimated in most projects, given that knowledge from many fields such as accounting, sample survey design, and land-use surveying must be coordinated. Supervision reports indicate that few PME components have yielded satisfactory results; most report delays in implementation and relatively poor output.

The constraints faced by designers of PME components are certainly not unique to watershed development projects. At least ten issues have been consistently identified as major problems in implementation encountered by project supervision teams:

(a) shortages of trained and competent staff;

(b) a weak, in some cases nonexistent, information base;

(c) inadequate interdepartmental cooperation and coordination requiring information exchange;

(d) overall lack of institutional commitment to PME tasks;

(e) poor understanding of external reporting requirements;

(f) poorly communicated objectives regarding the users and uses of monitoring and evaluation data;

(g) poorly supervised and enforced standards of report preparation;

(h) redundancies in reporting requirements (e.g. quarterly reviews and semiannual, making the same points over and over);

(i) lack of clarity about responsibilities and obligations of different units;

(j) inability of field supervision teams independently to verify reported progress.

Organizationally, at the project level, the responsibility for developing the details of PME components has usually been left to the individual project coordination or project implementation units. As a consequence, there appears to be little consistency across watershed projects about: how much and what type of baseline information is collected; the expenditure incurred to develop and maintain an ongoing management information system; the level and detail of supporting information required; the frequency of surveys and other data collection exercises; or the methodology employed or the technologies utilized to collect and manage information. This lack of consistency in approach makes the task of comparing project experiences somewhat more difficult.

As with functional responsibilities, there are also no clearly defined organizational and institutional blueprints relevant to all watershed development programs. Some watershed development projects have recommended the establishment of new project-level institutions, varying by level of decision-making authority and management responsibility. For example, the Indonesia Forest Institutions and Conservation Project, for which implementation commenced in 1988, has recommended establishing a project planning and implementation unit (PPIU) for each project component (forestry, soil conservation, pasture and grazing, etc.). Under this model, the individual unit has responsibility for monitoring its disciplinary specialty under the general guidance of a project liaison office. Another approach has been to establish formal, centralized PME units with more autonomy from the project implementing staff. Often, the tasks of PME are contracted out to independent research institutes, universities, or private consulting operations and are supervised by small monitoring units. Yet another institutional option, tested in the Pilot Project for Watershed Development in Rainfed Areas of India (implementation commenced in 1984), is to establish monitoring and evaluation responsibilities with a state-level watershed development cell. Each approach has enjoyed some success and endured some disappointments in implementation. What appears to be consistent in the review of previous projects is the recommendation that PME tasks and their execution remain functionally separate from implementing agencies in order to ensure objective evaluation of project performance.

Despite some setbacks, many program planners remain committed to the idea that a major objective of watershed development projects should be to establish, within appropriate lead agencies, capacities to carry out planning, monitoring and evaluation tasks. In past projects, such tasks have included, inter alia, the execution of diagnostic surveys, preparation of land-use and land-capability maps, development and maintenance of a watershed information system describing the baseline conditions of the watershed to be treated, the preparation of treatment plans, the execution of special research and investigative studies, training of staff in line agencies in the application of cost-effective planning tools and procedures, and training of field staff in appropriate techniques for eliciting public input in the watershed development process.

RATIONALE FOR PLANNING, MONITORING AND EVALUATION CELLS

The approach that will be described refers to a planning, monitoring and evaluation (PME) unit having three separate but closely related cells, one each for planning, monitoring and evaluation. While the conventional term, monitoring, is retained for the second of these cells in the general model, it is more functionally a management cell. Watershed development projects are predicated on the principle that watersheds are viable and meaningful physical units for development planning and program implementation. Most importantly, watersheds are viewed as convenient and logical units for evaluating the biological and physical linkages between upstream and downstream activities.

These activities are linked naturally through the hydrology of the watershed, because physical changes in upper catchments can result in a chain reaction of physical impacts downstream. This can only be done through a careful land-use planning process.

Watershed land-use planning is fundamentally concerned with delineating where, by whom, and in what sequence conservation and rehabilitation actions will be undertaken. The specific spatial arrangement and timing of activities are of critical importance to the success of the investment package and therefore should be approached systematically. In addition, the approach must be executed in a way which simultaneously considers the place of an individual watershed in its regional environmental and economic context (strategic planning) and the important role of public participation in the preparation of site-specific treatment plans (micro-planning).

It is generally believed that, in the absence of a systematic approach to watershed planning, conservation and development authorities will be constrained in their ability to describe accurately the current land-use situation, monitor the dynamics of land-use change, evaluate the state of land degradation, or predict the likely impact of proposed development projects. The difficulties created by this situation are cross-sectoral with implications for forestry, agriculture, water management and pasture development. In the context of watershed development projects, a planning cell must be capable of addressing several interrelated tasks. Typically these tasks include:

(a) establishment of watershed development priorities on a regional basis;

(b) coordination of implementation responsibilities among line agencies;

(c) elicitation of people's participation in the establishment of investment priorities;

(d) development of technically sound, sustainable land management alternatives through micro-level village planning; and

(e) effective and timely communication of project activities to the local inhabitants affected by the project.

The realization of these planning goals depends on several prerequisites, such as institutional ability to evaluate development proposals in a regional environmental and economic context; existence of a process which allows communications among line departments on a regular basis; existence of trained and committed staff to work with people at the grass-roots level; existence of local community organizations to articulate community needs and desires; and technical ability to articulate and implement sound and sustainable technical solutions to land management problems.

In the generic model, a monitoring cell would have responsibility for translating information and regional priorities defined by the planning cell into location-specific action plans, that is, a management function. Clearly, there is explicit linkage and perhaps a slight overlap in the responsibilities of the two units. Monitoring of watershed development projects will involve both socioeconomic household surveys (longitudinal, cross-sectional, informal interviews, etc.), as well as physical monitoring (erosion rates, revegetation rates, etc.). Ideally, one would wish to be able to compare a series of survey results with a reliable baseline of information. Unfortunately, this is not possible if baseline data are not available. While the establishment of baseline data is certainly a welcome long-term goal, it is not necessarily a prerequisite of monitoring programs.

Several key issues need to be addressed during the design of monitoring components: namely, the choice and articulation of key indicators to be measured and collected; the procedures and methodologies to be employed in collecting data; the temporal frequency of collecting information; the size of the sample; and how data will be utilized in future planning exercises.

Each project will vary according to staff skills, available budget, institutional capacity; nevertheless, the work of a monitoring cell should parallel the strategic planning efforts of the planning cell. Thus, it is critical that an adequate watershed management information system (WMIS) be established. It should be designed with long-term objectives in mind and at a minimum should address the functional tasks described below in the following section.

Evaluation tasks typically involve independent assessment of a wide range of considerations, including assessment of the replicability and sustainability of project objectives; the quality of project preparation and appraisal; the performance and efficiency of watershed investments in the context of original goals; the sequencing of project components; and the extent to which investments in different components were mutually reinforcing. In practice, evaluation has focused primarily on measuring physical progress and less on measuring behavioral changes of participating communities.

Within watershed projects, evaluation is generally regarded, somewhat like monitoring, as an ongoing management mechanism for identifying design and implementation problems and making appropriate adjustments to the project. In the longer term, evaluation reports are useful in the design of follow-up projects. Ideally, evaluations should be undertaken by independent organizations and budgetary allocations should be separated from the planning and monitoring budgets. As with other elements of a PME unit, blueprints for success are rarely available.

FUNCTIONAL TASKS OF WATERSHED PLANNING, MONITORING AND EVALUATION CELLS

Regardless of the organizational framework selected for PME components, the staff responsible for implementing planning, monitoring and evaluation components of watershed projects should address the following functional areas:

Technical Records Management

An important function of the PME Unit is to establish a systematic approach to recording and retrieving data on field trials and experiments, technical studies, species performance under different agroclimatic conditions, planting methods, costs, returns and effectiveness. These data have been particularly scarce in watershed projects and to paraphrase one project supervision report, "when it comes to hard facts regarding the technical or economic merits of recommended practices in relation to controlling erosion and sedimentation, to their impacts on agricultural productivity and farmers' incomes, to the rate of adoption under different conditions and to several related factors, no systematic, quantitative assessments are generally available." In practical terms, establishing a database of technical records involves the use of desktop computer workstations and laptops, together with appropriate database management software. In many jurisdictions, the data are available in numerous reports and documents, but need to be collated and recorded in a format more accessible to planners. In practice, the technical records database would be compiled both from existing data, as well as new field data, as it is collected and reported from experimental stations, demonstration plots, and operational field trials.

Geography (GIS) and Cartography

A second objective of a planning cell should be to improve the management of spatially referenced information such as maps, air photos, and satellite imagery. This function could be effectively supported through the development of a geographical information system (GIS). A GIS, in the context of watershed rehabilitation and stabilization projects, is a computer-based workstation which permits the integration of baseline data (physical and social) deemed relevant to watershed development planning and management. Typical GIS systems link computer mapping software and tabular database management software into one comprehensive system.

A GIS database is organized on a modular basis, each module corresponding to important planning parameters. The strength of the GIS approach is that data handling and analysis can be carried out on the spatial and nonspatial elements of the database simultaneously. These capabilities can be used either by themselves or in conjunction with other simulation or statistical modeling techniques. The main modules of a GIS database usually consist of some variation of the following:

(a) base module (administrative boundaries, transportation, communications facilities, settlements);

(b) terrain/soil module (land unit descriptions, soil types, geomorphology, erosion characteristics);

(c) land cover/land-use module (vegetative cover, major land-use types);

(d) hydrology module (rainfall, climate, river discharge data);

(e) socioeconomic module (farming systems, demographics).

If organized and implemented in a rationale manner, a GIS can be a valuable tool which facilitates the storage, retrieval and production of maps, statistical reports and, in some cases, the production and processing of satellite imagery. It is also thought to be an appropriate mechanism for storing, analyzing and disseminating field data from monitoring and evaluation field teams. GIS analytical techniques can be used on information derived from intensive ground studies or can be based on data derived from the use of remotely sensed imagery such as aerial photographs or space-craft pictures.

Village-Level Information Management

In many situations, reasonably reliable social and economic data exist for individual villages within a watershed, but often require systematic storage and retrieval to make the information more readily available to concerned agencies. To formulate site-development plans, additional information on the social and economic conditions prevailing in the village needs to be collected. Village-level data are usually collected by revenue officers and updated on a cyclical basis.

The standard approach is to collect and record village-level and other relevant socioeconomic information (fuel, fodder demand and supply, population, etc.) using previously designed data collection forms. The information on the forms could be efficiently managed on a small personal computer with appropriate spreadsheet or database management software.

Watershed Strategic Planning

The extent to which dryland degradation in upland watersheds can be reversed will depend on a much improved understanding of many factors: among them, the status and rate of vegetative denudation, the severity of local soil erosion processes, the intensity of human and livestock pressures, the ability to introduce sustainable measures to control degradation, and the ability to communicate unambiguous benefits to practitioners of these.

As a basis for priority selection of large-scale investments in the stabilization, conservation, and reclamation of degraded lands, planners require knowledge about the status of lands across an entire region. In most situations, evidence of widespread degradation is anecdotal or based on small-scale, special-purpose, local surveys. For most jurisdictions, almost no maps of regional degradation exist and rarely has systematic assessment of degradation been undertaken. An important element in the planning, monitoring and evaluation therefore is to assist in the establishment of regional baseline databases.

Strategic planning is used to refer to the process by which priorities for watershed development are articulated and recorded. This usually requires close interaction and coordination among line agencies and the resource users. The process of setting regional priorities for watershed programs should be based on careful consideration of:

(a) physical evidence of degradation (extent of gully and sheet erosion, erosion rates, deforestation, water quality);

(b) social and economic indicators of degradation (fodder and fuel deficiencies, decreasing farm yields); and

(c) likelihood of introducing sustainable technical packages (slope and soil characteristics, current land-use practices, local willingness).

On the surface, land-use planning appears to be a logical and necessary, if not essential, part of any watershed development activity. Numerous planning models have been proposed and tested in the field with varying levels of success. Still, many practitioners have questioned the overall utility of land-use planning exercises. Put simply, the development of land-use plans has frequently been described as burdensome, time-consuming and expensive. In situations where the planning goal has been to develop rigid village or regional master plans, the results often do not live up to expectations. In practice, many examples could be cited where detailed land-use plans have been drawn up based on elaborate soil surveys and land capability studies, only to be subsequently shelved and rarely consulted.

In most cases, the disappointment with land-use planning arises out of a fundamental confusion between the land-use plan as an end product and land-use planning as a mechanism for articulating local needs, resolving conflict, ensuring rights, and enforcing obligations of land users. The challenge to watershed development planners is to avoid the syndrome of focusing on elaborate programs aimed at developing the master plans and shift attention towards an iterative process of matching local needs to local constraints. Rather than being abandoned, land-use planning for watershed development should be reoriented towards village-level consultation, program flexibility, selectivity and institutional coordination of predetermined responsibilities.

Formulation of Site-Development Plans and Annual Work Program

Site development plans should flow naturally from the strategic planning performed in the planning cell. The tasks of such a unit include the management of public participation in the planning process and the development of site-specific action plans. The annual work program involves the scheduling of tasks to be performed, delegating responsibility to appropriate agencies, budgeting, and coordination of field activities.

The steps involved in preparing site-development plans seem well developed and understood. In most projects, site plans are formulated based on some variation of the following process:

(a) conduct diagnostic survey and local needs assessment;

(b) evaluate local resource potential and constraints;

(c) articulate local technical, financial and logistical prescriptions (the plan);

(d) secure local endorsement, commitment and support for proposed action plans;

(e) implement program;

(f) conduct periodic reviews to assess progress and revise prescriptions as necessary.

Many different types of reporting formats have been developed which may be adopted for each step of the interactive planning process. Whatever the format chosen, the village-level diagnostic survey should provide detailed descriptions of the specific location of areas requiring remedial treatment, the current status of these lands with respect to land-use practice, land capability, land ownership/tenure, the land users, and a description of treatment options to be considered.

The identification of treatments and options is largely a technical exercise based on diagnostic surveys, but the final decisions on the type, scale and timing of measures to be installed must be determined by the needs and preferences of local land-users. The operational challenge for watershed development practitioners is twofold: Firstly, how to efficiently obtain information and opinions from the rural residents. Secondly, how to convert and integrate that information into programs which are locally relevant, technically sound and which also serve broader, regional resource management goals. Unfortunately, little effort has been made toward incorporating or soliciting the active participation of the watershed land-users in the planning of site-development actions.

The need for public participation is especially important in watershed development schemes when the project treatments involve:

(a) private or communal lands;

(b) temporary land closures;

(c) changes in land management practices (e.g., grazing patterns, cut and carry, rotational management, etc.);

(d) investment of time and/or financial resources by local inhabitants (e.g., planting vetiver grass hedges or private construction of water-harvesting structures).

Several approaches to soliciting popular participation as well as monitoring beneficiary impact of watershed investments have been commonly used in the field. These approaches include:

(a) one-on-one interaction with local people (personal interviews, questionnaires, household surveys, individual observations);

(b) communication and interaction with community leaders (interviews with village leaders, traditional leaders, local entrepreneurs, progressive farmers, informants);

(c) dissemination of information and participation through community meetings (e.g., public forums, hearings, presentations); and

(d) interaction through community organizations [nongovernmental organizations (NGOs), religious organizations, local councils, regional organizations].

<u>Monitoring Progress</u>

Monitoring progress involves regularly scheduled site inspections to assess works completed and should include statements of expenditure incurred and problems and delays encountered. Monitoring progress is an essential feedback mechanism as these findings define how annual work plans should be modified or corrected. Monitoring activities use several different techniques. The most common approach is to have site inspectors record required information on pro-forma recording documents. These documents would be fed back into the WMIS as part of the permanent database record. In practice, independent field verification of progress reports has proven to be quite difficult in watershed projects, particularly when the watershed areas are remote or access is difficult. It has proven extremely difficult, for example, for World Bank supervision teams to verify the numbers of checkdams and gully plugs constructed or to make reliable estimates of total reforested areas treated by the project. A complementary approach is to utilize remote-sensing technology, such as high-resolution satellite pictures to assess physical progress. For example, site inspectors could clearly see the progress made, especially regarding forestry plantations in upland watershed areas. While these images could possibly be used quite effectively, for example, to evaluate the total impact of larger projects, they are probably not useful for monitoring small catchments of less than 3,000 hectares. Another approach, though not used widely as yet, would be to perform field monitoring using low-cost, hand-held video cameras to record construction or plantation activities as they are executed.

Monitoring Results

Monitoring results also involves field inspections and supervision, but rather than simply indicating physical progress, attempts to assess the effectiveness of activities in terms of survival rates, erosion control, fuelwood produced. Closely related is the concept of monitoring benefits. Sample surveys should be done on a regular basis (e.g., annually or quarterly) to assess the beneficiaries' perception of the project's effect on pasture rehabilitation, improved farm and fuelwood yields, and reductions in erosion rates. Village-level meetings should be held on a regular basis to elicit beneficiary response to the progress of works completed. Again, monitoring results could use a combination of personal interviews, video recordings, public meetings, and formal questionnaires to record information.

Monitoring results could also include more detailed long-term studies related to project progress, including information on disbursements, the type and location of erosion control structures financed, and dissemination of erosion control technology through extension services. Other programs might focus on physical monitoring for recording the effect of project investments on the rates of erosion.

Monitoring Benefits

Monitoring benefits attempts to describe the annual increments to production attributable, either directly or indirectly, to project investments. This monitoring function focuses on the interaction between project activities and reactions of the target populations. In watershed projects, it includes, but is not limited to, assessment of grazing, farming, and other benefits. Such monitoring is usually based on periodic household surveys and should be supported for a reasonable time period following completion of the project. Typically, monitoring beneficiaries would attempt to account for changes in household incomes and relative abundance of land-based resources such as fodder, fuel, access to grazing, or water supply that could be related to project investments.

Interim Project Evaluations

This function involves the careful review of experience during implementation, including institutional problems, technical achievements and constraints, and socioeconomic benefits derived. Interim evaluation would be based on field information collected in the monitoring stages of the project. Interim reporting must go beyond an accounting of project expenditures and physical progress and should focus on the relevance, performance, efficiency and impact of the project in the context of stated goals. Ideally, both interim and overall project evaluation should be performed by an independent external agency such as a university, research institute, or qualified consultants.

Evaluation of Impact of Physical Treatments

Impact evaluation involves detailed and objective evaluation of the overall effectiveness of watershed treatments such as soil conservation, pasture rehabilitation or land management practices. Ideally, the evaluation should also be carried out by a university, independent research institute, or qualified consultants. With respect to watershed projects, impact evaluation can be a very difficult task as many factors external to the project can influence the viability of investments.

Report Generation (Internal/External)

Report generation is an important element of all PME units, though typically it is overlooked. This function addresses the requirements for periodic reporting to the state on physical progress. The process is essentially manual, although word-processing facilities could be introduced to facilitate report writing. The reports would be generated directly from the data collected and systematically recorded in the watershed management information system.

Evaluation teams should also have the capacity to generate special-purpose reports for external institutions such as development agencies, NGOs, research groups, or public information campaigns. This capacity should be flexible enough to address the needs of formal evaluations such as mid-term reviews, project completion studies, and ex-post reviews, as well as informal management reviews. Like many other elements of the PME unit, report generation must rely on the quality and timeliness of information contained within the management information system. The reports and accounts generated by an evaluation team could be presented in a number of different formats such as formal written reports, diagnostic analyses or verbal and visual presentations.

SUMMARY

Watershed planning, monitoring and evaluation tasks are frequently cited as among the most important components of successful projects. Nevertheless, the potential of PME activities will be achieved only if it is clearly understood who is to use the results and for what purposes and if the practical limitations of available methodologies and techniques are accepted. In general, there is agreement that monitoring and measurement of physical processes (erosion, deforestation) or physical delivery of project inputs is easier than measuring the less tangible, people-centered goals of watershed rehabilitation programs such as increasing beneficiary participation.

In designing PME components of watershed projects, the mutually reinforcing nature of these tasks must be clearly understood. Casley and Kumar (1987) note that "monitoring and evaluation are separated by their objectives, reference periods, requirements for comparative analysis, and primary users. But having emphasized the differences, we need to enter a qualification: in spite of these distinct functions, there are common features which highlight the relation between them. In many cases, the same data are used for both and the indicators for monitoring may be included in the range of information required for evaluation, but they will be reviewed over longer time spans, with the use of comparative analytical techniques, and a larger group of users will be addressed."

One conclusion should be made clear; PME methodologies and procedures need to be flexible and well adapted to local circumstances. Due to the wide variation in objectives, scale and scope of investments in watershed projects, there can be no blueprint which is universally applicable or acceptable in all situations. Each situation will vary regarding the technical capabilities of existing staff, institutional commitment to PME tasks, availability of historical, time-series data and so on. In all situations, PME must be seen as an evolutionary process, building slowly on existing capabilities over relatively long time periods. This is particularly important when monitoring the effects of project investment on the productivity of natural systems such as forests, soils, or water.

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8. BIBLIOGRAPHIES ON SOIL AND MOISTURE CONSERVATION TECHNOLOGIES

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Table 8.2

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON
SOIL MOISTURE AND SURFACE RUNOFF

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	REMARKS
155	Conservation practices	USA	T	N/A	Agricultural	Watershed	Agricultural practices have significant effect on on-site runoff from small watersheds. Effects management dependant. Poor management will increase water yields. Significant runoff reduction associated intensely managed areas.	In 30 years of studies little effect of conservation practices on areas larger than 120 ha has been noted -- or studied.
110	Ferralsols (Oxisols)	Puerto Rico	W/D	N/A	Undisturbed	Watershed	Max/min infiltration rate = 15.4 / 8.4 cm/hr	Range of observed infiltration rates in undisturbed Puerto Rican soils.
	Acrisols/Nitosols (Ultisols)						Max/min infiltration rate = 23.6 / 7.4 cm/hr	
	Chernozems/Phaeozems (Mollisols)						Max/min infiltration rate = 19.5 / 8.2 cm/hr	
	Luvisols/Podzoluvisols (Alfisols)						Max/min infiltration rate = 11.5 / 2.7 cm/hr	
	Cambisols (Inceptisols)						Max/min infiltration rate = 13.2 / 2.7 cm/hr	
	Fluvisols/Gleysols/Regosols (Entisols)						Max/min infiltration rate = 27.5 / 2.3 cm/hr	
	Vertisols						Max/min infiltration rate = 9.5 / 0.1 cm/hr	
119	Removal of 5 cm of topsoil	Nigeria	W/D	NG	NG	Field	61% decrease in water holding capacity in Ultisols, 12 - 23% decrease in water holding capacity for Alfisols	Measurements taken at 7 months after topsoil removal
181	Land clearing	Colombia	W/D	Steep	Agriculture	Field	Decrease in surface runoff.	Attributed to increase in permeability from burning; soil = Andosol (Andept)
100	Land clearing	Ivory Coast	W/D	NG	Agriculture	Field	Large increase in surface runoff	Soil = sandy Alfisol
166	Land clearing - bulldozer	Peru	CW	NG	Agriculture	Plot	95% decrease in infiltration capacity	Comparison to clearing by slash and burn method
201	Land clearing - KG blade	Trinidad	W/D	NG	Agriculture	Field	29% increase in soil bulk density in top 16 cm -- decreased infiltration capacity.	Comparison to pre-treatment bulk density
6	Land clearing - slash/burn	Amazon	CW	2-4%	Agriculture	Field	37% decrease in infiltration rate	
	Land clearing - bulldozer with straight blade						96% decrease in infiltration rate	
	Land clearing - bulldozer with shear blade						90% decrease in infiltration rate	
160	Forest clearing	Ghana	CW	NG	Forestry	Field	13% decrease in non-capillary porosity	Soil = sandy loam
77	Conversion of forest to grassland	USA	T	Steep	Grassland	Watershed	Greater water yield, higher groundwater levels in deep soils, no significant difference in stormflow, peak stormflow, and stormflow duration when grass dense and vigorous	Comparison to pre-conversion parameters
77	Conversion of forest to grassland	USA	T	NG	Grassland	Watershed	No significant difference in total discharge when grass production high. Decrease in production increased discharge 12 cm/yr over predicted forest discharge	Comparison to pre-conversion parameters

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CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	REMARKS
134	Conversion of forest to grassland	Hawaii	CW	NG	Grassland	Watershed	Increase in runoff rates	Attributed to decreased rate of evapotranspiration by grass relative to natural rainforest cover
20	Bare soil	Korea	T	27%	Forestry	Watershed	132% increase in surface runoff	Comparison to grassed; soil = sandy clay loam; Pt = 1,370 mm/yr
	Hardwood plantation						36% decrease in surface runoff	
	Coniferous plantation						42% decrease in surface runoff	
176	Fern cover	Sri Lanka	EM	50%	Forestry	Watershed	110% increase in surface runoff	Comparison to closed canopy Pinus caribea plantation; Soils = sandy clay loam Nitosol (Typic Tropudult), Pt = 5,640 mm/yr
	Degraded grass cover			50%			55% increase in surface runoff	
	Grass cover			50%			No significant difference in surface runoff	
176	Fern cover	Sri Lanka	EM	50%	Forestry	Watershed	205% increase in average peak discharge	Comparison to closed canopy Pinus caribea plantation Soils = sandy clay loam Nitosol (Typic tropudult), Pt = 5,640 mm/yr
	Degraded grass cover			50%			220% increase in average peak discharge	
	Grass cover			50%			58% increase in average peak discharge	
62	Clearcut	Chile	W/D	30%	Forestry	Plot	73% increase in surface runoff	Comparison to 30 yr. old Pinus plantation; soil = clay loam; Pt = 2,000 mm/yr
	Pasture			30%	Pasture		52% increase in surface runoff	
	6 yr. old Pinus plantation			30%	Forestry		14% increase in surface runoff	
182	Grass cover	Colombia	W/D	22%	Pasture	Plot	70% decrease in surface runoff	Comparison to monthly tilled bare soil.
33	Grass cover	NSW, Australia	SATr	8%	Grassland	Plot	81% decrease in surface runoff	Comparison to wheat; soil = calcic and chromic luvisols, respectively; Pt = 644 and 561 mm/yr, respectively
	Grass cover			8.5%	Grassland	Plot	75% decrease in surface runoff	
202	Grass cover (Pennisetum, Cynodon,Urochloa,Panicum)	India	D/WM	5%	Agriculture	Field	No significant difference in surface runoff	Comparison to conventional cultivation of gorapaddy,urid, corn,peanut; soil = sandy clay, Pt = 1,302 mm/yr
161	Grass - Imperata,Saccharum	Philippines	D/WM	36-70%	Grassland	Field	No significant difference in surface runoff	Comparison to secondary forest; Soil = clay loam, Pt = 2,600mm/yr
	Plantation forest - Gliricidia,Leucaena				Forestry		No significant difference in surface runoff	
	Kaingin				Agriculture		165% increase in surface runoff	
160	Mulch/Cover crop	Pan-tropical	N/A	N/A	Agriculture	N/A	Protection from compaction and decreased infiltration	Luvisols, Nitosols, Acrisols (Ultisols and Alfisols) with sandy topsoils susceptible to compaction and resultingly lower soil moisture levels following cultivation.
97	Mulch	Nigeria	W/D	1%	Corn	Plot	69% decrease in surface runoff	Comparison to unmulched
	Forest cover			1%	Forest		73% decrease in surface runoff	
	Mulch			5%	Corn		81% decrease in surface runoff	
	Forest cover			5%	Forest		97% decrease in surface runoff	

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SOIL MOISTURE AND SURFACE RUNOFF

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	REMARKS
	Mulch			10%	Corn		87% decrease in surface runoff	
	Forest cover			10%	Forest		96% decrease in surface runoff	
	Mulch			15%	Corn		89% decrease in surface runoff	
	Forest cover			15%	Forest		89% decrease in surface runoff	
102	Desmodium spp. cover	Taiwan	D/WM	46%	Litchi	Field	No significant difference in surface runoff	Comparison to clean cultivation; Pt = 3,494 mm/yr
	Bahia grass			46%			98% decrease in surface runoff	
	Eragrostis spp. mulch			46%			69% decrease in surface runoff	
102	Eragrostis barrier/mulch	Taiwan	D/WM	23%	Banana	Field	30% decrease in surface runoff	Comparison to clean cultivation; Pt = 2,348 mm/yr
	Guinea grass barrier/mulch			23%			25% decrease in surface runoff	
	South African pigeon grass barrier/mulch			23%			No significant difference in surface runoff	
3	Grass strips (0.5m wide - Brachiaria, 1m wide - *Paspalum*)	Java	EM	15-22%	Agriculture	Field	9% decrease in surface runoff	Comparison to bare soil
183	Vegetative strip (Mucuna utilis)	Indonesia	D/WM	12%	Corn & cassava	Plot	No significant difference in runoff	Comparison to corn & cassave w/o vegetative strips
	Vegetative strip (Pucraica phaseoloide)						14% decrease in surface runoff	
	Vegetative strip (Mimosa invisa)						10% decrease in surface runoff	
	Vegetative strip (Pennisetum purpureum)						32% increase in surface runoff	
160	Mulch	Pan-tropical	N/A	N/A	Agriculture	N/A	Decrease soil moisture losses from evaporation	Ferrasols (Oxisols), Andosols (Andepts), and oxidic soils have a low range of available moisture (gravity dreined @ 0.1 bar)
96	Mulch	Nigeria	W/D	N/A	Agriculture	N/A	Increased soil water, decreased runoff, decreased evaporation rates	Best management practice for Luvisols, Podzoluvisols (Alfisols)
197	Mulch (1.1 t/ha)	USA	T	NG	Sorghum fallow	Field	38% increase in soil moisture storage	Comparison to unmulched
	Mulch (2.2 t/ha)			NG		Field	39% increase in soil moisture storage	
	Mulch (4.4 t/ha)			NG		Field	61% increase in soil moisture storage	
	Mulch (8.8 t/ha)			NG		Field	93% increase in soil moisture storage	
	Mulch (13.2 t/ha)			NG		Field	104% increase in soil moisture storage	
180	Mulch (12 t/ha)	USA	SATmp	NG	Agriculture	Field	104% increase in soil moisture storage	Comparison to no mulch
171	Mulch (0.33 t/ha, 22% cover)	USA	T	NG	Agriculture	Plot	No significant difference in surface runoff	Comparison to no mulch under rainfall simulator
	Mulch (0.44 t/ha, 37% cover)						No significant difference in surface runoff	
	Mulch (0.66 t/ha, 46% cover)						No significant difference in surface runoff	
	Mulch (0.88 t/ha, 58% cover)						No significant difference in surface runoff	
	Mulch (1.21 t/ha, 81% cover)						No significant difference in surface runoff	
	Mulch (1.87 t/ha, 87% cover)						No significant difference in surface runoff	
	Mulch (2.47 t/ha, 92% cover)						No significant difference in surface runoff	
113	Mulch (0.63 t/ha)	USA	T	5%	Agriculture	Plot	11% decrease in surface runoff	Comparison to no mulch; soil =

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IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON
SOIL MOISTURE AND SURFACE RUNOFF

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	REMARKS
	Mulch (1.23 t/ha)			5%			44% decrease in surface runoff	silt loam; rainfall simulator study
	Mulch (2.47 t/ha)			5%			89% decrease in surface runoff	
	Mulch (4.94 t/ha)			5%			96% decrease in surface runoff	
	Mulch (9.88 t/ha)			5%			100% decrease in surface runoff	
38	Mulch (5 cm rice straw)	India	D/WM	1%	Wheat/barley/ gram/linseed	Field	3% increase in soil moisture storage	Comparison to unmulched
192	Mulch	Indonesia	D/WM	NG	Corn	Plot	86% - 91% decrease in surface runoff	Comparison to unmulched corn
189	Mulch (9 t/ha)	Indonesia	W/D	NG	Soybean	Plot	Conserved equivalent of 23 days of plant's water requirements throughout growing season	Comparison to unmulched
199	Mulch (0.6 t/ha)	Indonesia	D/WM	7%	Upland rice	Plot	50% decrease in surface runoff	Comparison to unmulched (rice straw); soil = Latosol
	Mulch (1.0 t/ha)						69% decrease in surface runoff	
	Mulch (1.6 t/ha)						83% decrease in surface runoff	
	Mulch (0.6 t/ha)			9%			24% decrease in surface runoff	
	Mulch (1.0 t/ha)						69% decrease in surface runoff	
	Mulch (1.6 t/ha)						86% decrease in surface runoff	
	Mulch (0.6 t/ha)			14%			26% decrease in surface runoff	
	Mulch (1.0 t/ha)						48% decrease in surface runoff	
	Mulch (1.6 t/ha)						83% decrease in surface runoff	
188	Mulch (0.6 t/ha)	Indonesia	D/WM	7-14%	Upland rice	Plot	33% decrease in surface runoff	Comparison to unmulched (rice straw); soil = latosol
	Mulch (1.0 t/ha)						59% decrease in surface runoff	
	Mulch (1.6 t/ha)						84% decrease in surface runoff	
213	Mixed cropping & mulch (4.4 t/ha)	Indonesia	D/WM	20%	Corn & peanuts	Plot	43% decrease in surface runoff	Comparison to corn & peanuts strip cropped
	Mixed cropping						No significant difference in surface runoff	
106	Multicropping	Indonesia	D/WM	20%	Clove/banana/ cassava/ungor laut/coconut	Plot	99% decrease in surface runoff	Comparison to corn monculture
9	Corn & teak intercrop	Indonesia	SATr	NG	Agriculture	Plot	2% - 17% decrease in surface runoff	Comparison to corn monoculture; Pt = 715 - 848 mm/yr
173	Natural cover	India	SATr	0.5%	Natural cover	Field	99.9% decrease in surface runoff	Comparison to cultivated fallow; soil = silty clay loam, Pt = 800 mm/yr
	Natural cover			1%	Natural cover		99.9% decrease in surface runoff	
	Grass cover (Cynodon spp.)			0.5%	Grass		72% decrease in surface runoff	
	Grass cover (Cynodon spp.)			1%	Grass		56% decrease in surface runoff	
	Peanut			0.5%	Peanut		69% decrease in surface runoff	
	Peanut			1%	Peanut		52% decrease in surface runoff	
	Gram			0.5%	Gram		55% decrease in surface runoff	
	Gram			1%	Gram		25% decrease in surface runoff	
	Jowar			0.5%	Jowar		40% decrease in surface runoff	
	Jowar			1%	Jowar		18% decrease in surface runoff	
208	Agroforestry (intercropping)	Thailand	D/WM	NG	Gmelina arborea and rice	Field	840% increase in surface runoff	Comparison to Gmelina arborea cropped alone
63	Coffee - 1 yr old	Indonesia	D/WM	46-66%	Agriculture	Plot	135% increase in surface runoff	Comparison to undisturbed natural

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CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	REMARKS
	Coffee - 3 yr old						348% increase in surface runoff	forest.
	Coffee - 16 yr old						726% increase in surface runoff	
8	Tobacco	Indonesia	D/WM	30%	Agriculture	Plot	301% increase in surface runoff	Comparison to unweeded cassava;
	Potato						889% increase in surface runoff	soil = andosol
	Corn + beans						369% increase in surface runoff	
2	Manure (16 t/ha)	Indonesia	D/WM	16%	Agriculture	Plot	45% decrease in surface runoff	Comparison to unmanured; soil = "volcanic, dusty regosol"
21	Cow dung (5 t/ha)	Ghana	CW	7.5%	Corn	Plot	90% decrease in surface runoff	Comparison to bare fallow;
	Wood shavings (5 t/ha)			7.5%		Plot	92% decrease in surface runoff	Pt = 1,340 mm/yr
	Poultry manure (5 t/ha)			7.5%		Plot	93% decrease in surface runoff	
	Cow/poultry manure (5 t/ha)			7.5%		Plot	91% decrease in surface runoff	
	Commercial fertilizer			7.5%		Plot	59% decrease in surface runoff	
21	Cow dung (2 t/ha)	Ghana	SATr	2%	Sorghum	Plot	64% decrease in surface runoff	Comparison to bare fallow;
	Cow dung (4 t/ha)			2%		Plot	77% decrease in surface runoff	Pt = 320 mm/yr
	Cow dung (4 t/ha) & straw mulch (4 t/ha)			2%		Plot	89% decrease in surface runoff	
	Cow dung (5 t/ha)			2%		Plot	82% decrease in surface runoff	
	Cow dung (5 t/ha) & straw mulch (4 t/ha)			2%		Plot	91% decrease in surface runoff	
190	Mulch and minimum tillage	Indonesia	EM	3.5%	Cassava/rice/	Plot	75% decrease in surface runoff	Comparison to unmulched,
	Bare soil			3.5%	corn/peanuts/	Plot	70% increase in surface runoff	traditional cultivation;
	Mulch and minimum tillage			9%	beans	Plot	64% decrease in surface runoff	in order of treatment pairs
	Bare soil			9%		Plot	43% increase in surface runoff	soils = Nitosol (Tropudult),
	Mulch and minimum tillage			10%		Plot	No significant difference in surface runoff	Nitosol (Tropudalf),
	Bare soil			10%		Plot	No significant difference in surface runoff	Nitosol (Tropudalf),
	Mulch and minimum tillage			14%		Plot	63% decrease in surface runoff	Ferralsol (Haplorthox),
	Bare soil			14%		Plot	No significant difference in surface runoff	Nitosol (Tropudalf),
	Mulch and minimum tillage			14%		Plot	92% decrease in surface runoff	
	Bare soil			14%		Plot	No significant difference in surface runoff	
180	Stubble mulch tillage	USA	SATmp	NG	Wheat	Field	14mm increase in soil moisture storage	Comparison to clean cultivation,
	Clean cultivation/fallow					Field	35mm increase in soil moisture storage	continuous wheat
116	No-till	Thailand	D/WM	NG	Upland rice	Plot	67% decrease in surface runoff	Comparison to clean cultivation
	Stubble mulch			NG			42% decrease in surface runoff	
	Bare fallow			NG			208% increase in surface runoff	
116	Disk plow/stubble mulch	Thailand	D/WM	NG	Upland rice	Plot	84% decrease in surface runoff	Comparison to disk plowed and
	No-till/mulch			NG		Plot	88% decrease in surface runoff	no mulch
116	Disk plow/stubble mulch	Thailand	D/WM	NG	Peanuts	Plot	38% decrease in surface runoff	Comparison to disk plowed and
	No-till/mulch			NG		Plot	50% decrease in surface runoff	no mulch
212	No-till with stubble mulch (chemical weed control)	USA	T	3%	Corn	Field	16% increase in surface runoff	Comparison to conventional tillage with stubble mulch
84	Furrow dikes with stubble mulch	USA	T	NG	Wheat-sorghum-fallow	Field	25 - 30 mm/yr decrease in surface runoff	Soil = clay loam Xerosol (Torrertic Paleustoll),

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CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	REMARKS
								Pt = 1,270 mm/yr
54	Rows up & down slope	Peru	SATr	25%	Potato	Field	71% increase in surface runoff	Comparison to continuous fallow
	Contoured			25%			8% decrease in surface runoff	
	Cover cropped (Lupinus) and rows up & down slope			25%			44% increase in surface runoff	
	Mulched			25%			16% decrease in surface runoff	
54	Rows up & down slope/burned	Peru	W/D	30%	Potato	Field	19% increase in surface runoff	Comparison to continuous fallow
	Cover cropped and rows up & down			30%			6% increase in surface runoff	
	Contoured			30%			14% increase in surface runoff	
	Mulch and rows up & down slope			30%			15% increase in surface runoff	
122	Bare fallow	Ghana	W/D	7.5%	Corn	Field	214% increase in surface runoff	Comparison to traditional mixed cropping; soil = sandy loam to sandy clay, Pt = 1,500 mm/yr
	Zero-tillage			7.5%			51% decrease in surface runoff	
	Mulching			7.5%			85% decrease in surface runoff	
	Ridging across slope			7.5%			47% decrease in surface runoff	
	Minimum tilllage			7.5%			37% decrease in surface runoff	
122	Bare fallow	Ghana	W/D	3%	Corn	Field	722% increase in surface runoff	Comparison to traditional mixed cropping; soil = sandy clay loam to sandy clay, Pt = 1,400 mm/yr
	Zero-tillage			3%			18% decrease in surface runoff	
	Mulching			3%			82% decrease in surface runoff	
	Ridging across slope			3%			31% decrease in surface runoff	
	Minimum tillage			3%			7% decrease in surface runoff	
66	Cultivation	Brazil	CW	NG	Agriculture	Field	50% decrease in percentage of large soil aggregates, pore clogging	Soil = Ferrasol, Acrisols, Nitosols (Oxisols & Ultisols)
133	Cultivation	Brazil	CW	NG	Agriculture	Field	85% decrease in infiltration capacity	Result of 15 years cropping; attributed to compaction by machinery and illuviation of clay soil = Ferrasol (Oxisol)
157	No-till	Nigeria	W/D	1%	Agriculture	Field	86% decrease in surface runoff	Comparison to conventional plowing
	Bare fallow			1%		Field	127% increase in surface runoff	
	No-till			5%		Field	80% decrease in surface runoff	
	Bare fallow			5%		Field	130% increase in surface runoff	
	No-till			10%		Field	77% decrease in surface runoff	
	Bare fallow			10%		Field	90% increase in surface runoff	
	No-till			15%		Field	76% decrease in surface runoff	
	Bare fallow			15%		Field	134% increase in surface runoff	
73	Plow,clean till,contour	USA	T	6%	Agriculture	Field	48% decrease in surface runoff	Comparison to plow,clean till, and sloping rows
	No-till,contour			21%		Field	43% decrease in surface runoff	
90	Burn to clear/no-till	Japan	W/D	12-18%	Agriculture	Field	31% decrease in surface runoff	Comparison to burn to clear & tilled; soil = sandy clay loam; Pt = 2200 mm/yr
	Bulldoze to 4% slope & till			3-5%			47% decrease in surface runoff	
16	Contour cultivation	India	W/D	2.2%	Barley/jowar	Plot	29% decrease in surface runoff	Comparison to up & down slope cultivation

Table 8.2

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON SOIL MOISTURE AND SURFACE RUNOFF

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	REMARKS
46	Contour rows	India	D/WM	NG	Agriculture	Field	25% decrease in surface runoff	Comparison to up & down slope cultivation; based on review of 30 years of experiment station projects
28	Plough	USA	T	NG	Agriculture	Plot	858% increase in total water infiltrated	Comparison to untilled; attributed to surface roughness, not to increased permeability
	Plough-disk-harrow						250% increase in total water infiltrated	
	Cultivate						279% increase in total water infiltrated	
	Rotovate						72% increase in total water infiltrated	
158	Animal traction	France	T	5%	Winter barley	Plot	99.9% decrease in surface runoff	Comparison to permanent grassland Rainfall simulator study - 1 hr, 33mm rainfall
	Broken grassland			5%	Grassland	Plot	350% increase in surface runoff	
	till,stubble plow,subsoil			5%	Agriculture	Plot	150% increase in surface runoff	
	till,stubble plow			5%	Agriculture	Plot	600% increase in surface runoff	
	Heavy equipment, post harvest			5%	Potato/endive	Plot	1,317% increase in surface runoff	
178	Ridge-tillage	USA	T	NG	Agriculture	Field	May increase surface runoff	Increase in surface runoff due to concentration of flow in the furrows and ridges increasing slope.
24	Contour furrowing	USA	SATmp	NG	Rangeland	Field	8% increase in soil moisture storage in top 75 cm of soil	Generally, soils with medium to fine texture show most consistent beneficial response to furrowing
78	Furrowing	USA	SATmp	NG	Rangeland	Field	Little benefit as soil moisture conservation tool on clayey soils if compaction of soil surface occurs	
200	Furrowing	USA	SATmp	NG	Rangeland	Field	Ineffective as soil moisture conservation tool in sandy soils	
47	Furrowing	USA	SATmp	NG	Rangeland	Field	121% increase in soil moisture storage	Comparison to non-furrowed; soil = clay loam
164	Furrowing	USA	T	NG	Grassland	Field	Rainfall percolated 6-18 inches deeper	Comparison to non-furrowed
218	Furrowing	Australia	SATr	NG	Grassland	Field	Water storage upto 1 meter deeper	Comparison to non-furrowed
142	Broadbed & furrow	India	SATr	0.4%	Pearl millet/ sorghum	Field	61% decrease in surface runoff, 56% decrease in peak discharge	Comparison to traditional flat cropping system with a monsoon fallow; soil = very fine clay Vertisol (Typic Pellustert; Pt = 760mm/yr
	Broadbed & furrow			0.6%	intercrop with Cajanus cajan	Field	48% decrease in surface runoff, 31% decrease in peak discharge	
	Broadbed & furrow & field bunds			0.6%		Field	66% decrease in surface runoff 56% decrease in peak discharge	
	Flat on grade			0.6%		Field	36% decrease in surface runoff, no significant difference in peak discharge	
142	Broadbed & furrow	India	SATr	0.6%	Pearl millet/	Field	38% increase in surface runoff, 67% increase in peak discharge	Comparison to traditional cropping system wuth field bunds; soil = fine clay (Udic Rhodoustalf).
	Flat on grade with graded bunds			0.6%	sorghum intercrop with	Field	23% decrease in surface runoff, no significant difference in peak discharge	

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IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON
SOIL MOISTURE AND SURFACE RUNOFF

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	REMARKS
	Traditional with contour bunds			NG	Cajanus cajan	Field	37% decrease in surface runoff, 33% decrease in peak discharge	Alfisols unstable in bunds & furrows. Pt = 760mm/yr
130	Broadbed and furrow	India	SATr	NG	Agriculture	Field	50% decrease in surface runoff	Comparison to traditional flat land with bunds
131	Cross-slope planting Ridge & furrow(60 cm spacing)	India	D/W	1.5%	Grains	Plot	21% decrease in surface runoff 86% decrease in surface runoff	Comparison to up & downslope cultivation; Soil = well-drained, sandy loam (Inceptisol)
180	Furrow dams	USA	SATmp	0-5%	sorghum	Field	35-88mm of surface runoff conserved	5cm storage capacity before overtop; soil = clay loam
72	Bench terrace Afforestation	Indonesia	D/WM	10-47%	Agriculture	Plot	50% decrease in surface runoff 70% decrease in surface runoff	Comparison to unimproved local practices; Pt = 2,000-3,350 mm/yr
167	Terracing & reforestation	Indonesia	EM	NG	Agriculture	Watershed	50% decrease in runoff coefficients	Comparison to pre-treatment levels
177	Level terrace Pasture	USA	T	2-18% 2-18%	Corn Pasture	Field	No significant difference in surface runoff 37% decrease in surface runoff 10% decrease in peak runoff on both	Comparison to contour planted corn; soil = deep loess, Pt = 815 mm/yr.
102	Bench terrace Mulch/Bahia grass strips Mulch/Bahia grass cover	Taiwan	D/WM	28% 28% 28%	Citrus	Field	74% decrease in surface runoff 92% decrease in surface runoff NG	Comparison to clean cultivation; Pt = 1,634 mm/yr
102	Level terrace Grass barrier (2.5m spacing) Grass barrier (5m spacing) Mulch/Bahia grass cover	Taiwan	D/WM	24% 24% 24% 24%	Banana	Field	77% decrease in surface runoff 67% decrease in surface runoff 29% decrease in surface runoff 87% decrease in surface runoff	Comparison to clean cultivation, Pt = 2,274 mm/yr
103	Bench terraces Bench terraces with grass cover (Bahia,Love) or mulch	Taiwan	D/WM	28% 28%	Citrus orchard	Field	75% decrease in surface runoff 90% decrease in surface runoff	Comparison to clean cultivation; soil = clay loam
103	Bench terraces with Bahia Hillside ditches with Bahia	Taiwan	D/WM	28% 28%	Citrus orchard	Field	48% decrease in surface runoff 75% decrease in surface runoff	Comparison to bench terraces and hillside ditches without Bahia
102	Reverse slope bench terrace Mulch & close planted on the contour	Taiwan	D/WM	20% 20%	Pineapple	Field	86% decrease in surface runoff 82% decrease in surface runoff	Comparison to planting up & down slope; Pt = 1,373 mm/yr
68	Contour rows Up & down slope planting/ contour furrows Permanent grass Bench terrace	India	D/WM	25%	Potato	Field	70% decrease in surface runoff 10% decrease in surface runoff 70% decrease in surface runoff 50% decrease in surface runoff	Comparison to up & down slope cultivation
10	Terraces with increase in permanent grass/3 yr. crop rotation/deep tillage	USA	T	2-3%	Agriculture	Watershed	24% decrease in surface runoff	28 yr study; Soil = calcareous clay, Pt = 889 mm/yr

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IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON
SOIL MOISTURE AND SURFACE RUNOFF

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	REMARKS
	Terraces with shallow tillage and grazing of crop residues			2-3%			20% increase in surface runoff	
	Terraces with no improved practices			2-3%			No difference in surface runoff	
11	Terraces with conservation cropping & permanent cover	USA	T	NG	Agriculture	Watershed	20 - 33% decrease in surface runoff	200 ha watershed; Soils = black soils
74	Contour-strip on terraces	USA	T	NG	Agriculture	Watershed	30% decrease in annual surface runoff	Comparison to pre-treatment
	Terraces			NG		Watershed	No significant difference in annual surface runoff	
219	Contour farmed terraces	USA	T	NG	Agriculture	Watershed	9 - 37% decrease in surface runoff	General statement for USA
84	Graded furrows vs contour tilled graded terraces	USA	T	NG	Wheat-sorghum-fallow	Field	25% increase in surface runoff from graded terraces relative to graded furrows	Greatest increases in small storm events; Soil = clay loam Xerosol (Torrertic Paleustoll); Pt = 1,270 mm/yr
155	Graded furrows vs terraces	USA	T	2-3%	Cotton/sorghum/oats	Watershed	21% decrease in surface runoff from graded furrows relative to terraces.	Graded furrow system held up to storm that caused extensive terrace failure; Soil = black clay, Pt = 853 mm/yr
112	Land leveling	USA	T	NG	Sorghum	Field	No significant difference in soil moisture storage	Comparison to unleveled; Pt = 673mm/yr
187	Contour bunds	Indonesia	D/WM	12%	Agriculture	Plot	18% decrease in surface runoff	Comparison to unbunded
204	Field bunds	Indonesia	EM	NG	Irrigated rice	Field	Water efficiency of rice 25-30%, attributed to farmers maintaining water head too high thus increasing lateral flow into bunds and water lost to vertical percolation.	Results tally with other studies, range of efficiencies recorded - 18% (sands) - 45% (clay) in 10 countries.
126	Level pans	USA	T	NG	Agriculture	Field	12.7cm - 22.9cm increase in soil moisture storage.	Increase dependant on timing and distribution of rainfall
126	Level pans	USA	SATmp	NG	Sorghum	Field	7 month moisture storage equivalent to 19 - 21 month fallow	Pt = 422 mm/yr
182	Terrace	Colombia	W/D	45%	Coffee	Plot	116% increase in surface runoff	Comparison to unterraced coffee.
10	Terraces	USA	T	2-3%	Agriculture	Watershed	Reduction in peak runoff - magnitude of reduction inversely proportional to size of watershed	28 yr study; Soil = calcareous clay, Pt = 889 mm/yr
10	Terraces	USA	T	2-3%	Agriculture	Watershed	Wet soils - increase in surface runoff, dry soils - decrease in surface runoff	28 yr study; Soil = calcareous clay, Pt = 889 mm/yr
191	Bench terrace	Indonesia	D/WM	9%	Corn & cassava	Plot	44% - 65% decrease in surface runoff	Comparison to unterraced
	Bench terrace				Sweet potato		50% decrease in surface runoff	
	Bench terrace				Corn		31% decrease in surface runoff	
	Bench terrace				Cassava		52% decrease in surface runoff	

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IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON
SOIL MOISTURE AND SURFACE RUNOFF

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	REMARKS
140	Flat bench terrace Sloping bench terrace	Indonesia	D/WM	NG	Agriculture	Plot	17% increase in surface runoff 293% increase in surface runoff	Comparison to ridge terrace
163	Bench terrace Ridge terrace	Indonesia	D/WM	NG	Agriculture	Plot	31% increase-15% decrease in surface runoff 80% - 201% increase in surface runoff	Comparison to unimproved local farming system.
76	Zingg conservation bench terrace	USA	T	NG	Agriculture	Field	No significant difference in soil moisture storage	Comparison to unterraced.
17	Zingg conservation bench terrace	USA	T	1.5%	Sorghum/wheat/ fallow	Field	Excess soil moisture made tillage operations difficult.	Soil = silty clay
124	Zingg conservation bench terrace	USA	SATmp	1%	Sorghum	Field	7 month soil moisture storage in terrace equivalent to 19 month storage in fallow	Soil = silt loam to clay loam; Pt = 424mm/yr
75	Zingg conservation bench terrace	USA	SATmp	1.5%	Sorghum/wheat	Field	Soil moisture storage the same continuously cropped as level terrace fallowed 11 months	Soil = silty clay loam,
75	Zingg conservation bench terrace	USA	SATmp	1.5%	Sorghum/wheat	Field	No soil moisture conservation benefits in coarse or low water-holding capacity soils	
69	Zingg conservation bench terrace	USA	SATmp	1-5%	Wheat/corn/ bromegrass & alfalfa	Field	No increase in overwinter soil moisture storage, increase occurred in spring.	Soil = silt loam to silty clay loam, Pt = 445 mm/yr
169	Contour bunds Bench terrace Hillside ditches Intermittent terrace	Thailand	D/WM	NG NG NG NG	Agriculture	Field	70% increase in surface runoff 140% increase in surface runoff 70% increase in surface runoff 60% increase in surface runoff	Comparison to unterraced control; soil = Acrisol (Typic Paleudult); Pt = 1,612 mm/yr. Increased runoff undesirable.
68	Graded vs Bench terraces	India	D/WM	25%	Agriculture	Field	No significant difference in surface runoff between these two terrace types	
68	Contour bunds/ridge-type terraces/level terraces/ absorptive terraces	India	SATr & AT	NG	Agriculture	Field	Ponding due to insufficient drainage	Soil = Vertisols and other poorly drained soil types
168	Contour bunding/bench terracing/land levelling	India	SATr & DW/M	NG	Agriculture	Field	50% decrease in depth to which water percolated	Comparison to adjacent untreated lands
103	Bench terraces vs hillside ditches	Taiwan	D/WM	28%	Citrus orchard	Field	Runoff less from bench terraces relative to hillside ditches	If bench terrace topsoil not replaced, percolation rates are low and runoff rates are high; 4 years were necessary to consolidate soil on bench terrace so that less than from hillside ditches
89	Terraces - 42% watershed area Terraces - 75% watershed area	USA	T	NG NG	Agriculture	Watershed	11% decrease in surface runoff, 36% decrease in total discharge from 10 yr. storm 44% decrease in surface runoff, 60% decrease in total discharge from 10 yr storm	11,500 ha watershed

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IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON
SOIL MOISTURE AND SURFACE RUNOFF

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	REMARKS
108	Large-scale terracing	Switzerland	T	NG	Vineyards	Watershed	Significant increase in peak discharges, time to peak discharge, steeper slope of dry weather hydrograph recession curve, reduction in base and low flows, greater variability in runoff. Decrease in soil's hydraulic conductivity, decrease in soil moisture.	Effects attributed to : increase of asphalted roads and drainage system (gullies & pipes) and destruction of soil structure by mechanical action of heavy equipment in terrace building. Soil = deep loess.
110	Large-scale terracing	Switzerland	T	NG	Vineyards	Watershed		
58	Check dams to harvest water	Israel	SATmp	NG	NG	Watershed	Improved output from downstream shallow aquifers	Effective where installed in series along same river, hydrologic/hydrogeologic inputs are known, pumps and energy available, and technical staff to operate and maintain
206	Dirt roads	USA	T	0.2-30%	Dirt roads	Plot	24% - 96% of rainfall occurs as runoff	Range of runoff values from rainfall simulator study.

Table 8.3

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON EROSION AND SEDIMENTATION

CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
145	Forestry	Pan-tropical	Various	45+%	Forestry	Watershed	Minimize soil erosion	N/A	Most intensive management options, at the given range of slopes, to minimize soil erosion. *The shallower the soil, adjust down the upper end of the range.*
	Agroforestry			35-60%	Agroforestry	Watershed	Minimize soil erosion		
	Pasture			10-45%	Pasture	Watershed	Minimize soil erosion		
	Bench terraces & intensive crop management			10-35%	Agriculture/ Horticulture	Watershed	Minimize soil erosion		
	Bench terraces			10-25%	Agriculture/ Horticulture	Watershed	Minimize soil erosion		
215	Remove trees	Java	EM	9%	5 year old. Acacia spp. plantation	Plot	200% increase in sediment yield	N/A	Compared to undisturbed; soil = clay, Gleysol (Typic Tropaquept)
	Remove undergrowth			9%		Plot	400% increase in sediment yield		
	Remove trees/undergrowth			9%		Plot	100% increase in sediment yield		
	Remove undergrowth/litter			9%		Plot	26,000% increase in sediment yield		
	Remove all			9%		Plot	4,300% increase in sediment yield		
176	Fern cover	Sri Lanka	EM	50%	Forestry	Watershed	566% increase in sediment yield	0.56 t/ha/yr	Comparison to closed canopy Pinus caribea plantation
	Degraded grass cover			50%			170% increase in sediment yield		
	Grass cover			50%			No significant difference in sediment yield		
100	Land clearing	Ivory Coast	W/D	NG	Agriculture	Field	Large increase in erosion rate.	N/A	Soil = sandy Alfisol
98	Land clearing	Nigeria	W/D	NG	Agriculture	Field	Large increase in erosion rate	N/A	Soil = sandy Alfisol
97	Plowing	Nigeria	W/D	NG	Agriculture	Field	Erosion rate upto 115 t/ha/yr	N/A	Soil = sandy Alfisol
58	Contour cultivation	Israel	SATr	3-8%	Agriculture	Field	Slopes less than 3% no difference from cross-slope cultivation, slopes greater than 8% have washouts and increased erosion	N/A	
86	Cultivated fallow Bunds	India	SATr	NG NG	Agriculture	Field	Questionable practice due to erosion hazard. Erosion between bunds may be substantial, *and inadequate maintenance often results in breaches*	N/A	Soil = heavy soil, e.g. Vertisol
160	Traditional cultivation	Amazon	CW	Steep	Agriculture	Field	No indications of increased erosion	N/A	Soil = Ultisol
209	Shifting cultivation	Venezuela	W/D	Steep	Agriculture	Field	Little erosion amongst traditional cultivators, severe erosion amongst newcomers to shifting cultivation	N/A	
70	Conversion of forest to grassland	World-wide	All	N/A	Grassland	Watershed	No significant difference in erosion/ sediment yield once grass established.	N/A	"Lose mass wasting protection with conversion to grasslands"
134	Conversion of forest to grassland	Hawaii	CW	NG	Grassland	Watershed	Increased erosion/sedimentation	N/A	Attributed to increased runoff due to reduced evapotranspiration by Adropogon on rainforest soils
162	Natural erosion	Hawaii	CW	Steep	Natural cover	Watershed	Landslides observed only under forest and fern cover, not grass	N/A	Manoa Valley

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IMPACTS OF SOIL CONSERVATION TECHNOLOGIES
ON EROSION AND SEDIMENTATION

CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
147	Natural erosion	New Guinea	EM	N/A	Natural cover	Watershed	Dominant sediment sources are landslides and slopewash under forest cover	N/A	Annual runoff = 5,300-7,200mm/yr
30	Forest, litter removed/burned	Indonesia	D/WM	10%	Various	Plot	1,400% increase in erosion rate	5 t/ha/yr	Comparison to undisturbed forest; soil = deep volcanic soil
	40 yr. old teak plantation						1,400% increase in erosion rate		
	Plowed, rainfed maize						1,900% increase in erosion rate		
	Fired, dibbled rainfed maize						1,300% increase in erosion rate		
	Bench terraced, rainfed maize/cassava						300% increase in erosion rate		
	Coffee plantation						No significant difference in erosion rate		
	Dense Imperata grassland						No significant difference in erosion rate		
	Degraded forest, shrub, dense undergrowth						No significant difference in erosion rate		
176	Fern cover	Sri Lanka	EM	50%	Forestry	Watershed	90% of sediment yield in 30% rainfall events	N/A	Soils = sandy clay loam Nitosol (Typic Tropudult), Pt = 5,460 mm/yr
	Degraded grass cover			50%	Forestry		90% of sediment yield in 30% rainfall events		
	Grass cover			50%	Forestry		90% of sediment yield in 10% rainfall events		
	Closed canopy Pinus plantation			50%	Forestry		90% of sediment yield in 10% rainfall events		
48	Forest	Hawaii	CW	NG	Forest	Watershed	90% of sediment yield in 2% rainfall events	N/A	
29	Nile River basin	Egypt	SATr	N/A	Mixed	Watershed	100% of sediment from 10% of basin	N/A	
	Red Deer River basin	Canada	T	N/A	Mixed	Watershed	90% of sediment from 10% of basin		
	Amazon River basin	Brazil	CW	N/A	Mixed	Watershed	80% of sediment at the mouth from the Andes		
	Yellow River basin	China	D/WM	N/A	Mixed	Watershed	90% of sediment from 40% of basin		
	United States	USA	T	N/A	Mixed	Watershed	1.1 t/m/yr sediment from river banks		
	Spring Creek	Canada	T	N/A	Mixed	Watershed	36% increase in sediment yield following disturbance of 0.45% of the watershed		
	Small watershed	USA	T	N/A	NG	Watershed	51% of sediment from 1% of watershed		
32	Roads and trails	Honduras	W/D	NG	Mixed	Watershed	45% of sediment produced, 2% of area	N/A	
	Hillside cultivation				Agriculture		20% of sediment produced, 13% of area		
	Grazing land				Pasture		20% of sediment produced, 20% of area		
	Burned forest land				Forestry		4% of sediment produced, 10% of area		
	Brush lands				Mixed		1% of sediment produced, 20% of area		
	Forests				Forestry		1% of sediment produced, 35% of area		
49	Roads and trails	Kenya	W/D	N/A	Mixed	Watershed	Large fraction of sediment leaving agricultural catchments contributed by roads and trails	N/A	Based on sediment yield analysis from 61 catchments
206	Dirt roads	USA	T	N/A	Mixed	Plot	3 - 660 t/ha/yr sediment yield	N/A	Range of soil loss values reported in literature. Soil loss use dependant.
14	Soil loss tolerances	Brazil	CW	N/A	Agriculture	Field	Lithosol = 2-7 t/ha/yr Podzol = 5-13 t/ha/yr Dark red latosol = 12-16 t/ha/yr	N/A	Soil loss tolerance is that quantity of soil that may be eroded without a sites ability to sustain productivity being effected.

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IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON EROSION AND SEDIMENTATION

CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
107	Soil loss tolerances	Brazil	CW	N/A	Agriculture	Field	Acrisols and Nitosols (Ultisols with argillic horizon), Lithosols, Regosols = 4.6 - 16.6 t/ha/yr	N/A	
220	Soil loss tolerances	USA	T	N/A	Agriculture	Field	2.2 - 12.1 t/ha/yr	N/A	
13	Soil loss tolerances	USA	T	N/A	Agriculture	Field	Topsoil formation rate (under tillage) = approx. 30 yr/cm or 12.4 t/ha/yr	N/A	
27	Soil loss tolerances	Worldwide	All	N/A	N/A	N/A	Range of soil formation rate, in literature = 1.3 - 750 yr/cm or 286 - 0.5 t/ha/yr -- dependant on climate, parent material, and criteria (profile development vs total soil depth)	N/A	
51	Soil loss tolerances	Pan-tropical	EM & D/WM & CW & W/D	N/A	Agriculture	Field	On basis of erosion impacts, highly weathered tropical soils should have lower soil loss tolerances than their temperate counterparts.	N/A	
50	Soil loss tolerances	NSW, Australia	SATr	N/A	N/A	N/A	Soil formation rate : 350 yr/cm in alluvium, longer in bedrock	N/A	
2	Manure (16 t/ha)	Indonesia	D/WM	16%	Agriculture	Plot	42% decrease in erosion rate	341 t/ha	Comparison to unmanured
21	Cow dung (5 t/ha)	Ghana	CW	7.5%	Corn	Plot	99% decrease in sediment yield	64 t/ha/yr	Comparison to bare fallow; Pt = 1,340 mm/yr
	Wood shavings (5 t/ha)			7.5%		Plot	99% decrease in sediment yield		
	Poultry manure (5 t/ha)			7.5%		Plot	99% decrease in sediment yield		
	Cow/poultry manure (5 t/ha)			7.5%		Plot	99% decrease in sediment yield		
	Commercial fertilizer			7.5%		Plot	94% decrease in sediment yield		
21	Cow dung (2 t/ha)	Ghana	SATr	2%	Sorghum	Plot	73% decrease in sediment yield	5.2 t/ha/yr	Comparison to bare fallow; Pt = 320 mm/yr
	Cow dung (4 t/ha)			2%		Plot	81% decrease in sediment yield		
	Cow dung (4 t/ha) & straw mulch (4 t/ha)			2%		Plot	98% decrease in sediment yield		
	Cow dung (5 t/ha)			2%		Plot	83% decrease in sediment yield		
	Cow dung (5 t/ha) & straw mulch (4 t/ha)			2%		Plot	98%% decrease in sediment yield		
96	Mulch	Nigeria	W/D	N/A	Agriculture	Field	Protection from compaction and increased erosion	N/A	Best management practice for Luvisols, Podzoluvisols (Alfisols)
149	50% asphalt mulch	Venezuela	W/D	4%	Sorghum	Field	68% decrease in erosion rate	57 t/ha/yr	Comparison to no-mulch; soil = sandy loam (Typic Haplustalf)
	100% asphalt mulch			4%		Field	99.9% decrease in erosion rate		
123	Mulch (0.62 - 1.23 t/ha)	USA	T	15%	Agriculture	Field	66% decrease in sediment yield	N/A	Comparison to no mulch
	Mulch (2.5 t/ha)			15%			82% decrease in sediment yield		

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ON EROSION AND SEDIMENTATION

CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
	Mulch (5 - 10 t/ha)			15%			95% decrease in sediment yield		
99	Mulch (0.55 t/ha)	USA	T	2%	Agriculture	Field	40% decrease in interrill erosion rate	N/A	Comparison to no mulch; soil = silt loam (Typic Haplustalf) Interrill erosion = erosion by raindrop splash
	Mulch (2.2 t/ha)			2%			80% decrease in interrill erosion rate		
	Mulch (8.8 t/ha)			2%			Interrill erosion rate negligible		
171	Mulch (0.33 t/ha, 22% cover)	USA	T	NG	Agriculture	Plot	42% decrease in sediment yield	N/A	Comparison to no mulch under rainfall simulator
	Mulch (0.44 t/ha, 37% cover)						43% decrease in sediment yield		
	Mulch (0.66 t/ha, 46% cover)						62% decrease in sediment yield		
	Mulch (0.88 t/ha, 58% cover)						62% decrease in sediment yield		
	Mulch (1.21 t/ha, 81% cover)						81% decrease in sediment yield		
	Mulch (1.87 t/ha, 87% cover)						87% decrease in sediment yield		
	Mulch (2.47 t/ha, 92% cover)						92% decrease in sediment yield		
113	Mulch (0.63 t/ha)	USA	T	5%	Agriculture	Plot	69% decrease in sediment yield	31 t/ha	Comparison to no mulch; soil = silt loam; rainfall simulator study
	Mulch (1.23 t/ha)			5%			89% decrease in sediment yield		
	Mulch (2.47 t/ha)			5%			97% decrease in sediment yield		
	Mulch (4.94 t/ha)			5%			99.9% decrease in sediment yield		
	Mulch (9.88 t/ha)			5%			99.9% decrease in sediment yield		
199	Mulch (0.6 t/ha)	Indonesia	D/WM	7%	Upland rice	Plot	78% decrease in erosion rate	18.6 t/ha	Comparison to unmulched; soil = Reddish-brown Latosol; rice straw mulch
	Mulch (1.0 t/ha)						92% decrease in erosion rate		
	Mulch (1.6 t/ha)						96% decrease in erosion rate		
	Mulch (0.6 t/ha)			9%			24% decrease in erosion rate	22.3 t/ha	
	Mulch (1.0 t/ha)						44% decrease in erosion rate		
	Mulch (1.6 t/ha)						56% decrease in erosion rate		
	Mulch (0.6 t/ha)			14%			16% decrease in erosion rate	27.9 t/ha	
	Mulch (1.0 t/ha)						54% decrease in erosion rate		
	Mulch (1.6 t/ha)						59% decrease in erosion rate		
188	Mulch (0.6 t/ha)	Indonesia	D/WM	7-14%	Upland rice	Plot	35% decrease in erosion rate		Comparison to unmulched; soil = Reddish-brown Latosol; rice straw mulch
	Mulch (1.0 t/ha)						61% decrease in erosion rate		
	Mulch (1.6 t/ha)						68% decrease in erosion rate		
213	Mixed cropping & mulch (4.4 t/ha)	Indonesia	D/WM	20%	Corn & peanuts	Plot	74% decrease in erosion rate	250 lbs.	Comparison to corn & peanuts strip cropped
	Mixed cropping						No significant difference in erosion rate		
160	Mulch/Cover Crop	Pan-tropical	N/A	N/A	Agriculture	Field	Protection from compaction and increased erosion	N/A	Luvisols, Nitosols, Acrisols (Ultisols and Alfisols) with sandy topsoils susceptible to compaction and increased erosion following exposure and cultivation.
190	Mulch and minimum tillage	Indonesia	EM	3.5%	Cassava/rice/corn/peanuts/beans	Plot	99% decrease in sediment yield	16 t/ha	Comparison to unmulched, traditional cultivation; in order of treatment pairs soils = Nitosol (Tropudult), Nitosol (Tropudalf),
	Bare soil			3.5%		Plot	620% increase in sediment yield	136 t/ha	
	Mulch and minimum tillage			9%		Plot	92% decrease in sediment yield	332 t/ha	
	Bare soil			9%		Plot	245% increase in sediment yield	195 t/ha	
	Mulch and minimum tillage			10%		Plot	56% decrease in sediment yield	75 t/ha	

Table 8.3

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES
ON EROSION AND SEDIMENTATION

CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
	Bare soil			10%		Plot	25% increase in sediment yield		Nitosol (Tropudalf),
	Mulch and minimum tillage			14%		Plot	89% decrease in sediment yield		Ferralsol (Haplorthox),
	Bare soil			14%		Plot	149% increase in sediment yield		Nitosol (Tropudalf),
	Mulch and minimum tillage			14%		Plot	96% decrease in sediment yield		
	Bare soil			14%		Plot	431% increase in sediment yield		
116	Disk plow/stubble mulch No-till/mulch	Thailand	D/WM	NG NG	Upland rice	Plot Plot	64% decrease in sediment yield 75% decrease in sediment yield	5.5 t/ha	Comparison to disk plowed and no mulch
116	Disk plow/stubble mulch No-till/mulch	Thailand	D/WM	NG NG	Peanuts	Plot Plot	77% decrease in sediment yield 83% decrease in sediment yield	3 t/ha	Comparison to disk plowed and no mulch
41	Fascine Wattling Mulching Bare soil	Philippines	D/WM	20-35%	Grazing/kaingin	Field	154% increase in 5 yr sediment yield 142% increase in 5 yr sediment yield 145% increase in 5 yr sediment yield 1,110% increase in 5 yr sediment yield	48.3 t/ha	Comparison to grass sod of Love and Bermuda grasses/Alnus,Pinus, Psidium,and Eucalyptus seedlings; soil = clay loam, Pt=2,679 mm/yr
41	Fascine Wattling Mulching Bare soil	Philippines	D/WM	20-35%	Grazing/kaingin	Field	110% increase in sediment yield 96% increase in sediment yield 152% increase in sediment yield 14,500% increase in sediment yield	1.05 t/ha	Comparison to sediment yield at years 4 & 5 of grass sod of Love and Bermuda grass/Alnus,Pinus, Psidium,Eucalyptus seedlings, soil = clay loam, Pt=2,679 mm/yr
102	Desmodium spp. cover Bahia grass Eragrostis spp. mulch	Taiwan	D/WM	46%	Litchi	Field	95% decrease in sediment yield 99.6% decrease in sediment yield 96% decrease in sediment yield	55 t/ha	Comparison to clean cultivation; Pt = 3,494 mm/yr
182	Grass cover	Colombia	W/D	22%	Pasture	Field	97% decrease in erosion rate	0.3 t/ha	Comparison to monthly tilled bare soil.
50	Grass cover Grass cover	NSW, Australia	SATr	8% 8.5%	Grassland Grassland	Plot Plot	98% decrease in sediment yield 99% decrease in sediment yield	47 t/ha 148 t/ha	Comparison to wheat; soil = calcic and chromic luvisols, respectively; Pt = 644 and 561 mm/yr, respectively
215	Shaded grass Unshaded grass	Nigeria	W/D	NG	Agroforestry	Field	84% increase in erosion rate 91% decrease in erosion rate	0.1 t/ha	Comparison to tree plantation
202	Grass cover (Pennisetum, Cynodon,Urochloa,Panicum)	India	D/WM	5%	Agriculture	Field	70% decrease in in sediment yield	N/A	Comparison to conventional cultivation of gorapaddy,urid, corn,peanut; soil = sandy clay, Pt = 1,302 mm/yr
7	Grass - ungrazed 15 years Grass - heavily grazed	India	D/WM	Gentle	Pasture	Field	63% decrease in sediment yield 163% increase in sediment yield	8 t/ha/yr	Comparison to fenced and lightly grazed
211	Short duration grazing (few day high density grazing, many day rested)	USA	SATmp	0-3%	Pasture	Field	200% increase in sediment yield	N/A	Comparison to moderate, continuous grazing; soil = fine loam to loam Yermosol (Aridisol)
161	Grass - Imperata,Saccharum	Philippines	D/WM	36-70%	Grassland	Field	No significant difference in sediment yield	0.4 t/ha/yr	Comparison to secondary forest

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CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
	Plantation forest - Gliricidia, Leucaena				Forestry		No significant difference in sediment yield		
	Kaingin				Agriculture		2,760% increase in sediment yield		
217	Grass strips	USA	T	NG	Waste treatment	Field	99% decrease in sediment concentration and 67% decrease in BOD	5,215 ppm	Comparison to concentration levels and BOD of water prior to movement through grass strip
217	10 ft. wide grass strip 25 ft. wide grass strip	USA	T	NG	Agriculture	Plot	50% decrease in sediment yield 70% decrease in sediment yield	N/A	Comparison to sediment load of water prior to movement through grass strip
102	Eragrostis barrier/mulch Guinea grass barrier/mulch South African pigeon grass barrier/mulch	Taiwan	D/WM	23% 23% 23%	Banana	Field	97.5% decrease in sediment yield 97% decrease in sediment yield 97% decrease in sediment yield	53 t/ha/yr	Comparison to clean cultivation; Pt = 2,348 mm/yr
39	Vegetative buffers	USA	T	0-20%	Agriculture	Watershed	84-90% trap efficiency by riparian buffers	N/A	Trap efficiency = % of eroded sediments deposited in riparian zone
3	Grass strips (0.5m wide - Brachiaria, 1m wide - Paspalum)	Java	EM	15-22%	Agriculture	Field	93% decrease in sediment yield	N/A	Comparison to bare soil
31	Sediment basins Grass strips Mulch in furrows	USA	T	NG NG NG	Beans/peas/ sugarbeets/ alfalfa	Watershed Watershed Plot	80% decrease in sediment yield 40 - 60% decrease in sediment yield 90% decrease in erosion rate	N/A	Comparison to calibration period; soil = silt loam
4	Grass strip (P. notatum, 1 m wide) Grass strip (B. decumbena, 0.5 m wide)	Indonesia	D/WM	NG	Agriculture	Plot	21% decrease in erosion rate 24% decrease in erosion rate	NG	Comparison to no grass strip
183	Vegetative strip (Mucuna (utilis) Vegetative strip (Pucraica phaseoloide) Vegetative strip (Mimosa invisa) Vegetative strip (Pennisetum purpureum)	Indonesia	D/WM	12%	Corn & cassava	Plot	13% decrease in erosion rate No significant differenc in erosion rate 8% decrease in erosion rate No significant difference in erosion rate	89 t/ha	Comparison to corn & cassava w/o vegetative strips
74	Reforestation Seeding native grass Contour strips Crop rotation & fallow	USA	T	NG NG NG NG	Forestry Grassland Agriculture Agriculture	Watershed Watershed Watershed Watershed	99.9% decrease in sediment yield 99.9% decrease in sediment yield 50% decrease in sediment yield 50% decrease in sediment yield	N/A	Comparison to pre-treatment
22	Vegetative stabilization of streambanks	USA	T	N/A	Streambanks	Watershed	Must eliminate forces that cause bed degradation before possible to	N/A	Channel structures will become ineffective or deteriorate due

Table 8.3

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES
ON EROSION AND SEDIMENTATION

CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
							stabilize banks vegetatively.		to hydrology changes; must have maintenance.
137	Mulch and no-till	USA	T	5.5%	Corn/soy/oats	Plot	94% reduction in sediment yield	N/A	Comparison to same tillage type with less than 15% crop residue cover as mulch; soil = fine loam Luvisol (Typic Hapludalf)
	Mulch and mouldboard plow			5.5%		Plot	81% reduction in sediment yield		
	Mulch and sweep tillage			5.5%		Plot	77% reduction in sediment yield		
	Mulch and chisel			5.5%		Plot	45% reduction in sediment yield		
	Mulch and chisel & disk			5.5%		Plot	26% reduction in sediment yield		
116	No-till	Thailand	D/WM	NG	Rice	Plot	93% decrease in sediment yield	40 t/ha	Comparison to clean cultivation
	Stubble mulch			NG		Plot	90% decrease in sediment yield		
	Bare fallow			NG		Plot	375% increase in sediment yield		
212	No-till with stubble mulch (chemical weed control)	USA	T	3%	Corn	Field	60% increase in sediment yield	N/A	Comparison to conventional tillage with stubble mulch
173	Cultivated fallow	India	SAT	0.5%	Fallow	Field	1,239% increase in sediment yield	N/A	Comparison to natural cover; soil = silty clay loam, Pt = 800 mm/yr
	Cultivated fallow			1%	Fallow		850% increase in sediment yield		
	Grass cover (Cynodon spp.)			0.5%	Grass		12% increase in sediment yield		
	Grass cover (Cynodon spp.)			1%	Grass		6% decrease in sediment yield		
	Peanut			0.5%	Peanut		327% increase in sediment yield		
	Peanut			1%	Peanut		395% increase in sediment yield		
	Gram			0.5%	Gram		691% increase in sediment yield		
	Gram			1%	Gram		430% increase in sediment yield		
	Jowar			0.5%	Jowar		997% increase in sediment yield		
	Jowar			1%	Jowar		527% increase in sediment yield		
63	Coffee - 1 yr old	Indonesia	D/WM	46-66%	Agriculture	Plot	526% increase in erosion rate	0.31 t/ha	Comparison to undisturbed natural forest
	Coffee - 3 yr old						406% increase in erosion rate		
	Coffee - 16 yr old						310% increase in erosion rate		
8	Tobacco (cultivated)	Indonesia	D/WM	30%	Agriculture	Plot	138% increase in erosion rate	3.2 t/ha/mo	Comparison to non-cultivated cassava
	Potato (cultivated)						557% increase in erosion rate		
	Corn & beans (cultivated)						52% increase in erosion rate		
54	Rows up & down slope	Peru	SAT	25%	Potato	Field	176% increase in sediment yield	4.7 t/ha	Comparison to continuous fallow
	Contoured						12% increase in sediment yield		
	Cover cropped (Lupinus) and rows up & down slope						29% increase in sediment yield		
	Mulched						No increase in sediment yield		
54	Rows up & down slope/burned	Peru	W/D	30%	Potato	Field	680% increase in sediment yield	16.4 t/ha	Comparison to continuous fallow
	Cover cropped and rows up & down						157% increase in sediment yield		
	Contoured						576% increase in sediment yield		
	Mulch and rows up & down slope						490% increase in sediment yield		
122	Bare fallow	Ghana	W/D	7.5%	Corn	Field	964% increase in sediment yield	18.8 t/ha/yr	Comparison to traditional mixed cropping; soil = sandy loam to sandy clay, Pt = 1,500 mm/yr
	Zero-tillage			7.5%			80% decrease in sediment yield		
	Mulching			7.5%			98% decrease in sediment yield		

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ON EROSION AND SEDIMENTATION

CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
	Ridging across slope			7.5%			81% decrease in sediment yield		
	Minimum tillage			7.5%			83% decrease in sediment yield		
122	Bare fallow	Ghana	W/D	3%	Corn	Field	795% increase in sediment yield	2.1 t/ha/yr	Comparison to traditional mixed cropping; soil = sandy clay loam to sandy clay, Pt = 1,400 mm/yr
	Zero-tillage			3%			*205% increase in sediment yield*		
	Mulching			3%			38% decrease in sediment yield		
	Ridging across slope			3%			62% increase in sediment yield		
	Minimum tillage			3%			33% increase in sediment yield		
165	Reforestation/mulch/plate terraces	Japan	T	70%	Forestry	Watershed	99.7% decrease in sediment yield	69 t/ha/yr	Comparison to bare soil
208	Agroforestry (intercropping)	Thailand	D/WM	NG	Gmelina arborea and rice	Field	10% increase in sediment yield	N/A	Comparison to Gmelina arborea cropped alone
9	Agroforestry	Indonesia	SATr	NG	Corn & teak	Plot	12% - 31% decrease in erosion rate	6-28.7 t/ha	Comparison to corn monoculture
72	Acacia auriculiformis plantation - 5 yr old	Indonesia	D/WM	NG	Forestry	Field	24% increase in rainfall erosivity below plantation canopy	N/A	Comparison to rainfall erosivity outside of plantation
12	Clearcut/brush chopping (37% bare soil)	USA	T	30%	Forestry	Watershed	16.3 t/ha sediment yield	N/A	All 3 site prep methods increase sediment similarly; soil = sandy loam (Ultisols/Alfisols). Contour bedding difficult in steep, stump covered areas. Improper bedding causes gullies.
	Clearcut(with shear)/windrow (53% bare soil)			30%			16.5 t/ha sediment yield		
	Clearcut/contour bedding (69% bare soil)			30%			21.7 t/ha sediment yield		
62	Clearcut	Chile	W/D	30%	Forestry	Plot	2,140% increase in sediment yield	0.2 t/ha/yr	Comparison to 30 yr. old Pinus plantation; soil = clay loam; Pt = 2,000 mm/yr
	Pasture			30%	Pasture		100% increase in sediment yield		
	6 yr. old Pinus plantation			30%	Forestry		No significant difference in sediment yield		
215	Coffee & shade	Costa Rica	W/D	NG	Agroforestry	Field	78% decrease in erosion rate	0.4 t/ha	Comparison to coffee/no shade
215	Tea, 65% cover	India	D/WM	NG	Agroforestry	Field	87% decrease in erosion rate	4.6 t/ha/yr	Comparison to tea with 15% cover
	Tea, 95% cover			NG			95% decrease in erosion rate		
215	Multi-story tree garden	Pan-tropical	Various	Various	Agroforestry	Various	98% decrease in erosion rate	2.8 t/ha/yr	Median observed values from literature - Comparison to shifting cultivation during cropping period
	Natural forest			Various			89% decrease in erosion rate		
	Shifting cultivation, fallow period			Various			95% decrease in erosion rate		
	Forest plantation, undisturbed			Various			79% decrease in erosion rate		
	Forest plantation, burned, no litter layer			Various			1,800% increase in erosion rate		
	Tree crops with cover crop and mulch			Various			73% decrease in erosion rate		
	Taungya			Various			88% increase in erosion rate		
	Tree crops, clean weeded			Various			1,610% increase in erosion rate		
215	Multi-story tree garden	Pan-tropical	Various	Various	Agroforestry	Various	99.8% decrease in erosion rate	70 t/ha/yr	Maximum observed values from literature - Comparison to
	Natural forest			Various			91% decrease in erosion rate		

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ON EROSION AND SEDIMENTATION

CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
	Shifting cultivation, fallow period			Various			89% decrease in erosion rate		shifting cultivation during cropping period
	Forest plantation, undisturbed			Various			91% decrease in erosion rate		
	Forest plantation, burned, no litter layer			Various			50% increase in erosion rate		
	Tree crops with cover crop and mulch			Various			92% decrease in erosion rate		
	Taungya			Various			293% increase in erosion rate		
	Tree crops, clean weeded			Various			161% increase in erosion rate		
216	1 yr old reforestation	USA	T	NG	Various	Watershed	1% decrease in sediment yields	N/A	Comparison to before treatment.
	1 yr old reforestation & brush dams			NG			65% decrease in sediment yields		
	2 yr old reforestation			NG			4% decrease in sediment yields		
	2 yr old reforestation & brush dams			NG			70% decrease in sediment yields		
	5 yr old reforestation			NG			10% decrease in sediment yields		
	5 yr old reforestation & brush dams			NG			75% decrease in sediment yields		
	8 yr old reforestation			NG			38% decrease in sediment yields		
	8 yr old reforestation & brush dams			NG			95% decrease in sediment yields		
	12 yr old reforestation			NG			95% decrease in sediment yields		
	12 yr old reforestation & brush dams			NG			95% decrease in sediment yields		
20	Bare soil	Korea	T	27%	Forestry	Watershed	1,088% increase in sediment yield	1.7 t/ha/yr	Comparison to grassed; soil = sandy clay loam; Pt = 1,370 mm/yr
	Hardwood plantation						113% increase in sediment yield		
	Coniferous plantation						100% increase in sediment yield		
20	Bare soil	Korea	T	58%	Forestry	Watershed	38,900% increase in sediment yield	0.3 t/ha/yr	Comparison to grassed; soil = sandy
	Well-forested						433% increase in sediment yield		
	Young plantation						3,000% increase in sediment yield		
138	Clear cutting	New Zealand	T	Steep	Forestry	Watershed	3,900% increase in erosion rate	1.4 t/ha/yr	Comparison to pre-clearcut
141	Crop rotation	Indonesia	D/WM	NG	Corn & cassava	Plot	326% increase in erosion rate	5.5 t/ha/yr	Comparison to corn monoculture
	Crop rotation				Upland rice/ corn/cassava & peanuts/grass/ banana		440% increase in erosion rate		
106	Mixed cropping	Indonesia	D/WM	20%	Clove/banana/ cassava/ungor laut/coconut	Plot	99% decrease in erosion rate	8 tons	Comparison to corn monoculture
141	Crop rotation	Indonesia	D/WM	NG	Peanut/corn/ cassava-peanut	Plot	59% decrease in erosion rate	15.2 t/ha/yr	Comparison to corn/Ceiba pentandra intercrop
	Agroforestry with crop rotation				Upland rice/ corn/cassava/		35% - 73% decrease in erosion rate		

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CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
					beans/banana/grass/Ceiba pentandra				
150	Shifting cultivation	Guatemala	W/D	Steep	Corn/beans	Field	No significant difference in erosion rates following clearing.	N/A	Low bulk density volcanic soil - Andosol (Andept)
215	2 yr old corn swidden	Philippines	D/WM	NG	Agriculture	Field	275% increase in erosion rate	1.6 t/ha/yr	Comparison to 1 yr. old swidden
215	12 yr old rice swidden	Philippines	D/WM	NG	Agriculture	Field	7,350% increase in erosion rate	1.6 t/ha/yr	Comparison to 1 yr old swidden
73	Plow,clean till,contour	USA	T	6%	Agriculture	Field	86% decrease in sediment yield	51 t/ha	Comparison to plow,clean till, and sloping rows
	No-till,contour			21%		Field	99.9% decrease in sediment yield		
139	No-till, 4 t/ha mulch	Nigeria	W/D	2%	Corn	Field	99% decrease in sediment yield	8.5 t/ha	Comparison to conventional tillage (plow & harrow)
	Hand cultivation			2%		Field	38% decrease in sediment yield		
	Mouldboard plow			2%		Field	No significant difference in sediment yield		
	Plow, bare fallow			2%		Field	104% increase in sediment yield		
157	No-till	Nigeria	W/D	1%	Agriculture	Field	98% decrease in sediment yield	0.4 t/ha	Comparison to conventional plowing
	Bare fallow			1%		Field	400% increase in sediment yield		
	No-till			5%		Field	99.9% decrease in sediment yield	2.2 t/ha	
	Bare fallow			5%		Field	64% increase in sediment yield		
	No-till			15%		Field	99.9% decrease in sediment yield	3.9 t/ha	
	Bare fallow			15%		Field	310% increase in sediment yield		
67	No-till	Trinidad	W/D	11%	Corn	Field	70% decrease in sediment yield	N/A	Comparison to bare soil; soil = sandy clay Acrisol (Ultisol)
				11%	Cowpea		94% decrease in sediment yield		
	No-till			22%	Corn		74% decrease in sediment yield		
				22%	Cowpea		87% decrease in sediment yield		
	No-till			52%	Corn		61% decrease in sediment yield		
				52%	Cowpea		78% decrease in sediment yield		
67	No-till	Trinidad	W/D	22%	Corn	Field	90% decrease in sediment yield	N/A	Comparison to bare soil; soil = sandy clay Acrisol (Ultisol)
	Till			22%	Corn		89% decrease in sediment yield		
	No-till			22%	Cowpea		85% decrease in sediment yield		
	Till			22%	Cowpea		94% decrease in sediment yield		
36	Deep tillage	Senegal	W/D	NG	Agriculture	Field	63% decrease in erosion rate	10 t/ha/yr	Comparison to shallow tillage in sandy soils.
114	Deep tillage	Brazil	W/D	NG	Cotton	Field	100% increase in erosion rate	8 t/ha/yr	Comparison to shallow tillage in Ferrasol (Oxisol).
46	Contour rows	India	D/WM	NG	Agriculture	Field	30% decrease in sediment yield	N/A	Comparison to up & down slope cultivation; based on review of 30 years of experiment station projects
219	Contour rows	USA	T	1-2%	Agriculture	Field	40% decrease in erosion rate	N/A	Comparison to un-contoured rows; full benefits only in gully and
	Contour rows			3-5%			50% decrease in erosion rate		

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CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
	Contour rows			6-9%			50% decrease in erosion rate		depression free fields. If breakovers of contour rows occurs then erosion will be greater than in uncontoured.
	Contour rows			9-12%			40% decrease in erosion rate		
	Contour rows			13-16%			30% decrease in erosion rate		
	Contour rows			17-20%			20% decrease in erosion rate		
	Contour rows			21-25$			10% decrease in erosion rate		
132	Contour strip-cropping	All	All	Various	Agriculture	Field	35-75% reduction in sediment yield, slope dependent	N/A	Comparison to up & down slope tillage
195	Contour strip-cropping	USSR	T	NG	Agriculture	Field	50% decrease in erosion rate	N/A	Comparison to non-strip-cropped, when strips 50-100m wide
142	Broadbed & furrow	India	SATr	0.4%	Corn/sorghum intercropped with Cajanus cajan	Field	87% decrease in sediment yield	6.6 t/ha	Comparison to traditional cropping system; soil = very fine clay Vertisol (Typic Pellustert); Pt = 760 mm/yr
	Broadbed & furrow			0.6%		Field	82% decrease in sediment yield		
	Broadbed & furrow & field bunds			0.4%		Field	91% decrease in sediment yield		
	Flat on grade			0.6%		Field	80% decrease in sediment yield		
142	Broadbed & furrow	India	SATr	0.6%	Pearl millet/ sorghum intercropped with Cajanus cajan	Field	49% increase in sediment yield	2.52 t/ha	Comparison to traditional cropping system with field bunds; soil = fine Udic Rhodustalf. Alfisols unstable in bunds & furrows. Pt= 760 mm/yr
	Flat on grade with graded bunds			0.6%		Field	72% decrease in sediment yield		
	Traditional with contour bunds			NG		Field	87% decrease in sediment yield		
130	Broadbed and furrow	India	SAT	NG	Agriculture	Field	83% decrease in sediment yield	N/A	Comparison to traditional flat land with bunds
131	Cross-slope planting	India	W/D	1.5%	Grain	Plot	43% decrease in erosion rate	25.5 t/ha	Comparison to up & downslope planting; soil = well-drained, sandy loam (Inceptisol)
	Ridge & furrows						96% decrease in erosion rate		
178	Ridge-tillage	USA	T	NG	Agriculture	Field	May increase sediment yield	N/A	Increase in sediment yield by ridge-tillage function of runoff concentrated in furrows and ridges increasing slope.
	Ridge-tillage with crop residues in furrows						50-86% decrease in sediment yield		
90	Burn to clear/no-till	Japan	W/D	12-18%	Agriculture	Field	85% decrease in sediment yield	20 t/ha	Comparison to burn to clear & tilled; soil = sandy clay loam; Pt = 2200 mm/yr
	Bulldoze to 4% slope & till			3-5%			150% increase in sediment yield		
	Forested (tree ht. = 10 m)			12-18%			99.9% decrease in sediment yield		
102	Bench terrace	Taiwan	D/WM	28%	Citrus	Field	97% decrease in sediment yield	156 t/ha/yr	Comparison to clean cultivation; Pt = 1,634 mm/yr
	Mulch/Bahia grass strips						98% decrease in sediment yield		
	Mulch/Bahia grass cover						99% decrease in sediment yield		
102	Level terrace	Taiwan	D/WM	24%	Banana	Field	99.5% decrease in sediment yield	39 t/ha/yr	Comparison to clean cultivation, Pt = 2,274 mm/yr
	Grass barrier (2.5m spacing)						97% decrease in sediment yield		
	Grass barrier (5m spacing)						90% decrease in sediment yield		
	Mulch/Bahia grass cover						99.7% decrease in sediment yield		
102	Bench terrace vs Bahia grass	Taiwan	D/WM	20-28%	Perennial	Field	Soil conservation effect of all types of	N/A	

Table 8.3

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES
ON EROSION AND SEDIMENTATION

ITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
							bench terraces was poorer than that of Bahia grass (except level retention terraces)		
68	Contour rows	India	D/WM	25%	Potato	Field	60% decrease in sediment yield	N/A	Comparison to up & down slope cultivation
	Up & down slope planting/ contour furrows						30% decrease in sediment yield		
	Permanent grass						99% decrease in sediment yield		
	Bench terrace						97% decrease in sediment yield		
143	Contour cultivation	India	D/WM	25%	Potato	Field	1,400% increase in sediment yield	1.1 t/ha	Comparison to bench terraced; Pt = 1,295 mm/yr
16	Contour cultivation	India	W/D	2.2%	Barley/jowar	Plot	62% decrease in erosion rate	14 t/ha	Comparison to up & down slope cultivation; soil = eroded, alluvial soil.
102	*Reverse slope bench terrace*	Taiwan	D/WM	20%	Pineapple	Field	99.9% decrease in sediment yield	34 t/ha/yr	Comparison to planting up & down slope; Pt = 1,373 mm/yr
	Mulch & close planted on the contour						84% decrease in sediment yield		
92	Grass waterways	USA	T	All	Agriculture	Watershed	N/A	N/A	If erosion rates above waterway are high, than difficult to establish, expensive to maintain.
172	Vegetative gully control	India	All	N/A	All	N/A	Gully stabilization	N/A	If slope of gully channel < 19% and drainage area small, slope leveling and revegetation is appropriate approach
55	Outside gully channel measures to : decrease overland flow, spread water, increase infiltration	USA	SA/A	NG	Various	Watershed	25-60% decrease in sediment yield	N/A	Comparison to before treatment.
	Outside gully channel measures (same as above) & gully structures			NG			60-75% decrease in sediment yield		
	Inside gully channel tree plantings			N/A	N/A		May increase sediment yield as grow beyond sapling stage and divert flow flow into gully walls		
121	Contour bunds	South Africa	T	9%	Pineapples	Field	200% increase in sediment yield	33 t/ha/yr	Comparison to no contour bunds; soil = shallow, erodible sand
148	Contour bund every 10 rows	Hungary	T	32%	Vineyard	Field	25% decrease in sediment yield	4.4 t/ha/yr	Comparison to no contour bunds
	Contour bund every 5 rows						77% decrease in sediment yield		
	Contour bund every row						99.9% decrease in sediment yield		
79	Contour bunds - yr 1	Thailand	D/WM	11%	Agriculture	Field	100% trap efficiency	N/A	Trap efficiency = % of eroded sediments stored behind bund
	Contour bunds - yr 2			11%			100% trap efficiency		
	Contour bunds - yr 1			25%			51% trap efficiency		

Table 8.3

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON EROSION AND SEDIMENTATION

CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
	Contour bunds - yr 2			25%			0% trap efficiency		
	Contour bunds - yr 1			51%			42% trap efficiency		
	Contour bunds - yr 2			51%			0% trap efficiency		
	Contour bunds - yr 1			65%			36% trap efficiency		
	Contour bunds - yr 2			65%			0% trap efficiency		
159	Bunds - year 1	India	D/WM	NG	Agriculture	Watershed	117 breaches, avg. width - 2.2m	N/A	175 ha of bunded lands; soil = black soils
	Bunds - year 2			NG			47 breaches, avg. width - 3.8m		
	Bunds - year 3			NG			19 breaches, avg. width - 3.7m		
116	Graded contour banks (terraces)	Thailand	D/WM	3-10%	Agriculture	Watershed	Bank life span = 5 yrs.	N/A	
	Level absorption banks			3-10%			Commonly fail due to unsuitable soils (low infiltration rates)		
198	Terracing	USA	T	All	Agriculture/ Forestry	Watershed	N/A	N/A	"Terracing is more expensive per ton of soil erosion reduction than any other alternatives for soil erosion control"
187	Contour bunds	Indonesia	D/WM	12%	Agriculture	Plot	32% decrease in erosion rate	44.3 t/ha	Comparison to unbunded
177	Level terrace	USA	T	2-18%	Corn	Field	96% decrease in erosion rate	59 t/ha/yr	Comparison to contour planted corn; soil = deep loess, Pt = 815 mm/yr.
	Pasture			2-18%			96% decrease in erosion rate		
177	Level terrace	USA	T	2-18%	Corn	Watershed	Neglible sediment yield from gullying	N/A	
	Pasture			2-18%			Neglible sediment yield from gullying		
	Contour planted corn			2-18%			14.3 t/ha/yr sediment yield from gullying		
152	Bench terrace	Indonesia	D/WM	15-40%	Agriculture	Plot	81% - 95% decrease in erosion rate	NG	Comparison to unimproved local farming practices
	Silvipasture			> 50%			82% - 96% decrease in erosion rate		
205	Bench terraces	Taiwan	D/WM	28%	Bananas	Field	99% decrease in sediment yield	87 t/ha/yr	Comparison to clean cultivation; soil = clay loam, Pt = 2,334 mm/yr
	Grass barriers (weeping love grass)						93% decrease in sediment yield		
103	Bench terraces with grass cover (Bahia,Love) or mulch	Taiwan	D/WM	28%	Citrus orchard	Field	71% decrease in sediment yield	5 t/ha/yr	Comparison to bench terraces w/o grass cover or mulch; soil = clay loam
1	Bench terrace & crop residue management	Indonesia	D/WM	NG	Agriculture	Plot	99% decrease in erosion rate	185 t/ha/yr	Comparison to unterraced & no mulch
167	Terracing & reforestation	Indonesia	EM	NG	Agriculture	Watershed	90% decrease in sediment yield	N/A	Comparison to pre-treatment levels
33	Level bench terrace	Taiwan	D/WM	NG	Agriculture	Field	86% decrease in erosion rate	N/A	Based on preliminary 'P' factors for Taiwan derived from empirical studies in Taiwan
	Reverse slope bench terrace						95% decrease in erosion rate		
	Sloping bench terrace						65% decrease in erosion rate		
	Level retention bench terrace						99% decrease in erosion rate		

Table 8.3

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES
ON EROSION AND SEDIMENTATION

CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
	Drainage level bench terrace						97% decrease in erosion rate		
	Grass barrier						80% decrease in erosion rate		
	Hillside ditch with full grass cover						98% decrease in erosion rate		
167	Land abandonment	Nepal	D/WM	NG	Agriculture	Watershed	58% decrease in sediment yield	N/A	Comparison to pre-treatment levels
	Terraces						15% decrease in sediment yield		
219	Contour farmed terraces	USA	T	1-2%	Agriculture	Field	40% decrease in erosion rate	N/A	Comparison to contour farmed; Terraces include broad base, steep backslope, level
	Contour farmed terraces			3-8%			50% decrease in erosion rate		
	Contour farmed terraces			9-12%			40% decrease in erosion rate		
	Contour farmed terraces			13-16%			30% decrease in erosion rate		
	Contour farmed terraces			17-20%			20% decrease in erosion rate		
	Contour farmed terraces			21-25%			10% decrease in erosion rate		
155	Graded furrows vs terraces	USA	T	2-3%	Cotton/sorghum/ oats	Watershed	No significant difference in sediment yield	N/A	Graded furrow system held up to storm that caused extensive terrace failure; Soil = black clay, Pt = 853 mm/yr
170	Bench terraces	Jamaica	D/W	N/A	Agriculture	N/A	N/A	N/A	Upper limit for bench terraces = 47% slope and 100m in length
74	Terrace	USA	T	N/A	Agriculture	Watershed	90% decrease in sediment yield	N/A	Comparison to unterraced; soil = deep loess
163	Bench terrace	Indonesia	D/WM	Lowland	Agriculture	Plot	30% decrease in erosion rate	22.1 t/ha	Comparison to unimproved local farming system
	Ridge terrace						20% decrease in erosion rate		
	Bench terrace			Upland			90% decrease in erosion rate	34.4 t/ha	
	Ridge terrace						77% decrease in erosion rate		
191	Bench terrace	Indonesia	D/WM	9%	Corn & cassava	Plot	61% - 78% decrease in erosion rate	6.6-9.1 t/ha	Comparison to unterraced
	Bench terrace				Sweet potato		57% decrease in erosion rate	10.3 t/ha	
	Bench terrace				Corn		44% decrease in erosion rate	16.6 t/ha	
	Bench terrace				Casava		65% decrease in erosion rate	11.1 t/ha	
184	Bench terrace	Indonesia	D/WM	NG	Agriculture	Plot	49% - 70% decrease in erosion rate	35.4 t/ha	Comparison to traditional upland practices
71	Bench terrace	Indonesia	D/WM	25%	Agriculture	Plot	91% decrease in erosion rate	485 t/ha/yr	Comparison to unterraced
140	Flat bench terrace	Indonesia	D/WM	NG	Agriculture	Plot	125% increase in erosion rate	0.04 t/ha	Comparison to ridge terrace
	Sloping bench terrace						800% increase in erosion rate		
182	Terrace	Colombia	W/D	45%	Coffee	Field	89% decrease in erosion rate	0.2 t/ha	Comparison to unterraced coffee.
56	Level bench terrace	Ecuador	W/D	4-6%	Agriculture	Field	69% increase in sediment yield	0.6 t/ha	Comparison to unterraced control; soils = loam to loamy sand
	Bench terrace, 1.6% outslope						50% increase in sediment yield		
	Conservation bench terrace						9% decrease in sediment yield		
	Steep backslope terrace						36XX decrease in sediment yield		

Table 8.3

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON EROSION AND SEDIMENTATION

CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
	Broad base terrace						70% decrease in sediment yield		
169	Contour bunds	Thailand	D/WM	NG	Agriculture	Field	43% decrease in sediment yield	12 t/ha	Comparison to unterraced control; soil = Acrisol (Typic Paleudult); Pt = 1,612 mm/yr
	Bench terrace						46% decrease in sediment yield		
	Hillside ditches						50% decrease in sediment yield		
	Intermittent terrace						52% decrease in sediment yield		
87	Broad base/steep back/ narrow base terraces	USA	T	NG	Agriculture	Watershed	N/A	N/A	Studied 14.4 km of new terraces, all breached in first year; breaches due to slope failure and internal piping. Soil = deep loess.
87	Broad base/steep back/ narrow base terraces	USA	T	NG	Agriculture	Watershed	N/A	N/A	Survey of farmers - 18% terraces breach in first 5 years.
23	Bench terraces	Korea	T	N/A	Agriculture	N/A	N/A	N/A	Useful on 10-35% slopes where soildepth > 45cm and parent material weathered (no slick granite or shale)
94	Terraces (20m inter-terrace width)	Nigeria	W/D	1%	Agriculture	Plot	No significant difference in erosion rate	0.2 t/ha	Comparison to erosion rate from one storm event on 10m inter-terrace widths
	Terraces (20m inter-terrace width)			5%			81% decrease in erosion rate	16. t/ha	
	Terraces (20m inter-terrace width)			10%			26% decrease in erosion rate	24 t/ha	
	Terraces (20m inter-terrace width)			15%			No significant difference in erosion rate	60 t/ha	
129	Bench terrace	Sierra Leone	W/D	30%	Rice	Field	84% decrease in sediment yield	48 t/ha/yr	Comparison to rice, no conservation
	Stone bunding			30%			38% decrease in sediment yield		
	Stick bunding			30%			43% decrease in sediment yield		
	Contour bunding			30%			62% decrease in sediment yield		
129	Bench terrace	Sierra Leone	W/D	30%	Cassava	Field	85% decrease in sediment yield	33 t/ha/yr	Comparison to cassava, no conservation
	Stick bunding			30%			18% decrease in sediment yield		
	Contour bunding			30%			49% decrease in sediment yield		
143	Bench terrace	India	D/WM	25%	Potato	Field	93% decrease in sediment yield	17 t/ha	Comparison to contour rows; Pt = 1,295 mm/yr
144	Broad base terraces	India	SATr	NG	Agriculture	Field	92% decrease in sediment yield	N/A	Comparison to unterraced; soil = Vertisol
68	Graded vs Bench terraces	India	D/WM	25%	Agriculture	Field	No significant difference in sediment yield between these two terrace types	N/A	
104	Inward sloping bench terrace	Taiwan	D/WM	NG	Sugarcane	Field	94% decrease in sediment yield	N/A	Comparison to outward sloping bench terrace

Table 8.3

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES
ON EROSION AND SEDIMENTATION

CITE	TECHNOLOGY/TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	SCALE	IMPACT	COMPARISON	REMARKS
103	Bench terraces	Taiwan	D/WM	28%	Citrus orchard	Field	97% decrease in sediment yield	N/A	Comparison to clean cultivation; soil = clay loam
127	Sediment basins with pipe drainage from terraces	USA	T	NG	Corn, clean cultivated	Field	> 97% trap efficiency	N/A	Trap efficiency = % of sediment load of runoff deposited in basin; soil = (Entisol/Mollisol) Non-trapped sediment = 88% clay
30	Gully plugs & drop structures	Indonesia	D/WM	4-8%	Agriculture	Watershed	All structures failed within 2 years	N/A	
19	Gully headwall structures	NSW, Australia	SATr	N/A	Gully	Watershed	Greater than 50% of sediments derive from gully sidewalls, headwall control will not give short-term sediment reduction	N/A	
30	Check dam & bamboo	Indonesia	D/WM	4-8%	Agriculture	Watershed	Increased in-gully erosion	N/A	Gully was stabilized until construction of checkdam
37	Check dams	Taiwan	D/WM	54%	Mixed hardwood/ conifer forests	Watershed	No significant difference in reservoir siltation rates following construction of 70 check dams.	N/A	Comparison to siltation rates prior to construction; soil = rocky-gravelly sands; Pt = 3,020 mm/yr
60	Check dams	USA	T	N/A	N/A	Watershed	Gully reclamation	N/A	Numerous low, semi-pervious, temporary check dams are preferable & more economical
26	Check dams	USA	T	N/A	Various	Watershed	Increase flooding if used in perennial or flood susceptible streams.	N/A	Useful for drainages < 10 acres[1]
81	Check dams	Japan	T	N/A	Various	Watershed	Reduced bed gradient, regulated stream width, controlled sediment transport	N/A	Conclusions based on aerial photographs
59	Hogwire check dam Brush check dam Log check dam	Philippines	D/WM	36-119%	Various	Watershed	74% decrease in trap efficiency 4% decrease in trap efficiency 42% decrease in trap efficiency	N/A	Comparison to stone check dams; 5 years for treated gullies to stabilize and revegetate; only stone check dams still intact at year 5
207	Straw/fabric check dams Rock check dams	All	All	NG	All	Watershed	50-95% trap efficieny of sediments Trap only fine sands and coarser sediments	N/A	Straw/fabric dams only for flow velocities of < 0.06 ft/sec
154	Rock check dams	USA	T	NG	Construction site	Watershed	5-10% trap efficiency	N/A	Comparison to sediment load of runoff above check dam
43	Fabric check dam	USA	T	NG	Construction	Watershed	99.6% trap efficiency	N/A	Comparison to sediment load of runoff above check dam

Table 8.4

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES
ON CROP YIELD AND PRODUCTIVITY

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	IMPACT	REMARKS
95	Erosion	Worldwide	All	N/A	Agriculture	Inevitable reduction in productivity, in favorable subsoils erosion increases production costs with little or no losses in yield	Andosols (Andepts) and Cambisols (Inceptisols) have good subsoil charecteristics, old and highly weathered Ferrasols (Oxisols), Luvisols (Alfisols), Acrisols *(Ultisols), and Nitosols (Alfisols* and Ultisols) usually do not
95	Erosion	Tropics	All	N/A	Agriculture	On shallow, infertile tropical soils productivity may decline more rapidly than in temperate counterparts.	Drought effects are also magnified
93	Erosion	Tropics	All	N/A	Agriculture	From available data appears that yield reductions per unit soil loss of topsoil is more drastic for tropical vs temperate soils.	Attributable to lower inherent fertility, concentrations of plant-available nutrients and organic matter in top few cms, to root-restrictive & edaphologically unfavorable subsoil environments.
93	Erosion	Worldwide	All	N/A	Agriculture	Primary effects of erosion on productivity is through loss of plant-available water.	Conclusion of the U.S. National Soil Erosion-Soil Productivity Research Committee
93	1.Shallow soils, concentration of plant- available water and nutrients in top few cms 2.Deep soils, good structure, favorable distribution & high reserves for plant-available water and nutrients 3.Soils where topsoil horizon *buried by less favorable soil* material	Worldwide	All	N/A	Agriculture	1.Severe erosion-induced productivity decline; will not respond to management in severly eroded phases. 2.May show no significant yield decline despite significant erosion; fertility restorable with additions of N or organic matter. 3.May show yield increases as the result of *severe erosion*	Type 1 typically highly leached, tropical Ferrasol(Oxisol), Acrisol (Ultisol); Type 2 typically Andosols (Andepts); Type 3 would be rare.
95	Soil loss, natural	Nigeria	W/D	1% 5% 10% 15	Corn Corn Corn Corn	.26 t/ha decrease in yield/ mm of soil loss .10 t/ha decrease in yield/ mm of soil loss .08 t/ha decrease in yield/ mm of soil loss .10 t/ha decrease in yield/ mm of soil loss	Higher rate of yield decline at 1% slope attributed to severe crusting and sealing from raindrop impact
31	Soil loss, natural	USA	T	NG NG NG NG	Beans Peas Sugarbeets Alfalfa	27% decrease in yield 23% decrease in yield 15% decrease in yield 28% decrease in yield	Comparison to crop yields from plots where topsoil depth was about the same as when the land was first cultivated to plots where subsoil was exposed
57	Soil loss (0.5 - 1.4 cm/yr), natural	Poland	T	NG	Winter wheat	50% - 70% decrease in yield	
115	Soil loss (0.1 cm), natural Soil loss (0.8 cm), natural	Australia	SATr	NG NG	Agriculture	3% - 7.5% decrease in yield 10 - 25% decrease in yield	

Table 8.4

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON CROP YIELD AND PRODUCTIVITY

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	IMPACT	REMARKS
96	Soil removal (2.54 cm)	Nigeria	W/D	NG	Corn	50% decrease in yield	Soil = sandy Alfisol
	Soil removal (7.5 cm)					90% decrease in yield	
95	Soil removal (10 cm)	Nigeria	W/D	NG	Agriculture	65% and 38% decrease in yield for grain and stover, respectively	Soil = Paleustalf
	Soil removal (20 cm)					90% and 55% decrease in yield for grain and stover, respectively	
118	Soil removal (5 cm)	Nigeria	W/D	NG	Corn	95% decrease in yield	Comparison to no soil removal; Soil = Ultisol, Pt = 2,480 mm/yr
					Cowpea	63% decrease in yield	
	Soil removal (10 cm)				Corn	95% decrease in yield	
					Cowpea	71% decrease in yield	
	Soil removal (20 cm)				Corn	100% decrease in yield	
					Cowpea	68% decrease in yield	
118	Soil removal (5 cm)	Nigeria	W/D	NG	Corn	31% decrease in yield	Comparison to no soil removal; Soil = Alfisol, Pt = 1,307 mm/yr
					Cowpea	2% decrease in yield	
	Soil removal (10 cm)				Corn	74% decrease in yield	
					Cowpea	59% decrease in yield	
	Soil removal (20 cm)				Corn	92% decrease in yield	
					Cowpea	65% decrease in yield	
118	Soil removal (5 cm)	Nigeria	W/D	NG	Corn	73% decrease in yield	Comparison to no soil removal; Soil = Alfisol, Pt = 1,230 mm/yr
					Cowpea	43% decrease in yield	
	Soil removal (10 cm)				Corn	83% decrease in yield	
					Cowpea	33% decrease in yield	
	Soil removal (20 cm)				Corn	100% decrease in yield	
					Cowpea	81% decrease in yield	
186	Soil removal (10 cm)	Indonesia	W/D	NG	Soybean	48% decrease in seed weight	Liming of soils increased average plot yield by 15% but did not increase seed weight
	Soil removal (20 cm)					65% decrease in seed weight	
	Soil removal (40 cm)					79% decrease in seed weight	
	Soil removal (60 cm)					86% decrease in seed weight	
221	Soil removal (0 cm, 50% recommended fertilizer)	Hawaii	W/D	NG	Corn stover, 1st crop	22% increase in yield; no significant difference in water use efficiency	Comparison to no soil removal, fertilizer; Soil = clay Ferrasol (Tropeptic Eutrustox). Water use efficiency = Yield (kg)/Water use (kg)
	Soil removal (0 cm, 100% recommended fertilizer)			NG	Corn stover, 1st crop	46% increase in yield; no significant difference in water use efficiency	
	Soil removal (10 cm, no fertilizer)			NG	Corn stover, 1st crop	39% decrease in yield; 44% decrease in water use efficiency	
	Soil removal (10 cm, 50% recommended fertilizer)			NG	Corn stover, 1st crop	No significant difference in yield; 31% decrease in water use efficiency	
	Soil removal (10 cm, 100% recommended fertilizer)			NG	Corn stover, 1st crop	44% increase in yield; no significant difference in water use efficiency	
	Soil removal (35 cm, no fertilizer)			NG	Corn stover, 1st crop	91% decrease in yield; 90% decrease in water use efficiency	
	Soil removal (35 cm, 50% recommended fertilizer)			NG	Corn stover, 1st crop	35% decrease in yield; 67% decrease in water use efficiency	
	Soil removal (35 cm, 100% recommended fertilizer)			NG	Corn stover, 1st crop	21% increase in yield; 36% decrease in water use efficiency	

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IMPACTS OF SOIL CONSERVATION TECHNOLOGIES
ON CROP YIELD AND PRODUCTIVITY

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	IMPACT	REMARKS
221	Soil removal (0 cm, 50% recommended fertilizer)	Hawaii	W/D	NG	Corn, 2nd crop	165% and 34% increase in grain and stover yield, respectively	Comparison to no soil removal, no fertilizer; Soil = clay Ferrasol, (Tropeptic Eutrustox)
	Soil removal (0 cm, 100% recommended fertilizer)			NG	Corn, 2nd crop	317% and 64% increase in grain and stover yield, respectively	
	Soil removal (10 cm, no fertilizer)			NG	Corn, 2nd crop	46% and 41% decrease in grain and stover yield, respectively	
	Soil removal (10 cm, 50% recommended fertilizer)			NG	Corn, 2nd crop	83% increase in grain yield and no significant difference in stover yield	
	Soil removal (10 cm, 100% recommended fertilizer			NG	Corn, 2nd crop	302% and 51% increase in grain and stover yield, respectively	
	Soil removal (35 cm, no fertilizer)			NG	Corn, 2nd crop	100% and 91% decrease in grain and stover yield, respectively	
	Soil removal (35 cm, 50% recommended fertilizer)			NG	Corn, 2nd crop	39% and 41% decrease in grain and stover yield, respectively	
	Soil removal (35 cm, 100% recommended fertilizer)			NG	Corn, 2nd crop	112% and 16% increase in grain and stover yield, respectively	
117	Soil added (15 cm), 0 kg/ha N	USA	SATmp	NG	Sorghum	69% increase in yield	Comparison to non-treated; Soil = loessial, calcareous, silty Mollisol
	Soil removed (15 cm), 0 kg/ha N					46% decrease in yield	
	Soil removed (30 cm), 0 kg/ha N					61% decrease in yield	
	Soil added (15 cm), 34 kg/ha N					45% increase in yield	
	Soil removed (15 cm), 34 kg/ha N					22% decrease in yield	
	Soil removed (30 cm), 34 kg/ha N					27% decrease in yield	
	Soil added (15 cm), 68 kg/ha N					34% increase in yield	
	Soil removed (15 cm), 68 kg/ha N					13% decrease in yield	
	Soil removed (34 cm), 68 kg/ha N					21% decrease in yield	
96	Nutrient losses on eroded soil (kg/ha/yr)	Nigeria	W/D	1%	Agriculture	50 organic C, 6 N, 0.2 available P	
				5%		870 organic C, 100 N, 1.8 available P	
				10%		1850 organic C, 190 N, 2.2 available P	
				15%		3070 organic C, 230 N, 8.1 available P	
30	Nutrient losses on eroded soil (kg nutrients/ton of soil loss/ year)	Indonesia	D/WM	18%	Agriculture	30 organic matter, 1.5 N, 1.0 P, 2.0 K	
52	Nutrient losses on eroded soil (kg nutrients/metric ton of sediment/yr)	Zimbabwe	W/D	3-6.5%	Agriculture	Type I : 0.97 N, 0.16 P, 10.7 organic C Type II : 2.1 N, 0.16 P, 15.4 organic C	Type I = well-drained sands; Type II = other soils
96	Nutrient losses in runoff water (kg/ha/yr)	Nigeria	W/D	1%	Agriculture	2.9 N, 0.5 P, 4.7 K, 11.2 Ca, 2.4 Mg	
				5%		5.5 N, 0.5 P, 6.2 K, 17 Ca, 2.5 Mg	
				10%		5.7 N, 0.8 P, 5.6 K, 14.9 Ca, 3.1 Mg	
				15%		4.5 N, 0.7 P, 4.1 K, 12.5 Ca, 3.0 Mg	
61	4% to 5% decrease in plant available water	USA	T	NG	Agriculture	12% - 36% decrease in yield	Dependant on crop and degree of soil loss
182	Grass cover	Colombia	W/D	22%	Pasture	Decreases in nutrient losses : N - 72%, P - 85%, K - 75%, Ca - 89%, Mg - 83%	Comparison to monthly tilled bare soil.

Table 8.4

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES
ON CROP YIELD AND PRODUCTIVITY

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	IMPACT	REMARKS
82	Grassland	India	D/WM	NG	Grassland	20% increase in N	Comparison to forested lands; Soil = sandy loam to clay loam, Pt = 1,050 mm/yr; attributed to higher phosphate levels (aids in N fixation) in grasslands
85	Cover cropping with N-fixing plant (Mimosa invisa) - 2 years	India	D/WM		Mimosa invisa	0.4% increase in organic matter,30% increase in available N, 98% increase in available P, 28% increase in K	Comparison to clean cultivation
160	Green Manure	Worldwide	All	N/A	Agriculture	Only effects next crop	Usually limited to mechanical agriculture as the power to incorporate green manure into soil often beyond manual labor
160	Organic matter	Worldwide	All	N/A	Agriculture	In unfertilized soils supplies N, S, blocks P fixation, maintains CEC, improve structure of poorly aggregated soils, form complexes with micro-nutrients	Essential in non-fertilized systems, important in low CEC soils and poorly aggregated sands.
160	Commercial fertilizer	Worldwide	All	N/A	Agriculture	Increase soil organic matter due to increased root decomposition	If soils are adequate, sound fertilization practices decrease need for organic matter
160	Organic vs Commercial fertilizer	Worldwide	All	N/A	Agriculture		Choice between predominately based on economics, transport, accessability,and social criteria
21	Cow dung (5 t/ha) Wood shavings (5 t/ha) Poultry manure (5 t/ha) Cow/poultry manure (5 t/ha)	Ghana	CW	7.5% 7.5% 7.5% 7.5%	Corn	105% increase in yield 53% increase in yield 32% increase in yield 11% increase in yield	Comparison to commercial fertilizer (200 kg/ha Urea, 100 kg/ha triple superphosphate, 120 kg/ha muriate of potash; Pt = 1,340 mm/yr
21	Cow dung (4 t/ha) Cow dung (4 t/ha) & straw mulch (4 t/ha) Cow dung (5 t/ha) Cow dung (5 t/ha) & straw mulch (4 t/ha)	Ghana	SATr	2% 2% 2% 2%	Sorghum	75% increase in yield 75% increase in yield 88% increase in yield 100% increase in yield	Comparison to 2 t/ha cow dung, Pt = 320 mm/yr
197	Mulch (1.1 t/ha) Mulch (2.2 t/ha) Mulch (4.4 t/ha) Mulch (8.8 t/ha) Mulch (13.2 t/ha)	USA	T	NG NG NG NG NG	Sorghum	35% increase in crop yield 46% increase in crop yield 67% increase in crop yield 107% increase in crop yield 124% increase in crop yield	Comparison to no mulch; Pt = 808 mm/yr
38	Mulch	India	D/WM	1%	Wheat/barley/gram/linseed	30% increase in yield	Comparison to unmulched; Soil = sandy clay loam
153	Mulch	India	Satr	NG	Agriculture	40% increase in yield	Comparison to unmulched in 4 crops

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IMPACTS OF SOIL CONSERVATION TECHNOLOGIES
ON CROP YIELD AND PRODUCTIVITY

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	IMPACT	REMARKS
							in 6 regions for 3 years
185	Mulch (5 t/ha)	Indonesia	N/A	0%	Corn	63%% increase in biomass	Greenhouse study
91	Mulch	Indonesia	W/D	N/G	Rice	69% increase in yield	Plots on 20 yr old terraces; soil = latosol
	Mulch				Corn	10% - 188% increase in yield	
193	Mulch (6 t/ha)	Indonesia	W/D	14%	Rice	30% increase in yield	Soil = red latosol
149	50% asphalt mulch	Venezuela	W/D	4%	Sorghum	39% increase in yield	Comparison to no-mulch; soil = sandy loam, Typic Haplustalf
	100% asphalt mulch			4%		110% increase in yield	
174	Mulch - polyethylene sheets	India	SATr	NG	Wheat	Yield increase did not justify expense	Comparison to unmulched; Soil = silty clay loam
	Mulch - dry grass (10 t/ha)			NG		24% increase in grain yield, 30% increase in straw yield	
153	Vertical mulching (8m interval)	India	SATr	NG	Sorghum	35% increase in yield	Comparison to no vertical mulch; Soil = heavy black soil
	Vertical mulching (4m interval)			NG		34% increase in yield	
190	Mulch and minimum tillage	Indonesia	EM	NG"	Peanuts	no significant difference in yield	Comparison to unmulched, traditional cultivation; Soil = Ferrasol (Haplorthox)
	Mulch and minimum tillage			NG"	Soybeans	no significant difference in yield	
	Mulch and minimum tillage			NG"	Corn	58% increase in yield	
	Mulch and minimum tillage			NG"	Cassava	33% increase in yield	
	Mulch and minimum tillage			NG"	Mung beans	139% increase in yield	
	Mulch and minimum tillage			NG"	Upland rice	24% increase in yield	
190	Mulch and minimum tillage	Indonesia	EM	NG	Peanuts	no significant difference in yield	Comparison to unmulched, traditional cultivation; Soil = Nitosol (Tropudult)
	Mulch and minimum tillage			NG	Corn	15% increase in yield	
	Mulch and minimum tillage			NG	Mung beans	48% increase in yield	
	Mulch and minimum tillage			NG	Upland rice	31% increase in yield	
212	No-till with stubble mulch (chemical weed control)	USA	T	3%	Corn	7% decrease in yield	Comparison to conventional tillage with stubble mulch
40	Land clearing (bulldoze, plow, level)	Bolivia	W/D	NG	Sugarcane	No significant difference in yield	Comparison to slash-and-burn
136	Land clearing (D-6 with conventional blade)	Brazil	CW	NG	Rice (2nd crop)	44% decrease in yield	
				NG	Rice (3rd crop)	32% decrease in yield	
				NG	Rice (4th crop)	74% decrease in yield	
				NG	Cassava	55% decrease in yield	
				NG	Soybean	83% decrease in yield	
				NG	Guinea grass	16% decrease in yield	
136	Land clearing (D-6 with conventional blade, addition of lime to pH 6.2, 50 kg/ha N, 172 kg/ha P, 40 kg/ha K. Same N and K additions after each crop or grass cutting)	Brazil	CW	NG	Rice (2nd crop)	21% decrease in yield	Comparison to slash-and-burn; Soils = Acrisols (Ultisols)
				NG	Rice (3rd crop)	10% decrease in yield	
				NG	Rice (4th crop)	29% decrease in yield	
				NG	Cassava	6% decrease in yield	
				NG	Soybean	44% decrease in yield	
				NG	Guinea grass	24% decrease in yield	

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ON CROP YIELD AND PRODUCTIVITY

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	IMPACT	REMARKS
166	Land clearing (slash-and-burn)	Peru	CW	NG	Agriculture	Increased crop yields	Comparison to bulldozed sited; attributed to benefits of ash, soil compaction and topsoil disturbance by bulldozer
153	Deep tillage	India	SATr	NG	Agriculture	28% increase in yield	Comparison to shallow tillage in 10 crops in 7 regions over 4 years
44	Tillage	Indonesia	EM	NG	Agriculture	Drastic reduction of fertilizer loss	Soil = Ferrasol (Oxisol); rainfall simulator study performed in pans
	Artificial stabilization of soil surface (Polyacrylamide)			NG		95% decrease in N & P, and 90% in K losses	
97	Minimum tillage	Nigeria	W/D	NG	Corn	50% increase in crop yield	Comparison to conventional tillage
					Cowpeas	24% increase in crop yield	
					Soybeans	21% decrease in crop yield	
					Sweet potatoes	24% increase in crop yield	
					Pigeon peas	No significant difference in yield	
122	Minimum tillage	Ghana	W/D	7.5%	Corn	16% increase in yield	Comparison to traditional mixed cropping; soil = sandy loam to sandy clay, Pt = 1,500 mm/yr
	Zero-tillage			7.5%		8% decrease in yield	
	Mulching			7.5%		57% increase in yield	
	Ridging across slope			7.5%		16% increase in yield	
122	Minimum tillage	Ghana	W/D	3%	Corn	15% decrease in yield	Comparison to traditional mixed cropping; soil = sandy clay loam to sandy clay, Pt = 1,400 mm/yr
	Zero-tillage			3%		51% decrease in yield	
	Mulching			3%		7% increase in yield	
	Ridging across slope			3%		21% increase in yield	
158	Mechanized agriculture	Loessial soils	All	N/A	Agriculture	Rapid physical degradation and productivity decline in tropics; process slower in temperates	Beneficial effects of tillage do not last unless lime or use rotation with deep rooted grass
36	Hand cultivation (< 5cm)	Senegal	W/D	NG	Millet	24% yield increase	Comparison to non-cultivated
	Mechanical cultivation(15-20cm)				Millet	22% yield increase	
	Hand cultivation (<5cm)				Sorghum	24% yield increase	
	Mechanical cultivation(15-20cm)				Sorghum	25% yield increase	
	Hand cultivation (< 5cm)				Corn	35% yield increase	
	Mechanical cultivation(15-20cm)				Corn	73% yield increase	
	Hand cultivation (< 5cm)				Rice	103% yield increase	
	Mechanical cultivation(15-20cm)				Rice	73% yield increase	
	Hand cultivation (< 5cm)				Cotton	25% yield increase	
	Mechanical cultivation(15-20cm)				Cotton	38% yield increase	
	Hand cultivation (< 5cm)				Peanuts	22% yield increase	
	Mechanical cultivation(15-20cm)				Peanuts	8% yield increase	
16	Contour cultivation	India	W/D	2.2%	Jowar	28% increase in yield	Comparison to up & downslope planting; soil = eroded, alluvial loam
	Contour cultivation				Barley	23% increase in yield	
46	Contour rows	India	D/WM	Up to	Sorghum	Up to 35% increase in yield	Comparison to non-contour

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ON CROP YIELD AND PRODUCTIVITY

CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	IMPACT	REMARKS
				3%			cultivated; based on review of 30 years of experiment station projects
131	Cross slope planting	India	W/D	1.5%	Grain	23% increase in yield	Comparison to up & downslope planting; soil = well-drained, sandy loam (Inceptisol)
	Cross slope planting				Straw	10% increase in yield	
	Ridge & furrow (60 cm spacing)				Grain	59% increase in yield	
	Ridge & furrow (60 cm spacing)				Straw	36% increase in yield	
25	Ripped furrows	USA	SATmp	NG	Grassland (Bouteloua spp)	250% increase in yield	Comparison to non-ripped
47	Furrows	USA	SATmp	NG	Grassland (Buchloe spp)	300% increase in yield, 50% increase in cover	Comparison to non-furrowed
104	Bench terrace	Taiwan	D/WM	12%	Sugarcane	4% decrease in yield	Comparison to up & down slope cultivation
	Contour cultivation			12%		10% increase in yield	
34	Contour/mulch/close planting	Taiwan	D/WM	28%	Pineapple	105% increase in yield	Comparison to up & down slope/wide planting.
	Bench terrace					72% increase in yield	
	Contour/close planting					66% increase in yield	
105	Contouring	Taiwan	D/WM	17%	Tea	6% increase in yield	Comparison to clean cultivated; Soil = gravelly loam
	Mulching			17%		6% decrease in yield	
	Bench terrace			17%		32% decrease in yield	
	Contouring			32%		27% increase in yield	
	Mulching			32%		71% increase in yield	
	Bench terrace			32%		16% increase in yield	
5	Contour bunds & terraced	Indonesia	W/D	9%	Potato	No significant difference in yield	Comparison to contour bunding only; soil = Andosol
	Contour bunds & mulch					No significant difference in yield	
	Contour bunds & terraced			12%	Cabbage	8% decrease in yield	
	Contour bunds & mulch					No significant difference in yield	
180	Furrow dams	USA	SATmp	NG	Sorghum	20% increase in yield	
					Cotton	15% increase in yield	
86	Bunds	India	SATr	NG	Agriculture	No significant or stable yield increase	Construction of bunds as a soil or moisture conservation practice have not shown, in controlled ICRISAT experiments, to achieve either significant or stable yield increase due to moisture conservation
68	Contour bunding/level terrace/ ridge-type terrace/absorptive-type terrace	India	SATr & AT	NG	Agriculture	Ponded water damaged crops and interfered with tillage operations resulting in lowered yields on treated sites 8 years out of 8 years on poorly drained soils	Comparison to non-treated; Soil = Vertisol
88	Bunds	India	D/WM	NG	Wheat/barley/ gram/corn/juar	35% increase in yields	Comparison to unbunded, unleveled.
	Levelling					63% increase in yields	

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CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	IMPACT	REMARKS
	Bunds & levelling					98% increase in yields	
112	Land leveling	USA	T	NG	Sorghum	No significant difference in yield	Comparison to unleveled; Soil = sandy clay loam & fine sandy loam, Pt = 684 mm/yr
126	Level pan	USA	SATmp	NG	Grain sorghum Forage sorghum	130% increase in yield 180% increase in yield	Comparison to plots outside level pans
125	Level pan	USA	SATmp	NG	Sorghum	100% increase in yield	Comparison to unleveled areas; Pt = 422 mm/yr
68	Graded vs Bench terrace	India	D/WM	25%	Potato	10% greater yield on bench terrace	
182	Terrace	Colombia	W/D	45%	Coffee	Decreases in nutrient losses : N - 50%, Increases in nutrient losses : P - 250%, K - 100%, Ca - 33%, Mg - 29%	Comparison to unterraced coffee.
74	Terrace	USA	SATmp	NG	Agriculture	No yield benefits from terracing alone.	
42 68	Inward sloping bench terrace Outward sloping bench terrace Puerto Rico structural terrace * Puerto Rico vegetative terrace	India	D/WM	25%	Potato	10% increase in yield 9% increase in yield 23% increase in yield 43% increase in yield	Comparison to inward sloping bench terrace; Highest yields attributed to minimized soil disturbance on Puerto Rico vegetative terrace. * - PR terraces = structural or vegetative barriers built on the contour and allowed to fill with soil, usu. 2-4 years to build up terrace; yield differences in 5 year total yield.
76	Conservation bench terrace	USA	SATmp	1.5%	Sorghum/wheat/ fallow	Little or no yield benefits from bench leveling alone.	Comparison to non-terraced
75	Conservation bench terrace	USA	SATmp	1.5%	Sorghum/wheat/ fallow	50% increase in yield on fine or medium textured soils with good water holding capacity	No increases on coarse textured soils; Soils = silty clay loam & sand
17	Conservation bench terrace	USA	T	NG	Sorghum/wheat/ fallow	27% increase in yield over the long term. Yield reductions persisted for 6 years following leveling.	Bench terraces require deep fertile soil on moderate slopes to permit topsoil removal necessary for leveling.
124	Conservation bench terrace	USA	SATmp	1%	Sorghum	40% increase in yield	Comparison to unterraced; Soil = silt loam to clay loam, Pt = 424 mm/yr
18	Conservation bench terrace	USA	SATmp	2-8%	Wheat	Topsoil loss due to leveling resulted in need for high application rates of fertilizer to sustain yield.	Subsoil properties poor, replacement of 2 inches of topsoil increased yields as much or more than highest rates of fertilizer application

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CITE	TECHNOLOGY\TREATMENT	LOCATION	CLIMATE	SLOPE	LAND USE	IMPACT	REMARKS
							over two year period. Soil = silt loam, Pt = 325 mm/yr
69	Conservation bench terrace	USA	SATmp	1-5%	Wheat	19% increase in yield	Comparison to unterraced; Soil = silt loam to silt clay loam, Pt = 111 mm/yr of study
				1-5%	Corn	No significant difference in yield	
				1-5%	Brome/alfalfa	100% increase in yield	
35	Closed-end terrace/graded terrace	India	D/WM	2%	Barley/gram/linseed/niger	Significant yield decreases in all years (3) and in all crops	Comparison to non-terraced; Soil = sandy clay loam, Pt = 1,170 mm/yr; attributed to poor drainage resulting in higher soil moisture causing poor tilth as a result of tillage operations in moist clay
135	Bench terrace	Indonesia	W/D	N/G	Rice	18% increase in yield	Comparison to crops on ridge terraced lands
	Bench terrace				Peanut	No significant difference in yield	
	Bench terrace				Cassava	No significant difference in yield	
111	Bench terrace	Indonesia	W/D	N/G	Agriculture	34% - 38% increase in yield	Crops : bawang preg, corn, beans
56	Level bench terrace	Ecuador	W/D	4-6%	Corn	No significant difference in yield	Comparison to unterraced control; soils = loam to loamy sand
	Bench terrace, 1.6% outslope			4-6%		33% increase in yield	
	Conservation bench terrace			4-6%		12% decrease in yield	
	Steep backslope terrace			4-6%		18% increase in yield	
	Broad base terrace			4-6%		No significant difference in yield	

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