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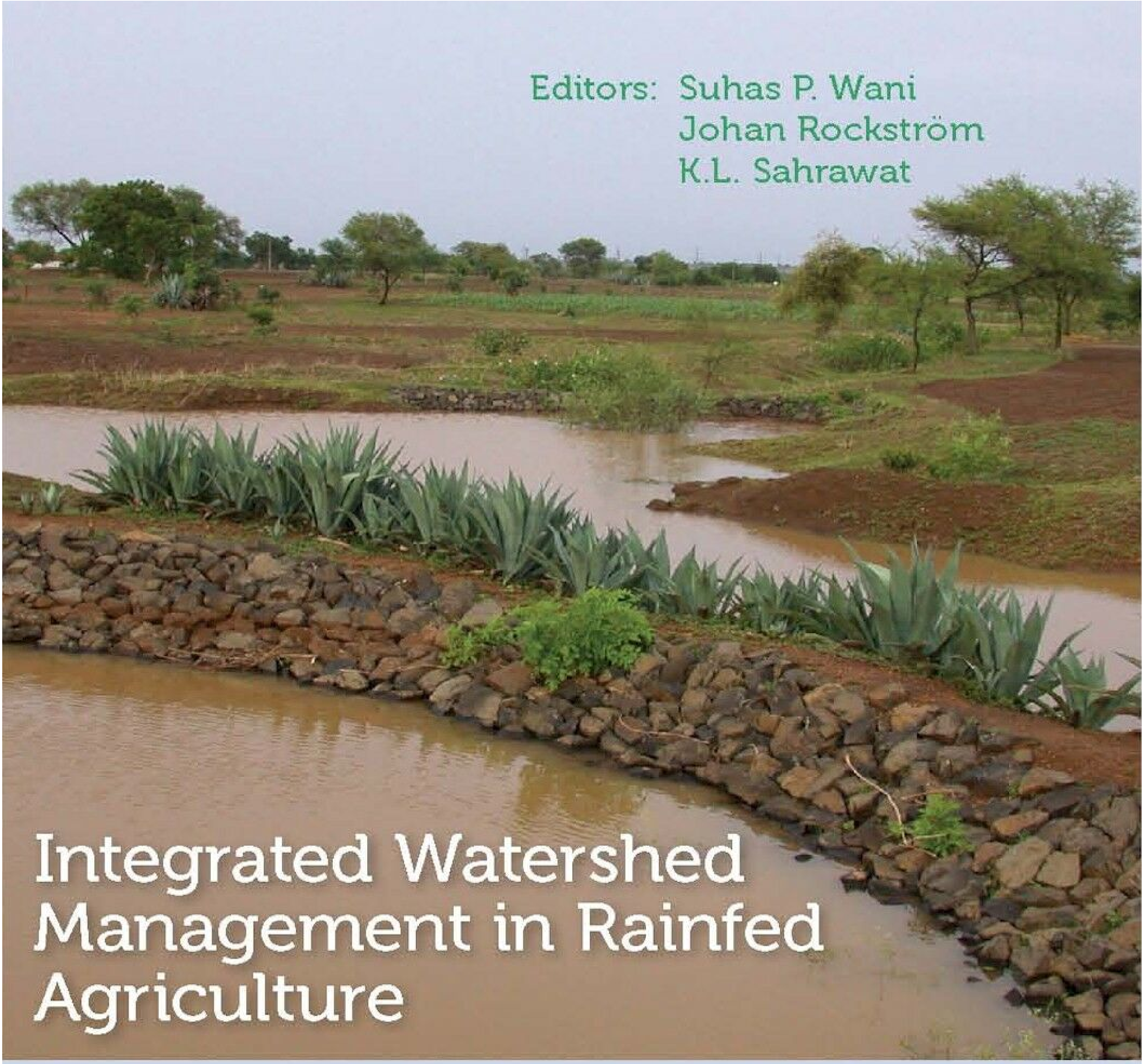
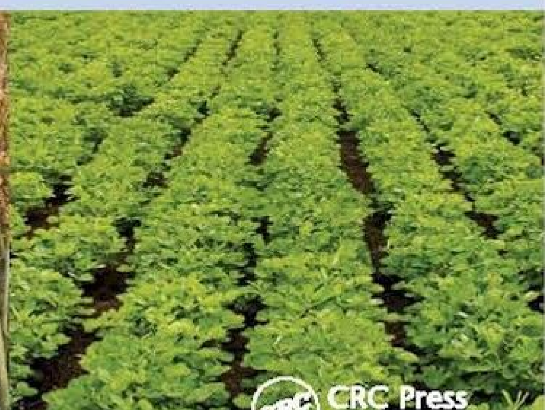


Integrated Watershed Management in Rainfed Agriculture





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Chapter 7

Soil and water conservation for optimizing productivity and improving livelihoods in rainfed areas

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7.1 INTRODUCTION

Soil and water are the most valuable natural resources to meet the basic needs of food, feed, and fiber for human beings. However, conserving soil and water resources is a growing challenge as they are under increasing stress to produce more food for the ever growing population. The loss of soil surface layer, which contains most nutrients and organic matter, reduces fertility. In addition, high runoff water causes moisture stress in the later part of the season, leading to low and variable crop productivity especially under rainfed conditions. Globally, total area affected by moderate to serious soil erosion is estimated around 1028 million ha, of which 748 million ha is due to water erosion and the rest by wind erosion. In Asia and Africa, 673 million ha area is impacted by erosion (Oldeman *et al.*, 1991). It is estimated that 186 million ha area is affected by chemical and physical degradation, which reduce vegetative cover and exacerbate soil erosion (Oldeman *et al.*, 1991). In Asia, South America, and Africa soil erosion rates are the highest with estimated average of 30–40 $t\,ha^{-1}\,yr^{-1}$, while in Europe and North America average rates are somewhat lower at about 17 $t\,ha^{-1}\,yr^{-1}$. A sustainable rate of soil loss (rate of soil loss is equal to rate of soil formation) is thought to be about 1 $t\,ha^{-1}\,yr^{-1}$ (Pimental *et al.*, 1995).

The high erosion hazards have serious on-site and off-site impacts on productivity, ecosystem services, and environmental quality. In rainfed regions where population growth and poverty level are high and external inputs for farming are meager due to economic reasons, the erosion impacts on agricultural productivity are generally very high both in the short- and the long-term. El-Swaify (1993) reported the results from the long-term experiments on crop responses to different levels of soil erosion (Table 7.1). Clearly, the erosion-induced changes in soil quality and the resulting unfavorable root proliferation combine to reduce water and nutrient use efficiency by crops on the eroded soils. These unfavorable effects have implications especially for the rainfed farming systems, since inefficient use of stored soil water further exacerbates the already costly water loss by uncontrolled runoff. The net results could be frequent crop failures in systems that are mainly dependent on seasonal rainfall.

In recent years, off-site (or downstream) erosion impacts have received increasing attention. This is partly due to mounting concerns with sediment-based nonpoint source pollution and its detrimental effects on water quality. In the tropics, increased encroachment of human populations and activities in the upper reaches of river basins and watersheds have significantly accelerated sediment production and delivery to

Table 7.1 The changes in water and fertilizer use efficiency by maize as a result of erosion and restorative fertilization on an Oxisol[a]

Erosion level (cm)	*Fertility level*	*Water use efficiency (kg stover dm^{-3} of water)*	*Fertilizer/amendment use efficiency (kg stover kg^{-1} of elemental added amendment)*
0	Low	0.42	40.0
	Intermediate	0.48	8.6
	Optimum	0.60	2.6
	Average	0.50	17.0
10	Low	0.25	24.0
	Intermediate	0.36	5.6
	Optimum	0.51	2.3
	Average	0.37	11.0
35	Low	0.07	3.8
	Intermediate	0.17	4.0
	Optimum	0.37	1.9
	Average	0.20	3.2

[a]Source: El-Swaify (1993).

low-lying lands. Runoff and eroded sediments cause siltation of waterways, dams, and reservoirs thus reducing the efficiency of hydroelectric power generating plants. Runoff also causes burial and flooding of low-lying lands, property, life, and shoreline fisheries and reefs and destruction of roads, terraces, and other structures. This upsets the balance involving sediment removal and deposition in beds and banks of rivers or streams serving as water resources and transport network (El-Swaify *et al.*, 1982).

Water scarcity is undoubtedly the most critical issue in rainfed agriculture. The demand for fresh water is increasing globally at an accelerated rate especially for agriculture and other sectors including domestic, energy, and industrial uses. It is estimated that approximately 7100 $km^3 yr^{-1}$ water is consumed globally to produce food, of which 5500 $km^3 yr^{-1}$ is used in rainfed agriculture and 1600 $km^3 yr^{-1}$ in irrigated agriculture (De Fraiture *et al.*, 2007; Molden *et al.*, 2007). The analysis also predicts large increases in the amount of water needed to produce food by 2050, ranging from 8500 to 11,000 $km^3 yr^{-1}$, depending on the assumptions regarding the improvements in rainfed and irrigated agricultural systems. However, the rainfall in rainfed regions generally occurs in short torrential downpours. Large portion of this water is lost as runoff. The current rainfall use efficiency for crop production is low ranging from 30 to 55%; thus annually large percentage of seasonal rainfall goes unproductive, lost either as surface runoff, evaporation, or deep drainage. Groundwater levels are depleting in the rainfed regions and most rural rainfed areas are facing general water scarcity and drinking water shortages. Though the problem of water shortages and land degradation have been in existence in the past also, the pace of natural resource degradation has greatly increased in recent times due to the burgeoning population and the increased exploitation of natural resources.

In rainfed agriculture, accelerated water demand can be met through efficient rainwater conservation and management. For this both in-situ and ex-situ rainwater management play crucial roles in increasing and sustaining the crop productivity.

The Comprehensive Assessment of water management in agriculture describes a large untapped potential for upgrading rainfed agriculture and calls for increased water investments in the sector (Molden *et al.*, 2007; Rockström *et al.*, 2007). Yield gap analyses carried out by Comprehensive Assessment for major rainfed crops in semi-arid regions in Asia and Africa reveal large yield gaps with farmers' yields being a factor of two to four times lower than achievable yields for major rainfed crops (Rockström *et al.*, 2007).

To achieve the vast potential, rainfed agriculture needs to be upgraded. Soil and water conservation should be used as entry point activity for upgrading rainfed agriculture through a more holistic approach based on converging all the aspects of natural resource conservation, their efficient use, production functions and income-enhancement avenues through value-chain and enabling policies (Wani *et al.*, 2003; Rockström *et al.*, 2007, 2010). Thus, soil and water conservation play a critical role in increasing and sustaining agricultural productivity in rainfed areas in the fragile agroecosystems.

This chapter reviews in brief in-situ and ex-situ soil and water conservation practices, which have been found promising for improving productivity and controlling land degradation in different rainfed regions of Asia and Africa. An "integrated watershed management approach" for enhancing the impacts of soil and water conservation is highlighted. The key factors, which would facilitate the greater adoption of soil and water conservation practices by the farmers are also discussed.

7.2 SOIL AND WATER CONSERVATION PRACTICES

In the past, most soil conservation programs were based on the introduction of practices and measures aimed mainly at conserving soil by slowing down and safely disposing of runoff. All of these are technically sound and there will be a place for them in the future. However, these measures take up valuable space and can be costly and time consuming to maintain. Farmers therefore, are usually reluctant to adopt such measures and they frequently fail for the lack of their maintenance. Strategies should therefore aim at retaining and using rainwater where it falls. If this is done, the chances of healthy plant growth and better yields are increased, while effects of drought and crop failure are decreased. This strategy is also expected to greatly reduce runoff and thereby soil erosion.

Based on experiences from the various rainfed regions of Asia and Africa, the soil and water conservation practices for the different rainfed regions are given in Table 7.2. It clearly shows that for different regions the problems of soil and water conservation are quite different. This information could be useful in determining the appropriate soil and water conservation practices for various regions. This classification and related information also assists in utilizing the research and field experience of one place to other places of identical soil, climatic, and topographic conditions.

7.2.1 In-situ soil and water conservation

In-situ soil and water conservation measures are important for effective conservation of soil and water at the field level. The main aim of these practices is to reduce or prevent either water erosion or wind erosion, while achieving the desired moisture

Table 7.2 Soil and water conservation problems and recommended technologies for different rainfed regions of Asia and Africa

Annual rainfall (mm)	*Problems*	*Recommended technology*	*General remarks*
≤500	Extreme moisture stress and drought, overgrazing, improper land management, shifting sand dunes, wind erosion	Contour cultivation with conservation furrows, ridging sowing across slopes, off-season tillage, minimum tillage, inter-row water harvesting system, small water harvesting structures, vegetative barriers, contour bunds, field bunds, mulching, scoops, tied ridges indigenous methods such as *khadin*	Major focus needs to be given on in-situ soil and water conversation with low-cost technologies. Vegetative barrier along with appropriate land use systems should be used to control wind erosion.
>500–≤750	Sheet erosion, ravine lands, shortage of moisture, recurring droughts, moderate to high runoff overgrazing, siltation of reservoirs and tanks, lack of adequate groundwater recharge	Contour cultivation with conservation furrows, compartment bunding, ridging, sowing across slopes, minimum tillage, zingg terrace, off-season tillage, broad-bed and furrow (BBF), contour/graded border strips, scoops, tied ridges, mulching, inter-row water harvesting system, small basins, stone bunds, field bunds, graded bunds, contour bunds, vegetative bunds, small gully control structures, runoff water harvesting structures	On Vertisols and associated soils major emphasis needs to be given on in-situ soil and water conversation. On Alfisols and associated soils emphasis needs to be given on both in-situ and ex-situ soil and water conversation.
>750–≤1200	High sheet and gully erosion, ravine lands, high runoff, waterlogging, poor workability of soils, moisture stress particularly during postrainy and summer seasons, siltation of reservoirs and tanks, downstream flooding	BBF (for Vertisols and associated soils), flat-on-grade cultivation, conservation furrows, sowing across slopes, field and main drains, conservation tillage, contour/graded border strips, small basins, stone bunds, field bunds, vegetative bunds, graded bunds, modified contour bunds, *Nadi* Zingg terrace, gully control structures, runoff water harvesting and groundwater recharging structures	Emphasis needs to be given on both in-situ and ex-situ soil and water conservation practices. On Vertisols and other heavy soils, graded type soil and water conservation practices which provide balance between moisture conservation and waterlogging need to be adopted. Good potential for harvesting runoff and groundwater recharging.

Table 7.2 Continued

Annual rainfall (mm)	*Problems*	*Recommended technology*	*General remarks*
>1200	High soil erosion, gully formation, waterlogging, poor workability of soils, shortage of water during postrainy and summer seasons, siltation of reservoirs and tanks, downstream flooding	BBF (Vertisols), field bunds, stone bunds, vegetative bunds, flat-on-grade cultivation, field and main drains, conversation tillage, contour/graded border strips, modified contour bunds, gully control structures, runoff water harvesting and groundwater recharging structures, graded bunds	Emphasis on controlling soil erosion and safe disposal of excess runoff water. Excellent potential of harvesting runoff and groundwater recharge.

for sustainable production. The suitability of any in-situ soil and water management practice depends greatly upon soil, topography, climate, cropping system, and farmers resources. Some of the promising in-situ soil and water conservation practices from the different rainfed regions are discussed below.

7.2.1.1 Contour cultivation and conservation furrows

In several rainfed regions, the up and down cultivation is still a common practice. This results in poor rainfall infiltration and accelerated soil erosion. Contour cultivation or cultivation across the slope is a simple method of cultivation, which can effectively increase rainfall infiltration and reduce runoff and soil loss on gently sloping lands. The contour cultivation involves performing cultural practices such as plowing, planting, and cultivating on the contours (Figure 7.1). It creates a series of miniature barriers to runoff water when it flows along the slope. Mishra and Patil (2008) reported that this system in farmers' fields on Alfisols of Kabbalanala watershed near Bengaluru, India increased soil moisture during the cropping season from 35th to 43rd weeks over farmers' practice of up and down cultivation (Figure 7.2). Contour cultivation conserved the rainwater and reduced the runoff and soil loss, and increased the yields of sesame, finger millet, and groundnut in the Alfisols at Bengaluru.

The effectiveness of this practice was greater when the crops were fertilized with nitrogen (N) and phosphorus (P) nutrients and other improved practices were implemented (Krishnappa *et al.*, 1999). This practice resulted in 35% and 22% increase in sorghum and *Setaria* yield, respectively on Vertic inceptisols and 66% increase in sorghum yield on Alfisols over the up and down method of cultivation.

In most situations the effectiveness of contour cultivation can be greatly enhanced by adding conservation furrows into the system. In this system in addition to contour cultivation, a series of furrows are opened on contour or across the slope at 3.0–7.5 m apart (Figure 7.3). The spacing between the furrows and its size can be chosen based on the rainfall, soils, crops and topography (Pathak *et al.*, 2009a). The furrows can be made either during planting time or during interculture operations using traditional plow. Generally, two passes in the same furrow may be needed to obtain the required

Figure 7.1 Contour cultivation at Kurnool watershed in Andhra Pradesh, India (See color plate section)

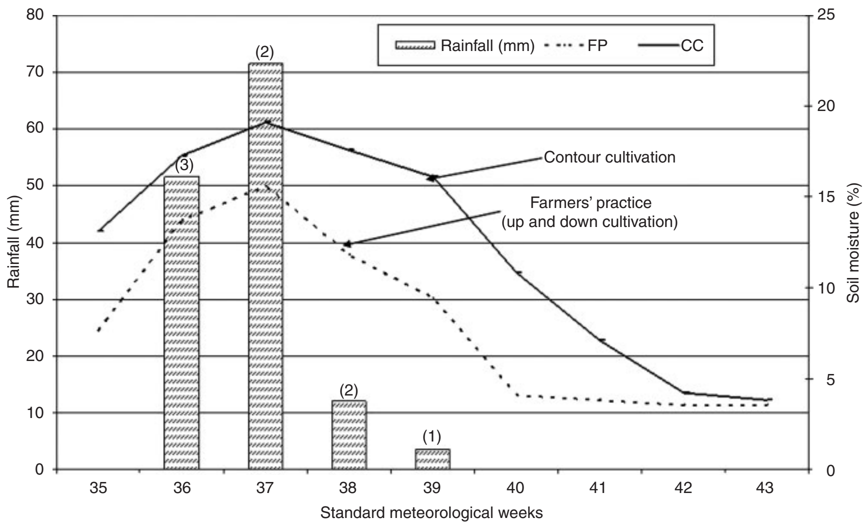

Figure 7.2 Soil moisture as influenced by farmers' practice (FP) and contour cultivation (CC) (Note: Number of rainy days is given in parenthesis) (Source: Mishra and Patil 2008)

furrow size. These furrows harvest the local runoff water and improve soil moisture in the adjoining crop rows, particularly during the period of moisture stress. One of the major advantages of this system is that it provides stability to contour cultivation particularly during moderate and big runoff events. Using the farmer participatory approach, Pathak *et al.* (2009a) reported on the performance of the practices followed

Figure 7.3 Conservation furrow system at Hedigonda watershed, Haveri, Karnataka, India; (right) conservation furrows prepared with local implements; and (left) groundnut crop with conservation furrows (See color plate section)

Table 7.3 Crop yields in different land and water management systems at Sujala watersheds in different districts of Karnataka, India[a]

District	*Crop*	*Yield with farmers' practice (t ha^{-1})*	*Yield with contour cultivation with conservation furrows (t ha^{-1})*	*Increase in yield (%)*
Haveri	Maize	3.35	3.89	16
Dharwad	Soybean	1.47	1.80	23
Kolar	Groundnut	1.23	1.43	16
Tumkur	Groundnut	1.25	1.50	21
	Finger millet	1.28	159	24

[a]Source: ICRISAT (2008).

by farmers (flat cultivation) as compared with contour cultivation along with conservation furrows based on the results of 121 trials conducted in farmers' fields in four districts of Karnataka during 2006–08 (Table 7.3). Contour cultivation along with conservation furrows was found promising both in terms of increasing crop yields and better adaptation by farmers. This land and water management system increased the crop yields of maize, soybean, and groundnut by 16–21% over the farmers' practice.

Contour cultivation along with conservation furrows was also found economically profitable to farmers (Table 7.4). Due to this system the benefit-cost ratio increased by 12 to 23% compared to farmers' practice of flat cultivation. The average benefit-cost ratio in contour cultivation with conservation furrow system was 1.94 and in farmers' practice it was 1.66 with overall average increase of 17%. One major advantage of this system is its very low cost. The average additional expenditure incurred for implementing contour cultivation along with conservation furrow system was only ₹400 ha^{-1}. Results from these large number of trials suggest that there is good possibility of getting good returns on the investments made on this simple land management system.

Table 7.4 Benefit-cost ratio for different crops and land management systems in Sujala watersheds, Karnataka, India[a]

			Benefit-cost ratio		
District	*Watershed*	*Crop*	*Farmers' practice*	*Contour cultivation with conservation furrows*	*Increase (%)*
Haveri	Aremallapur	Maize	2.00	2.32	16
Dharwad	Anchatageri	Soybean	1.84	2.26	23
Kolar		Finger millet	1.18	1.32	12
Tumkur	Belaganahalli	Groundnut	1.23	1.43	16
Mean			1.56	1.83	16.75

[a]Source: ICRISAT (2008).

7.2.1.2 Tied ridges

Tied ridges or furrow diking is a proven soil and water conservation method under both mechanized and labor-intensive systems, and is used in many rainfed areas of the world. Tied ridging results in the formation of small earthen dikes or dam across the furrow of a ridge furrow system. It captures and holds runoff water in place until it infiltrates into the soil. Tied ridges are most effective when constructed on the contour. Under mechanized systems, the furrow dykes are usually destroyed by tillage operations and need to be reconstructed each season. They also obstruct cultivation and other field operations.

Morin and Benyamini (1988) determined the optimum requirements for the implementation of furrow dykes. They used rainfall simulator to determine infiltration characteristics, storm intensity distribution, runoff amount and rate and by combining infiltration function and rainfall intensity pattern predicted the long-term runoff using rainfall probability distribution. Simulation models to determine the effects of tied ridging on runoff were developed by Krishna and Arkin (1988) and William *et al.* (1988) for various cropping systems. When combined with crop modeling, the potential effect of tied ridges on crop yield can be determined. Krishna and Gerik (1988) reported that tied ridges are most effective in the annual rainfall range of 500–800 mm. These models can be effectively used to determine the optimum size and other details of tied ridges and their possible impacts on crop yield, runoff, and soil loss under different rainfall and topographic conditions.

The tied ridge system reduced runoff and soil loss and also increased crop yield. For example, Vogel (1992) reported that tied ridging reduced the soil loss $<0.5\,t\,ha^{-1}\,yr^{-1}$ whereas the soil loss under conventional tillage system was up to $9.5\,t\,ha^{-1}\,yr^{-1}$ on a sandy soil in Zimbabwe. Njihia (1979) reported from Katumani in Kenya that tied ridging resulted in producing maize in low rainfall years, whereas the flat planted crops gave no grain yield.

El-Swaify *et al.* (1985) summarized the experiences of tied ridging in Africa and reported that under certain circumstances, the system has been beneficial not only in reducing runoff and soil loss but also for increasing crop yields. However, during the high rainfall years or in years with long wet periods, significantly lower yields were

Figure 7.4 Scoops with sorghum crop on an Alfisol at ICRISAT, Patancheru, India (Source: Pathak and Laryea 1995a)

reported from tied ridges system than from graded systems, which reduced the ponding of water on the soil surface (Dagg and Macartney 1968). Under such conditions, tied ridging enhanced waterlogging, resulting in the development of anaerobic conditions in the rooting zone and excessive leaching of N fertilizer (Kowal 1970). Jones and Stewart (1990) expressed serious concerns about overtopping of tied ridges and emphasized that this system should be so designed that the tied are lower than ridges, which themselves should be graded so that excessive runoff is drained along the furrows and not down the slope. Further, a support system of conventional contour bunds/furrows must be installed to manage the runoff from big storms.

7.2.1.3 Scoops (or pitting)

Scoops have been extensively used in the Asian, Australian, and African semi-arid tropics (SAT) as an in-situ soil and water conservation system. Scoops on agricultural land involve the formation of small basin depression at closely spaced interval to retain runoff water and eroded sediments from rainstorm (Figure 7.4). Scoops can be made manually or by machine. The commonly used machine for making scoops is a tractor-drawn chain diker equipment, which is extensively used in Australia, USA, and Africa. In India, at Hagari in Bellary district, Karnataka intercultivation by hoes was practiced successfully for scooping purpose in a cost-effective manner. Scoops helped in reducing the runoff by 50% and soil loss by 65%. In Bijapur, Karnataka, implementation of pitting increased sorghum yield by 12% (Mishra and Patil 2008). In Australia, scoops are used to promote vegetation on grazing land. In the SAT areas of Africa, farmers have shown interest in using these techniques for range improvement in Baringo, Kenya (Smith and Chitchley 1983). The implementation of chain diking treatment reduced runoff by 46% compared to the non-diked treatment on a fine sandy loam soil. Scoops did not appear to hinder subsequent tillage operations.

Pathak and Laryea (1995a) conducted studies to arrive at an optimum design (shape, size, and spacing) of scoops for greater stability and increased soil and water

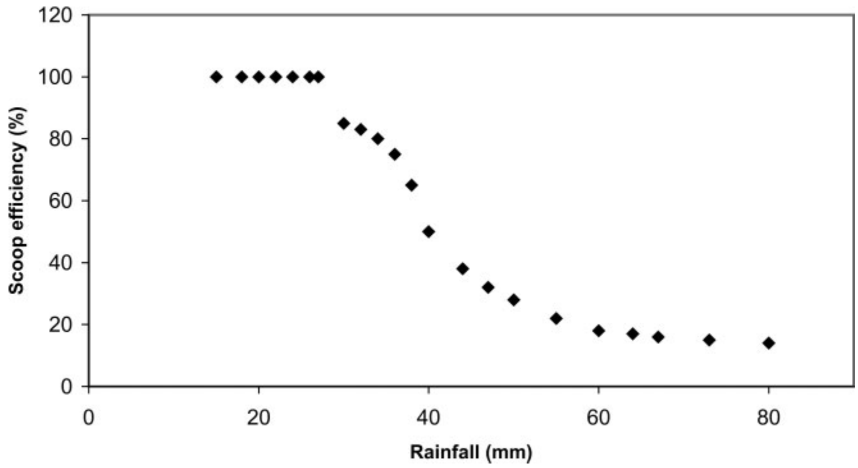

Figure 7.5 Effect of rainfall amounts on the performance of scoops and flat land on an Alfisol (Source: Pathak and Laryea 1995a)

conservation. Experiments were conducted both under simulated (using rotating disc type rainfall simulator) and under natural rainfall conditions to study the effects of various parameters, viz., shape and size of scoops, rainfall amount and intensities, slope, soil texture, soil type, surface cover and others, on the performance of scoops. The relative performances of scoops with other land management systems were also studied. The effect of rainfall amount on the performance of scoops and flat land in terms of runoff is shown in Figure 7.5 where scoop efficiency (P_e) is defined as follows:

$$P_e = (R_f - R_p/R_f) * 100 \qquad (1)$$

where, R_f is the runoff (mm) from flat land, and R_p is the runoff (mm) from the scooped land.

Scoop efficiency is a measure of the effectiveness of scoops in controlling runoff compared to the flat land treatment. Rainfall amount greatly influences scoop efficiency. The results showed that the scoops were efficient in controlling runoff only from small- and medium-size storms (20–40 mm h^{-1}) and their effectiveness for big storms (i.e., rainfall >50 mm) was relatively low.

Overall, runoff and soil loss under the scoop treatment were significantly lower than from the flat land surface. However, the comparative advantage of scoops over the flat land treatment for reducing runoff and soil loss varied considerably under various rainfall and soil cover conditions (Table 7.5).

The salient results from the several experiments conducted under simulated and natural rainfall were:

- Scoops and tied ridges significantly reduced runoff and soil loss compared with flat seedbed cultivation. Using runoff and soil loss from the flat land as a basis for

Table 7.5 Runoff and soil loss under scoop and flat land treatments from the application of 46 mm rainfall on an Alfisol at ICRISAT, Patancheru, India[a]

	Runoff (mm)			*Soil loss (kg ha^{-1})*		
Treatment	*Scoops*	*Flat*	*SE*	*Scoops*	*Flat*	*SE*
Bare surface						
Rainfall intensity 28 mm h^{-1}	16	27	±3.1	1781	2906	±210
Rainfall intensity 65 mm h^{-1}	26	34	±4.2	4969	8344	±479
Surface with mulch (60% cover)						
Rainfall intensity 28 mm h^{-1}	6	14	±2.1	750	1875	±138
Rainfall intensity 65 mm h^{-1}	15	24	±1.9	2063	2813	±291

[a]Source: Pathak and Laryea (1995a).

comparison, scoops reduced seasonal runoff by 69% and soil loss by 53%, while runoff in the tied ridge system was reduced by 39% and soil loss by 28%.

- Scoops are relatively more stable than tied ridges, particularly during high-intensity rainfall and runoff conditions.
- On Alfisols, scoops reduced runoff and soil loss significantly over flat cultivation during the early part of the crop-growing season.
- The stability of scoops can be greatly enhanced by providing a graded outlet system in the field. Scoops are recommended only for low and medium rainfall areas (annual rainfall ≤800 mm) for increasing crop yields over flat cultivation.
- Scoops are effective in conserving runoff and soil loss only up to 5–6% land slopes. On higher slopes the chances of breaching of scoops increases substantially.
- The effectiveness of scoops is greatly influenced by the texture of surface soil layer. On very sandy soils (sand >93%), the effectiveness of scoops is extremely low.

7.2.1.4 Broad-bed and furrow and related systems

On Vertisols and associated soils, the problem of waterlogging and water scarcity occurring during the same cropping season is quite common. For such a situation, there is a need for an in-situ soil and water conservation and proper drainage technology that can protect the soil from erosion throughout the season and provide control at the place where the rain falls. A raised land configuration broad-bed and furrow (BBF) system, has been found to satisfactorily attain these goals (Figure 7.6). The BBF system consists of a relatively raised flat bed or ridge approximately 95 cm wide and shallow furrow about 55 cm wide and 15 cm deep (Figure 7.7). The system is laid out on a grade of 0.4 to 0.8% for optimum performance. This BBF system is most effectively implemented in several operations or passes. After the direction of cultivation has been set out based on the topographic survey (Figure 7.7), furrows are made by an implement attached to two ridgers with a chain tied to the ridgers or a multipurpose tool carrier called "tropicultor" to which two ridgers are attached (Figure 7.6). A bed former is used to further shape the broad-beds. If there are showers before the beginning of the rainy season, another cultivation is done after showers to control weeds and improve

Figure 7.6 The broad-bed and furrow (BBF) system at ICRISAT, Patancheru, India: (top) BBF formation with tropicultor; and (bottom) groundnut crop on BBF (See color plate section)

the shape of the BBFs. Thus at the beginning of the growing season, the seedbed is receptive to rainfall and, importantly, moisture from early rains is stored in the surface layer without disappearing into deep cracks of the Vertisols. The BBFs formed during the first year can be maintained by reshaping for the long-term (more than 30 years). This will save considerable cost as well as preferentially improve the health of the soil on the bed.

Different land and water management systems, viz., BBF at 0.6% slope, BBF at 0.4% slope, flat on grade at 0.6% slope, and traditional flat system with monsoon fallow system at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India showed that runoff, soil loss, and peak runoff rates were significantly reduced in BBF treatments (Table 7.6). The BBF system

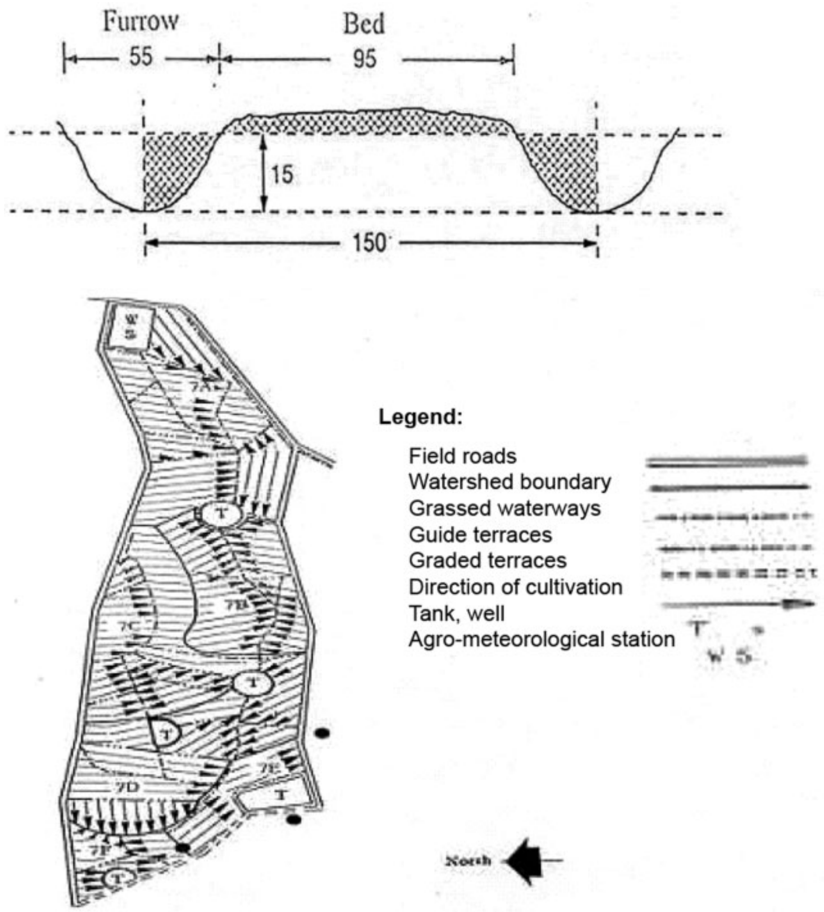

Figure 7.7 Broad-bed and furrow (BBF) system dimension (in cm) and field layout based on topographic map (Source: Pathak *et al.*, 2009a)

was found more efficient in controlling soil and water losses as compared to the flat on grade system. But the BBF system at 0.6% slope within existing farmers' field bunds was found most efficient in reducing runoff and soil loss. On an average, this system reduced annual runoff to one-third, soil loss to one-eleventh, and peak runoff rate to half when compared with the traditional system.

After perfecting the BBF system at ICRISAT, Patancheru, this technology was taken up for large-scale adoption by farmers in Madhya Pradesh. This state has a large area of deep black soils (Vertisols) and they are kept fallow during the rainy season and the crops are sown during the postrainy season. The rainy season fallow area covers about 1.83 million ha of the 13.2 million ha total crop area in Madhya Pradesh. Five districts of Madhya Pradesh, viz., Vidisha, Sagar, Guna, Sehore, and Raisen have large percentage of area under rainy season fallow. Farmer participatory

Table 7.6 Effect of alternative land management systems on annual runoff, soil loss, and peak runoff rate on Vertisols at ICRISAT, Patancheru, India (average annual values from 1975–80)[a]

		Runoff			
Treatment	*Rainfall (mm)*	*mm*	*% of rainfall*	*Peak runoff rate (cum sec^{-1} ha^{-1})*	*Soil loss (t ha^{-1})*
Broad-bed and furrow at 0.6% slope	810	116	17.3	0.11	1.12
Broad-bed and furrow at 0.6% slope with farmers field bunds	808	76	9.4	0.07	0.58
Broad-bed and furrow at 0.4% slope	853	91	10.7	0.07	0.86
Flat-on-grade at 0.6% slope	812	173	17.6	–[b]	1.35
Traditional flat, monsoon fallow	806	220	27.3	0.16	6.67

[a]Source: Pathak *et al.* (1985).
[b]Data not available; problem with recorder.

Table 7.7 Mean soybean yield in improved and traditional management system in Madhya Pradesh during 2007–09[a]

	Grain yield (t ha^{-1})		
District	*Improved system*	*Farmers' practice*	*Increase in yield over farmers' practice (%)*
Guna	1.7	1.46	16
Raisen	2.28	1.56	45
Vidisha	2.23	1.72	30
Indore	2.90	2.51	15
Sehore	2.50	2.09	19
Mean	2.32	1.87	24

[a]Source: ICRISAT (2008).

research-cum-demonstrations were taken up to enhance crop yields in these five districts of Madhya Pradesh.

In total, 140 farmer participatory action research-cum-demonstrations were conducted in 17 villages on enhancing water use efficiency (WUE) through increased crop yields during 2007-09. With BBF, improved varieties and application of micro and secondary nutrients (50 kg ha^{-1} zinc sulfate for zinc and 2.5 kg ha^{-1} agribor for boron) significantly increased crop yields by 16 to 45% with an average increase of 24% due to improved technology over farmers' practice (Table 7.7).

Farmers requested a simpler BBF maker for greater adoption of this technology. A customized user-friendly tractor-drawn modular inclined plate planter-cum-BBF maker was designed and developed for use by farmers for increased adoption of the BBF system (Figure 7.8). This equipment was designed for easy and efficient planting with BBF making simultaneously, which saves the additional cost of operation for forming BBF. The adoption of BBF system by the farmers increased substantially with increased availability of the new BBF maker and seed drill units.

The BBF system has been found quite promising for Ethiopian highlands with Vertisols covering an area of 7.6 million ha. These soils are usually cultivated with

Figure 7.8 Development of modular type seed drill-cum-BBF maker at CIAE, Bhopal, India: (top) for intercrop sowing; and (bottom) sowing with new implement

low-yielding food crops that are normally planted during the later part of the rainy season to avoid waterlogging damage to crops. The practice leaves a great proportion of the bare land resulting in high runoff and soil loss (60 to 100 $t\,ha^{-1}\,yr^{-1}$). During 1991 the BBF system was introduced by ICRISAT along with its three partners, viz., International Livestock Research Institute (ILRI), Alemaya University, and Ethiopian Agricultural Research Organization. Experiments on BBF system were conducted at the research stations in Ethiopian highlands. The BBF system increased wheat yield significantly compared to flat cultivation (Table 7.8). Following on-station trials the

Table 7.8 Effect of different BBF systems on grain yield of wheat (cv ET-13) at two locations in Ethiopia, 1991[a]

Location	*Treatment*	*Bed height (cm)*	*Yield (kg ha^{-1})*	*Increase in yield over control (%)*
Ginchi	Flat cultivation (control)	–	835 (±75)*	–
	Normal BBF	13	979 (±45)	17
	Raised BBF	26	1221 (±45)	46
Akaki	Flat cultivation (control)	–	960 (±62)*	–
	Normal BBF	13	1286 (±73)	34
	Raised BBF	26	1481 (±73)	54

[a]Source: Srivastava *et al.* (1993).

BBF system was tested at several on-farm sites in Ethiopian highlands in collaboration with farmers selected from peasant associations. For making the BBFs in farmers' fields, a simple broadbed maker was developed. This implement greatly facilitated the adoption of the BBF technology by the Ethiopian farmers. Since 1998, the Government of Ethiopia has introduced market liberalization policies and strategies to achieve food self-sufficiency. In response to the policy change the diffusion and adoption process was also strengthened. The Ministry of Agriculture and several non-government organizatons (NGOs) including Sasakawa Global 2000 took part in diffusing the BBF system along with other improved technologies. In order to reach their food production targets, the Ethiopian government in 2004 initiated a new program for promoting the adoption and use of the BBF and other improved systems through price subsidies, increased access to credit, and increased training. The uptake of BBF system in Ethiopia was recently assessed by a multidisciplinary team of ICRISAT scientists along with officials from Ministry of Agriculture, Ethiopia. In 2010, the BBF system was adopted by more than 120,000 farmers in highlands of Ethiopia. The Government of Ethiopia has prepared a 5-year plan to increase this number enormously in the next five years (2011–15). The appropriate technology, simple implement for making BBF, and sustained substantial support by the Ministry of Agriculture (through appropriate policies) seems to be the key drivers of the rapid uptake of BBF system in recent years in Ethiopia.

Channappa (1994) reported that the graded furrowing at the time of sowing the crop at 1.5 to 3 m intervals was found to increase and stabilize yield levels over years by 8 to 10%, apart from better rainwater management during low as well as high intensity rains. Modified technique known as paired row in pigeonpea–finger millet intercrop with a furrow in between the pigeonpea rows and 8 to 10 rows of finger millet was found to be the best intercrop as well as inter-terrace management practice for the Alfisol regions of Karnataka state in India. The relative performance of different bed systems, i.e., flat bed, BBF, narrow bed and furrow, and raised-sunken bed was studied on the black soils at Indore. The results indicated that maize yield was maximum (2.01 t ha^{-1} and WUE of 8.81 kg ha^{-1} mm^{-1}) in the BBF system, followed by raised-sunken bed and flat bed systems. In the Vertisols of Bellary, Karnataka, the BBF system proved effective in conserving the rainwater, increasing the soil water in the profile and thus the winter sorghum grain yield increased by 23.7% and safflower yield by 7.7% as compared to flat bed sowing.

Variation of BBF system has been used in North America (Phillips 1963) and in Central Africa. A variation known as camber-bed system was used in Kenya. An extension of BBF system developed in India (Pathak *et al.*, 1985) has been made on similar soils in Ethiopia. Another variation using small ridges was developed at Agricultural Research Center for Semi-Arid Tropics (CPATSA) of the Brazilian Enterprise for Agricultural Research (EMBRAPA) located at Petrolina, Brazil (Lal 1985, 1986). Some of the major benefits of the semi-permanent BBF system are given below:

- The raised bed portion acts as an in-situ 'bund' to conserve more moisture and ensures soil stability. The shallow furrows provide good surface drainage to promote aeration in the seedbed and root zone, and also prevent waterlogging of crops on the bed.
- The BBF design is quite flexible for accommodating crops and cropping systems with widely differing row spacing requirements.
- Precision operations such as seed and fertilizer placement and mechanical weeding are facilitated by the defined traffic zone (furrows), which saves energy, time, and cost of operation and inputs.
- The system can be maintained for the long-term (25–30 years).
- It reduces runoff and soil loss and improves soil properties over the years.
- It facilitates double cropping and increases crop yields.

7.2.2 Bunding

Bunding is one of the most commonly used methods for the conservation of soil and water on agricultural lands. A bund is a mechanical measure where an embankment or ridge of earth is constructed across a slope to control runoff and minimize soil erosion. The experiences with some of the most commonly used bunding systems are discussed below.

7.2.2.1 Contour bunding

Contour bunding is one of the extensively used soil and water conservation technique in several rainfed areas of Asia and Africa. In India during 1947–79 contour bunds have been constructed on about 21 million ha of agricultural lands costing about US$ 30 ha^{-1}; this figure constitutes about 90% of the total expenditure on soil conservation on agricultural lands in India. Contour bunding involves the construction of small bunds across the slope of the land along a contour so that the long slope is reduced to a series of small ones. Each contour bund is provided with an elevated spillway at the lower end of the field for the safe disposal of excess water. The contour bund acts as a barrier to the flow of water down a hillside and thus increases the time so that water concentrates in an area, thereby allowing more water to be absorbed into the soil profile.

Extensive studies conducted on the alluvial soils of Gujarat showed that 1.3 m^2 cross section bunds spaced at 1.83 m vertical interval are suitable for lands having slope between 6 and 12%. For slopes less than 6%, contour bunds with cross section of 0.9 to 1.3 m^2, spaced at 0.9 to 1.2 m vertical interval were found to be effective (Bhumbla *et al.*, 1971). In the Alfisols of Hyderabad, contour bunding recorded increase in crop yields of sorghum, pigeonpea, and pearl millet and reduced runoff and soil loss.

Figure 7.9 Conventional contour bund system with water stagnation at ICRISAT, Patancheru, Andhra Pradesh, India

Contour bunding in agricultural watersheds of many regions were found to reduce runoff and soil erosion considerably. In Dehradun region, runoff observations from a 55-ha agricultural watershed treated with contour bunds have shown that runoff volume and peak runoff rate were reduced to 62 and 40% respectively (Ram Babu *et al.*, 1980). Research conducted in the Doon valley, India with an annual rainfall of 1680 mm, indicted 88% reduction in soil loss from the area with contour bunding treatment as compared to the cultivated fallow (Gurmel Singh *et al.*, 1990). The studies undertaken on lateritic hills with 8 to 10% slope in the heavy rainfall area with finger millet as a test crop indicated that contour bunding is more effective in reducing soil loss. Gund and Durgude (1995) reported that lowest runoff was observed in contour bunding supported by live bunding of *subabul* (*Leucaena leucocephala*) at Bengaluru. However, in India the use of contour bunds to retain runoff has not always been found to be effective. When used mainly as a soil and water conservation measure in areas with 750–1250 mm rainfall on deep Vertisols, it was found that disadvantage of waterlogging in the vicinity of the bund both uphill and downhill exceeded the advantage of increased cropping intensity from the stored moisture in the dry season (Pathak *et al.*, 1987).

7.2.2.2 Modified contour bunds

Well-designed and maintained conventional contour bunds on Alfisols and other light-textured soils undoubtedly conserve soil and water, and for this purpose contour bunds are perhaps efficient. However, the associated disadvantages – mainly water stagnation (particularly during the rainy season) (Figure 7.9) causing reduction in crop yields – outweigh any advantage from the view point of soil and water conservation.

Figure 7.10 Gated-outlet contour bund system at ICRISAT, Patancheru, India; (inset) gated-outlet

The modified contour bunds with gated-outlets (Pathak *et al.*, 1989a) have shown promise because of the better control on ponded runoff water (Figure 7.10). This system involves constructing embankments on contours with gated-outlet at the lower end of the field. The gated-outlet system allows the runoff to be stored in the field for a desired period, which is then released at a predetermined rate through the spillway, thus reducing the time of water stagnation behind the bund that would have no adverse effects on crop growth and yield and also facilitates the water infiltration into soil to its optimum capacity. The results on the comparison of gated-outlet contour bunds with the other alternative land management systems are shown in Table 7.9. The conventional contour bunds and gated-outlet contour bunds were found to be most effective in controlling runoff and soil loss. However, only contour bunds with gated outlets were found to be more effective in increasing yield and this system produced highest crop yields and provided adequate control of runoff and soil loss. The benefits of this system are given below:

- The problem of prolonged water stagnation around the contour bund and bund breaching are reduced in the gated outlet contour bund system. This results in better crop growth and higher crop yields.
- More timely tillage and other cultural operations are possible in the gated-outlet contour bund system because of better control on ponded runoff water.
- Gated-outlet contour bund system involves low cost for modification and is simple to adopt.

7.2.2.3 Graded bunding

Graded bunding on grades varying from 0.2 to 0.4% is generally practiced in areas with more than 600 mm annual rainfall to drain the excess runoff water into the grassed

Table 7.9 Grain yield, runoff, and soil loss from different land management systems in Alfisol watersheds at ICRISAT, Patancheru, India[a]

Land management systems	*Crop*	*Grain yield (kg ha^{-1})*	*Runoff (mm)*	*Soil loss (t ha^{-1})*
Conventional contour bund	Sorghum/	2520		
	Pigeonpea	710	75	0.97
	Pearl millet/	2230		
	Pigeonpea	730		
Modified contour bund gated-outlet	Sorghum/	3020		
	Pigeonpea	970	160	0.92
	Pearl millet/	2730		
	Pigeonpea	1010		
Broad-bed and furrow	Sorghum/	2740		
	Pigeonpea	880	289	3.61
	Pearl millet/	2400		
	Pigeonpea	920		
Contour cultivation with field bunds	Sorghum/	2810		
	Pigeonpea	910	215	3.35
	Pearl millet/	2510		
	Pigeonpea	920		

[a]Source: Pathak *et al.* (1987).

waterway. Gurmel Singh *et al.* (1990) reported that graded bund can reduce the soil loss by 86% compared to the cultivated fallow. Similar results were also reported by Kale *et al.* (1993), wherein soil loss in the graded bund plot was 9.71 t ha^{-1} compared to 18.92 t ha^{-1} in the control treatment. In the deep black soils of Bellary, India the increase in yield of sorghum, cotton, and safflower from graded bunds was 14, 25, and 12%, respectively. Chittaranjan *et al.* (1997) conducted a study on the semi-arid Vertisols of South India. The results revealed that graded bunds with farm pond at the tail end are the most suitable soil and water management measures compared to contour bund and conservation ditch.

7.2.2.4 Field bunding

Field bunding is traditionally practiced by a large number of farmers. Stabilizing and strengthening of the existing field bunds will not allow the fragmentation of fields of small farmers. This is acceptable to one and all. Singh *et al.* (1973) evaluated various practices for conserving soil moisture, viz., field bunding, field bunding + land shaping, basin listing, deep furrow and control (no bunding and no land shaping) with pearl millet as the test crop. The results of three-year study showed that field bunding plus land shaping practice gave the highest pearl millet grain yield.

7.2.2.5 Compartmental bunding

Compartmental bunding is extensively practiced in several rainfed areas of Asia and Africa. This is done by dividing fields into small land parcels of square or rectangle shapes, by providing small bunds. In deep black soils depending upon the land slopes, the entire field is laid out into small bunded compartments varying in size from 6 m × 6 m to 10 m × 10 m. Rains received during the rainy season are collected in these bunded areas; these are slowly harrowed and land is prepared into a good seed bed for raising postrainy season crops (Mishra *et al.*, 2002a).

Selveraju and Ramaswami (1997) recorded significantly higher sorghum and pigeonpea grain yields in the intercropping system with compartmental bunding as compared to flat cultivation. A study on the best cultivation practices for effective rainwater management, revealed that the seed and stalk yields of castor were significantly influenced by different land treatments (control, compartmental bunding, opening of ditches across the slope, interculturing and forming ridges at last interculturing) (Anonymous 1998). The highest seed yield of castor (1219 kg ha^{-1}) was recorded under the compartmental bunding treatment, which was at par with treatment of opening of ditches across the slope.

More *et al.* (1996) reported that there was beneficial effect of compartmental bunding on in-situ moisture conservation. This was reflected on the better performance of the winter sorghum. The overall percent increase in grain and fodder yield by compartments was 38 and 50%, respectively over the control.

7.2.2.6 Vegetative barriers

Vegetative barriers or vegetative hedges or live bunds have drawn greater attention in recent years because of their long life, low cost, and low maintenance needs. In several situations, the vegetative barriers are more effective and economical than the mechanical measures, viz., contour and graded bunds.

Vegetative barriers can be established either on contour or on moderate slope of 0.4 to 0.8%. In this system, the vegetative hedge acts as a barrier to runoff flow, which slows down the runoff velocity, resulting in the deposition of eroded sediments and increased rainwater infiltration. It is advisable to establish the vegetative hedges on small bunds. This increases the effectiveness particularly during the first few years when the vegetative hedges are not so well established. The key aspect of design of vegetative hedge is the horizontal distance between the hedge rows which mainly depends on rainfall, soil type, and land slope. Species of vegetative barrier to be grown, number of hedge rows, plant to plant spacing, and method of planting are very important and should be decided based on the main purpose of the vegetative barrier. If the main purpose of the vegetative barrier is to act as a filter to trap the eroded sediments and reduce the velocity of runoff, then the grass species such as vetiver, *sewan* (*Lasiurus sindicus*), *sania* (*Crotalaria burhia*), and *kair* (*Capparis aphylla*) could be used. But if the purpose of the vegetative hedges is to stabilize the bunds, then plants such as *Gliricidia* could be effectively used (Figure 7.11). The *Gliricidia* plants grown on bunds not only strengthen the bunds while preventing soil erosion, but also provide N-rich green biomass, fodder, and fuel. The cross section of earthen bund can also be reduced. A study conducted at ICRISAT, Patancheru indicated that by adding the N-rich green biomass from the *Gliricidia* plants planted on the bund at a spacing of 0.5 m apart for a length of 700 m could provide about 30–45 kg N ha^{-1} yr^{-1} (Wani and Kumar 2002).

In the shallow Alfisols of Anantapur (mean annual rainfall 570 mm), vetiver alone increased groundnut yield by 11% and with contour cultivation the yield increased up to 39% with greater conservation of rainwater (Mishra and Patil 2008). However,

Figure 7.11 *Gliricidia* plants on bunds and aerial view of a watershed with *Gliricidia* on graded bunds at ICRISAT, Patancheru, India (See color plate section)

in Alfisols at Bengaluru (mean annual rainfall 890 mm), combination of graded bund and vetiver conserved more soil and water and was better than other treatments. In the shallow Alfisols of Hyderabad (mean annual rainfall 750 mm), *Cenchrus* or vetiver barriers along with a small section bund recorded higher yields over conventional mechanical measures. In the Vertisols of Deccan Pleateau at Bellary, the vegetative barrier proved effective in conserving soil and rainwater and increasing the soil water availability in the profile. The increased water availability has resulted in better plant growth with increased grain yield of winter sorghum by 35% over control (Table 7.10).

Table 7.10 Effect of vegetative barrier on resource conservation and sorghum grain yield during 1988–89 to 1996–97 in Vertisols at Bellary, India[a]

Treatment	*Slope (%)* 0.5	1.0	1.5	*Average*
Runoff (mm)				
Up and down cultivation (control)	49.65	54.81	59.14	55.53 –
Vegetative barrier	22.69	39.86	44.10	35.55 (36%)
Soil loss (kg ha^{-1})				
Up and down cultivation (control)	1053	2167	1712	1644 –
Vegetative barrier	500	1372	1027	966 (41%)
Grain yield (kg ha^{-1})				
Up and down cultivation (control)	911	685	475	690 –
Vegetative barrier	1149	848	787	928 (35%)

[a]Source: Rama Mohan Rao *et al.* (2000).
Data is average of eight years for 100 mm rainfall.

The vegetative barrier reduced the runoff by 36% and soil loss by 41% over control. The vegetative barrier was more effective (Rama Mohan Rao *et al.*, 2000) at higher slope (1.5%) and increased winter sorghum grain yield by 66% at 1.5% slope, 25% at 1.0% slope, and 26% at 0.5% slope. In Bellary with 500 mm mean annual rainfall, the exotic *vetiver* was less effective than the native grass (*Cymbopogan martinii*). Vetiver requires higher rainfall (>650 mm) and can perform better in well drained red soils with neutral pH as compared to areas with low rainfall and soils with pH in the alkaline range (>8.5) such as at the Bellary site. The native grass (*C. martinii*) is also not grazed by animals and can be used for thatch making, in addition to its medicinal use.

In areas with long dry periods, vegetative hedges may not survive or perform well. The establishment of vegetative barriers in very low rainfall areas, and the maintenance in high rainfall areas, could be the main problems. Proper care is required to control pests, rodents, and diseases for optimum growth and survival of both vegetative hedges and main crops (Rama Mohan Rao *et al.*, 2000).

7.2.3 Tillage

Most of the soils in the rainfed regions are fragile and structurally unstable when wet. A major consequence of the lack of stability of their aggregates is the tendency of many soils, to exhibit rapid surface sealing during rainfall, crusting and in some cases hardening of a considerable depth of soil profile during subsequent drying cycles. Tillage on such poor soils helps to increase pore space and also keeps the soil loose so as to maintain higher level of infiltration. Laryea *et al.* (1991) found that cultivation of the surface greatly enhanced water intake of soil particularly in the beginning of rainy season. In the absence of cultivation, the highly crusting Alfisols produce as much or even more runoff than the low permeable Vertisols under similar rainfall situations. Larson (1962) stated that pulling a tillage implement through soil results in the total porosity and thickness of the tilled area being greatly increased temporarily. Surface

Table 7.11 Effect of subsoiling on root density 89 days after emergence of maize (Deccan Hybrid 103) on an Alfisol, ICRISAT, Patancheru, India during rainy season 1984[a]

	Root density (cm cm^{-3})		
Soil depth (cm)	*Subsoiling*	*Normal tillage*	*SE±*
0–10	0.55	0.42	0.072
10–20	0.29	0.21	0.022
20–30	0.20	0.09	0.034
30–40	0.15	0.10	0.028
40–50	0.12	0.06	0.016
50–60	0.14	0.05	0.039

[a]Source: Pathak and Laryea (1995a).

Table 7.12 Effect of normal and deep primary tillage on sorghum yield, runoff, and soil loss on Alfisols at ICRISAT, Patancheru, India[a]

Tillage practices	*Sorghum yield (kg ha^{-1})*	*Runoff (mm)*	*Soil loss (t ha^{-1})*
Normal tillage (mold board plowing 12 cm deep)	2160	285	3.27
Deep tillage (cross chiseling 25 cm deep)	2720	195	2.86
LSD ($P = 0.05$)	386	44.0	0.702

[a]Source: ICRISAT (1985).

roughness and micro depressions thus created play greater role in higher retention of water (Unger and Stewart 1983).

On many soils in the semi-arid tropics (SAT), intensive primary tillage has been found necessary for creating favorable root proliferation and enhancing rainfall infiltration. Deep tillage with plow, followed by chiseling (Channappa 1994) opens the hard layers and increase the infiltration and water storage capacity and this results in better crop growth with higher yields on Alfisols at Bengaluru, Karnataka, India. Similarly, on Alfisols in farmers' fields in Coimbatore, Tamil Nadu, India, deep plowing with chisel plow and disc plow plus cultivator increased the soil water stored in the profile at different stages of sorghum growth as compared to soil cultivation with cultivator once or twice, i.e., reduced tillage operations (Manian *et al.*, 1999). Primary tillage carried out in the Alfisols at ICRISAT, Patancheru (Pathak and Laryea 1995b) improved the soil physical properties with better root development (Table 7.11). Also deep tillage reduced runoff and soil loss, and increased the soil water; sorghum yield was increased by 26% over normal tillage (Table 7.12). The positive effects of deep tillage on rainwater conservation, better root development, and increased crop yields were observed for 2 to 5 years after deep tillage, depending on the soil texture and rainfall.

On Alfisols, the problems of crusting, sealing, and hardening are more encountered during the early part of the crop growing season when the crop canopy is not yet fully developed. Pathak *et al.* (1987) studied the effectiveness of shallow tillage imposed as

Table 7.13 Effects of inter-row cultivation (shallow tillage) in addition to normal tillage on runoff, soil loss, and grain yield in 1981–83 on an Alfisol, ICRISAT, Patancheru, India[a]

					Grain yield (kg ha^{-1})			
						Intercrop		
Year	*Rainfall (mm)*	*Tillage treatment*	*Runoff (mm)*	*Soil loss (t ha^{-1})*	*Sole sorghum*	*Sorghum*	*Pigeonpea*	*Sole pearl millet*
1981	1092	Normal[b]	246	5.0	2350			
		Additional[c]	223	4.9	2360			
		SE	±10.6	±0.34	±50			
1982	780	Normal	159	3.1		2260	925	
		Additional	120	2.6		2620	920	
		SE	±8.0	±0.33		±25	±41	
1983	990	Normal	231	4.2				2620
		Additional	196	4.0				2970
		SE	±12.3	±0.24				±32

[a]Source: Pathak *et al.* (1987).
[b]Two inter-row cultivations.
[c]Two additional shallow inter-row cultivations.

secondary inter-row cultivation in breaking up the crust and improving infiltration and soil moisture conservation. Results showed that additional shallow tillage effectively reduced runoff and soil loss in all years (Table 7.13). In some years, it was also effective in reducing moisture loss through evaporation by acting as dust mulch. However, a significant increase in crop yield was obtained only in low and normal rainfall years.

On Alfisols, the off-season tillage serves several useful purposes and should be done whenever feasible. At ICRISAT, Patancheru, the off-season tillage has been found to be helpful in increasing rainwater infiltration and in decreasing weed problems. In most years, off-season tillage alone increased crop yields by 7–9% over the control. Also, it significantly reduced the early season runoff and soil loss. Furthermore, the off-season tillage has been found to minimize the loss by evaporation of stored water by "mulching" effect and thus allowing the acceleration of planting operations and extension of the growing season (Pathak *et al.*, 1987). Similar results were also reported by Mishra and Patil (2008).

7.2.3.1 Zero tillage or minimum tillage or conservation tillage

Sub-optimal subsoil conditions have significant impact on soil water and nutrient regime, base exchange between soil and atmosphere, and crop growth. Adverse effects on crop growth have agronomic and economic implications, while those on soil water and aeration regime lead to ecological and environmental problems of regional and global importance. Soil surface management in general and tillage practices in particular play major role in magnitude and seasonal trends in gaseous emission from soils. Minimum tillage is an ecological approach to resource conservation and sustainable production.

However, the tillage in SAT soils is critically dependent upon available draft power and soil moisture. Timeliness of tillage operations is important, as the rainfall is erratic and the limited water-holding capacity of some of the soils may make them either too

Table 7.14 Effect of different tillage practices and amendments on grain yield (kg ha^{-1}) of rainy season maize and postrainy chickpea on Vertisols at ICRISAT, Patancheru, India[a]

Tillage Practices	*1983–84* Maize	*1983–84* Chickpea	*1984–85* Maize	*1984–85* Chickpea
Flat configuration				
Zero tillage (including chemical weed control)	3500	330	2320	340
15 cm deep primary tillage (normal tillage)	4030	990	2970	970
30 cm deep primary tillage	4390	1160	3140	1060
BBF configuration				
15 cm deep primary tillage (normal tillage)	4380	1150	3320	1090
15 cm deep primary tillage, cross plowing, and reformation of beds every year	4290	1160	3110	1030
30 cm deep primary tillage	4240	1050	3300	1170
30 cm deep primary tillage (without blade hoeing before sowing second crop)	4210	830	3280	1060
30 cm deep primary tillage + application of phosphogypsum at 10 t ha^{-1}	4710	1280	3270	1060
Crop residue incorporation at 5 t ha^{-1} with 30 cm deep primary tillage[b]	5010	1240	3240	1250
SE	±133	±49	±105	±56

[a]Source: ICRISAT (1987).
[b]Chopped dry rice straw incorporated in 1983–84; chopped dry maize stalk incorporated in 1984–85.

wet or too dry to cultivate. Conservation tillage techniques that lower energy inputs and prevent the structural breakdown of soil aggregates have been used particularly in USA, Australia, and in experimental station trials of developing countries of the SAT. In conservation tillage, it is still necessary to follow the accepted and recognized cultural practices of fertilization, pest control, and correct planting time and also use improved varieties, it reduces production costs, greatly reduces energy needs, ensures better soil water retention, reduces runoff, and wind erosion, ensures little or no damage from machinery, and saves labor (Young 1982).

The success of mechanized conservation tillage depends largely on herbicides (which may be expensive and hazardous in nature for use by the resource-poor farmers of the SAT). Crop residues left on the soil surface protect it against the impact of torrential rains, and no-till planting equipment allows precision sowing through trash. Unfortunately, most of the farmers in the SAT use crop residues to feed their animals and to construct fences and buildings. In most parts of semi-arid India, animals are allowed to roam freely on the field after crops have been harvested. Consequently, most of the residue left over is consumed by these animals (Laryea *et al.*, 1991).

Notwithstanding, a comparison between different tillage practices (Table 7.14) on a Vertisol at ICRISAT, Patancheru showed on flat land, the highest yield of maize-chickpea from 30 cm deep primary tillage treatment while zero-tilled plots gave the lowest yield. On BBF landform, incorporation of 5 t ha^{-1} crop residue with deep primary tillage (30 cm) gave on average the highest yield of maize and chickpea. There were no significant differences among the other treatments for maize or chickpea yields.

On Alfisols at ICRISAT, Yule *et al.* (1990) while comparing the effects of tillage (i.e., no-till, 10 cm deep till, 20 cm deep till), amendments (i.e., bare soil, rice straw mulch applied at 5 t ha^{-1}, farmyard manure applied at 15 t ha^{-1}), and the use of perennial species (e.g., perennial pigeonpea, *Cenchrus ciliaris*, and *Stylosanthes hamata* alone or in combination) on runoff and infiltration found that straw mulch consistently reduced runoff compared with bare plots. Tillage produced variable responses in their study. Runoff was reduced for about 20 days after tillage, but the tilled plots had more runoff than no-tilled treatments during the remainder of the cropping season, suggesting some structural breakdown of the soil aggregates in the tilled plots. On average, straw mulch and tillage increased annual infiltration by 127 and 26 mm, respectively. These results of Yule *et al.* (1990) indicate that mulching or keeping the soil covered (as in the case of *Stylosanthes*) should be an important component in the cropping systems of the SAT.

Studies conducted in the semi-arid regions of Africa also indicate that some of the conservation tillage systems, particularly no-till techniques give lower yield than conventional tillage methods. For example, Huxley's (1979) no-till experiments at Morogoro in Tanzania showed that no-tilled maize yielded two-thirds to three-quarters the amount of that in cultivated soil. Furthermore, Nicou and Chopart (1979) conclude in their studies in Senegal, West Africa that in order to be effective, straw mulch in conservation tillage systems needs to be applied in sufficient quantity to cover the surface of the soil completely so that it can fully protect the soil against evaporation and runoff. Straw tends to be used for animal feed in most parts of the SAT, particularly in India, Senegal, and Mali. Therefore while mulches appear to be useful theoretically, from a practical point of view it is difficult to see how they can be used in the present conditions of SAT agriculture. It is even debatable if production of more biomass through breeding will induce farmers in the region to apply residue to their soils or induce them to sell their extra residues in view of the attractive prices offered for fodder during the dry season.

7.2.4 Ex-situ soil and water conservation (runoff harvesting and supplemental irrigation)

The mean annual rainfall in most rainfed regions is sufficient for raising one or in some cases, two good crops in a year. However, the onset of rainfall and its distribution are erratic and prolonged droughts are frequent. A large part of rain occurs as high intensity storms, resulting in sizeable runoff volumes. In most rainfed regions harvesting of excess runoff and storage into appropriate structure as well as recharging groundwater is very much feasible and a successful option for increasing and sustaining the productivity of rainfed agriculture through timely and efficient use of supplemental irrigation. In the areas with annual rainfall >500 mm, this approach could be widely adopted to enhance the cropping intensity, diversify the system into high value crops, increase the productivity and incomes from rainfed agriculture and at the same time, create assets in the villages. Different types of runoff harvesting and groundwater recharging structures are currently used in various regions. Some of the most commonly used runoff harvesting and groundwater recharging structures are earthen check-dam, masonry check-dam, stop check-dam, farm ponds, tank, sunken pits, recharge pits, loose boulder, gully checks, drop structure, and percolation pond (Figure 7.12).

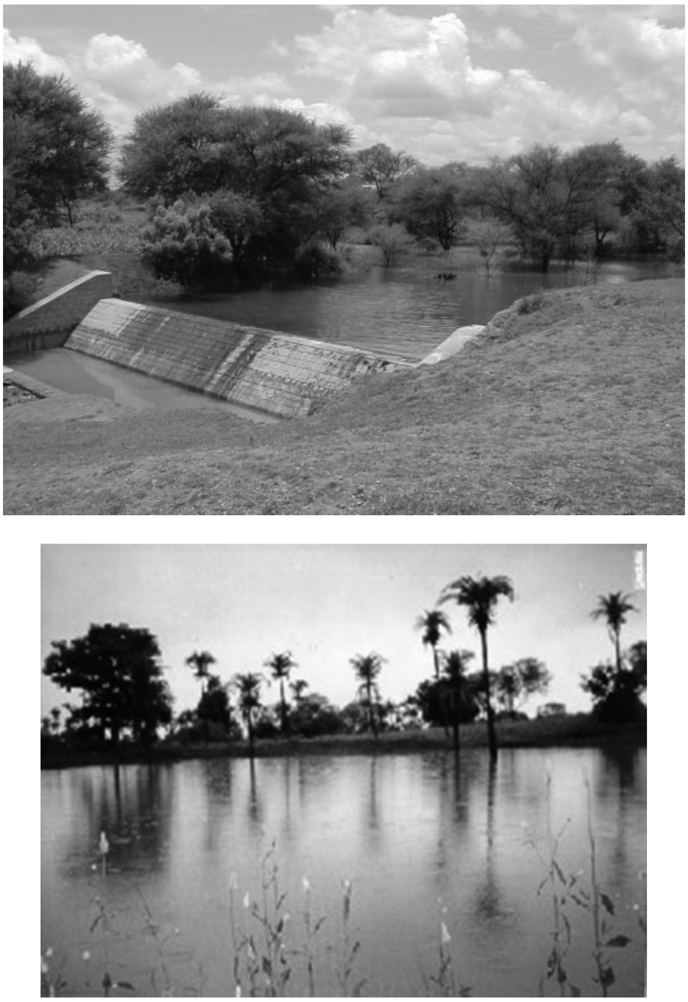

Figure 7.12 Commonly used water harvesting and groundwater recharging structures (Source: Pathak *et al.*, 2009a) (See color plate section)

Designing these structures requires estimates of runoff volume, peak runoff rate, and other hydrological parameters, which are generally not available in most of the rainfed regions. Due to non-availability of the data many times these structures are not properly designed and constructed resulting in higher costs and often failure of the structures. Studies conducted by ICRISAT scientists have shown that the cost of water harvesting and groundwater recharging structures varies considerably with type of structures (Figure 7.13) and selection of appropriate location. Selection of appropriate location for structures also can play very important role in reducing the cost of structures (Figure 7.14).

Figure 7.12 Continued

Pathak *et al.* (2009b) reported that considerable information on various aspects of runoff water harvesting and supplemental irrigation could be obtained by using various models (Pathak *et al.*, 1989b; Ajay Kumar 1991), viz., runoff model, water harvesting model (Sireesha 2003), and model for optimizing the tank size (Sharma and Helweg 1982; Arnold and Stockle 1991). These models can assess the prospects of runoff water harvesting and possible benefits from irrigation. The models also can be used to estimate the optimum tank size, which is very important for the success of the water harvesting system. The information generated can also help in developing

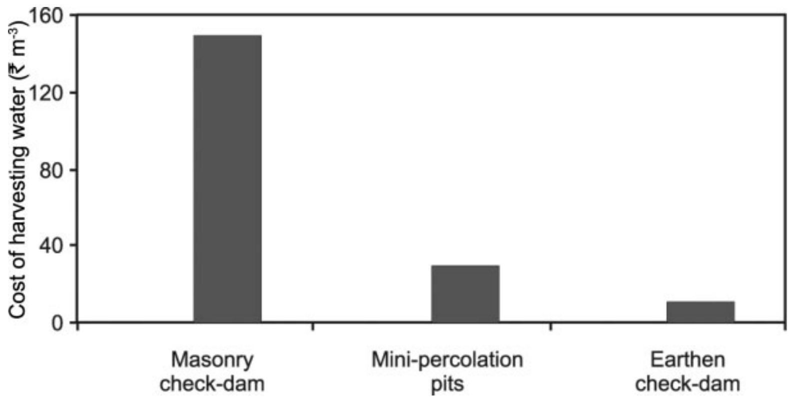

Figure 7.13 Cost of harvesting water in different structures at Kothapally watershed, Andhra Pradesh, India (Source: Pathak *et al.*, 2009a)

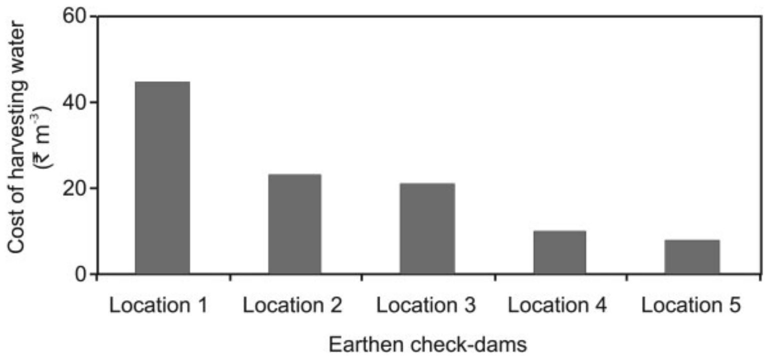

Figure 7.14 Cost of water harvesting at different locations in Lalatora watershed, Madhya Pradesh, India (Source: Pathak *et al.*, 2009a)

strategies for scheduling supplemental irrigation particularly in cases where more than one drought occurs during the cropping season.

Rainfed agriculture has traditionally been managed at the field scale. Supplemental irrigation systems, with storage capacities generally in the range of 20–100 mm of irrigation water, even though small in comparison to irrigation storage, require planning and management at the catchment scale, as capturing local runoff may impact other water users and ecosystems. Legal frameworks and water rights pertaining to the collection of local surface runoff are required, as are human capacities for planning, constructing, and maintaining storage systems for supplemental irrigation and moreover, farmers must be able to take responsibility for the operation and management of the systems. Supplemental irrigation systems also can be used in small vegetable gardens during the dry seasons to produce fully irrigated cash crops. Supplemental irrigation is a key strategy, still underused, for unlocking the rainfed productivity potential and water productivity.

Table 7.15 Effect of supplemental irrigation and fertilizer on sorghum grain yield (kg ha^{-1}), Sahel, 1998–2000[a]

	1998		*1999*		*2000*		*1998–2000*	
Treatment	*Mean*[b]	*SD*	*Mean*[b]	*SD*	*Mean*[b]	*SD*	*Mean*[b]	*SD*
C	666[a]	154	238[a]	25	460[a]	222	455[a]	232
I	961[a]	237	388[b]	182	787[b]	230	712[b]	320
F	1470[b]	254	647[c]	55	807[b]	176	975[c]	404
IF	1747[b]	215	972[d]	87	1489[c]	123	1403[d]	367

[a]Source: Fox and Rockström (2003).
C = Control; I = Irrigation application; F = Fertilizer application; IF = Supplemental irrigation and fertilizer application.
SD = Standard deviation.
[b]Test of treatment effect. Mean values in a column followed by different letters are significantly different at the 5% level using the Student-Newman-Keul's test.

7.2.4.1 Crop responses to supplemental irrigation

Good response to supplemental irrigation had been reported from several parts of the SAT of Africa (Carter and Miller 1991; Jenson *et al.*, 2003; Oweis and Hachum 2003; Barron 2004; Rockström *et al.*, 2007). On-farm research in the semi-arid locations in Kenya (Machakos district) and Burkina Faso (Ouagouya) indicates a significant scope of improving water productivity in rainfed farming through supplemental irrigation, especially if the practice is combined with soil fertility management (Oduor 2003). From the experiments conducted in the Sahel region, Fox and Rockström (2003) reported that supplemental irrigation alone resulted in sorghum grain yield of 712 kg ha^{-1}, while supplemental irrigation combined with fertilizer application resulted in grain yield of 1403 kg ha^{-1}, which was higher than the farmer's normal practice by a factor of 3 (Table 7.15).

Barron (2004) reported from the studies made in Kenya that the water productivity for maize was 1796 m^3 t^{-1} of grain with supplemental irrigation and 2254 m^3 t^{-1} of grain without supplemental irrigation, i.e., decrease in water productivity by 25%. The study concluded that the water harvesting system for supplemental irrigation of maize was both biophysically and economically viable. However, the viability of increased water harvesting implementation at the catchment scale needs to be assessed so that other downstream uses of water remain uncompromised.

Excellent responses to supplemental irrigation have been reported from several locations in India (Singh and Khan 1999; Gunnell and Krishnamurthy 2003). Vijayalakshmi (1987) reported that the effect of supplemental irrigation was largest in rainy season sorghum and pearl millet and yields increased by 560 and 337% respectively and for pigeonpea the yield increased by 560%, but a comparatively lesser response in case of groundnut where the yield increased by only 32% (Table 7.16). For postrainy season crops, an increase by 123% for wheat, 113% for barley, 345% for safflower, and 116% for rapeseed were reported for crops grown at several research stations in India. Havanagi (1982) reported similar crop yield responses to supplemental irrigation in Bengaluru.

Table 7.16 Effect of supplemental irrigation on crop yields at different locations in India[a]

Crop	*Irrigation (cm)*	*Yield (t ha^{-1})*	*Yield increase due to irrigation (%)*	*Location*
Short-duration rainy season crops				
Sorghum	1.6	2.51	560	Hyderabad
Maize	1	2.66	15	Jhansi
	2	4.43	40	
Finger millet	5	2.32	43	Bengaluru
Soybean	8	2.05	14	Indore
Long-duration rainy season crops				
Castor	5	1.32	31	Hyderabad
Pigeonpea	3	0.17	240	Jhansi
(sole crop)	5	0.33	560	
Tobacco	4	1.30	58	Dantiwada
Postrainy season crops				
Wheat	2	1.58	35	Dehradun
	4	2.06	78	
	6	2.60	123	
Rape seed	1	0.35	40	Ranchi
	3	0.46	84	
	5	0.54	116	

[a]Source: Vijayalakshmi (1987).

Singh and Khan (1999) also summarized the yield responses of crops to supplemental irrigation at different locations in India; the data indicated that one supplemental irrigation at critical stage of crop growth considerably increased the crop yields. Introduction of high value crops such as hybrid cotton under protective irrigation further helps in enhancing the income of dryland farmers. Due to better moisture availability through supplemental irrigation, crops respond to the application of higher rates of nutrients. In an experiment carried out on medium deep black soils at Bijapur, Karnataka, India, the responses of horticultural crops, viz., *ber* (jujube), guava, and fig to supplemental irrigation was studied. The highest (122.6%) response to supplemental irrigation was recorded in guava and the lowest (41.7%) in fig (Radder *et al.*, 1995).

On SAT Alfisols, excellent benefits have been reported from supplemental irrigation at ICRISAT, Patancheru (Pathak and Laryea 1990). As shown in Table 7.17, good yield responses to supplemental irrigation were obtained on Alfisols in both rainy and postrainy seasons. The average water application efficiency (WAE) for sorghum (14.8 kg mm^{-1} ha^{-1}) was more than that for pearl millet (8.7 to 10.1 kg mm^{-1} ha^{-1}). Tomatoes responded very well to water application with an average WAE of 186.3 kg mm^{-1} ha^{-1}.

On SAT Vertisols, Srivastava *et al.* (1985) found that the average WAE was largest for chickpea (5.5 kg mm^{-1} ha^{-1}), followed by chili (4.0 kg mm^{-1} ha^{-1}) and safflower (2.0 kg mm^{-1} ha^{-1}). They concluded from their experiments that irrigation was profitable for sequential crops of chickpea and chili on Vertisols.

Table 7.17 Mean grain yield response of cropping systems to supplemental irrigation on an Alfisol watershed, ICRISAT, Patancheru, India, 1981–84[a]

One irrigation of 40 mm	*Increase due to irrigation (kg ha^{-1})*	*WAE (kg mm^{-1} ha^{-1})*	*Two irrigations (40 mm each)*	*Increase due to irrigation (kg ha^{-1})*	*WAE (kg mm^{-1} ha^{-1})*	*Combined WAE (kg mm^{-1} ha^{-1})*
Intercropping system						
Pearl millet			Pigeonpea			
2353	403	10.0	1197	423	5.3	6.8
Sorghum			Pigeonpea			
3155	595	14.9	1220	535	6.7	9.4
Sequential cropping system						
Pearl millet			Cowpea			
2577	407	10.2	735	425	5.3	6.9
Pearl millet			Tomato			
2215	350	8.8	26250	14900	186.3	127.1

[a]Source: Pathak and Laryea (1990).

Pathak *et al.* (2009b) critically analyzed the crop response to supplemental irrigation from different regions. The following key points emerge from the analysis:

- To get the maximum benefit from supplemental irrigation, factors that limit crop productivity must be removed; responsive cultivars, fertilizers, and other recommended package of practices should be followed.
- The best responses to supplemental irrigation were obtained when irrigation water was applied at the critical stages of crop growth.
- On Alfisols and other sandy soils, the best results from limited supplemental irrigation were obtained during the rainy season. On these soils, the additional benefits from one or two supplemental irrigations during postrainy season were found to be limited.
- On Vertisols in medium to high rainfall areas, pre-sowing irrigation for postrainy season crops was found to be most beneficial.
- Crop responses to supplemental irrigation on lighter soils were found better than on heavier soils in the low and medium rainfall areas. However, this was not true for high rainfall areas (<850 mm).
- To get the maximum benefit from the available water, growing high value crops, viz., vegetables and horticultural crops are getting popular even with poor farmers.

7.2.5 Indigenous soil and rainwater conservation practices

Indigenous knowledge is the local wisdom that people have gained through inheritance from their ancestors. It is a people derived science and represents people's creativity, innovations, and skills. Indigenous technological knowledge pertains to various cultural norms, social roles, or physical conditions. Such knowledge is not a static body of wisdom, but instead consists of dynamic insights and techniques, which are changed

Table 7.18 Some documented indigenous soil and water conservation measures in semi-arid India[a]

Categories	*Indigenous soil and water conservation measures*
Agronomic, tillage practices	Cultivation and sowing across the slope, wider row spacing and deep interculturing, mixed cropping, Cover cropping, application of organic manure, strip cropping, green manuring, conservation furrows with traditional plow, deep plowing, summer plowing, and repeated tillage during monsoon season
Bunding and terracing (mechanical and vegetative barrier)	Vegetative barrier, stone bunding, compartmental bunding, peripheral bunding/field bunding, conservation bench terrace, strengthening bunds by growing grasses, bund farming of pulse crops in *kharif* under rainfed situation, earthen bunds, stone-cum-earthen bunding and live bunding by raising cactus
Soil amendment/mulching	Application of tank silt, sand mulching, gravel sand mulching, and retention of pebbles on the soil surface
Erosion control and runoff diversion structures	Sand bags as gully check, loose boulder checks, stone waste weir, waste weir, brushwood structure across the bund, grassed waterways, and *nala* plugging
Water harvesting, seepage control, and groundwater recharge	Seepage control by lining farm ponds with white soil, harvesting of seepage water, wells as runoff storage structures, farm pond percolation pond/tank, groundwater recharging through ditches and percolation pits, dug wells, *haveli/Bharel* system, *bandh* system of cultivation, earthen check-dams, field water harvesting, *Nadi* farming system, and rainwater harvesting in *Kund/Tanka*

[a]Source: Mishra *et al.* (2002b).

over time through experimentation and adoption to environmental and socioeconomic changes. This knowledge is based on hundreds and sometimes thousands of years of adoption, while bearing odds and evens of the time.

Traditional knowledge and practices have their own importance as they have stood the test of time and have proved to be efficacious to the local people. Many indigenous soil and water conservation practices are practiced in different countries. They need to be scientifically evaluated to qualify as modern technological knowledge for wider adoption by addressing the researchable issues. A detailed study of indigenous technical knowledge on soil and water conservation in India was taken up by Mishra *et al.* (2002b). Some documented indigenous practices from different rainfed regions of India are presented in Table 7.18.

In Africa also, cultivators apply a wide range of techniques, both mechanical and agronomic practices, such as crop rotation, crop mixtures, application of manure, protection of N-fixing trees, terrace building, pitting systems, drainage ditches, and small dams in valley floors, to conserve soil and water and to prevent soil degradation. Reij (1991) has attempted to assess current knowledge on indigenous soil and water conservation in Africa. Several examples of indigenous soil conserving practices in the tropical region of Africa presented in Table 7.19. These indigenous techniques are not an exception and they are applied over large parts of the continent. Several reports create an impression that African indigenous soil and water conservation practices are at peril and have no future because these techniques are increasingly abandoned due to several reasons such as political instability, population density, and efficiency of market

Table 7.19 Indigenous soil conserving practices in the tropical region of Africa

Country	*Rainfall (mm)*	*Indigenous SWC techniques*	*Major crops*	*Reference*
Burkina Faso (Central)	400–700	Stone lines, stone terraces, planting pits (Zey)	Sorghum, millet	Savonnet (1958); Reij (1991)
Burkina Faso (South)	700–800	Stone lines	Sorghum, millet	
Burkina Faso (Southwest)	1000	Contour stone bunds on slopes, drainage channels	Sorghum, millet	Pradeau (1975)
Mali (Djenne-Safara)	400	Pitting systems	Sorghum, millet	Ayers (1989)
Sudan (Djebel Marra)	600–1000	Bench terraces	Millet/sorghum	Miehe (1986)
Tanzania (Uluguru mountains)	1500	Ladder terraces		Temple (1972)
Tchad (Ouddai)	250–650	Various earth-bunding systems with upslope wing walls, in drier regions with catchment area (water harvesting)		Sommerhalter (1987)

forces. However, there are many locations where indigenous techniques continue to be maintained and even expanded. In some instances, indigenous techniques, abandoned some decades ago have been revived recently.

7.3 ENHANCING THE IMPACTS OF SOIL AND WATER CONSERVATION AND WATER HARVESTING INTERVENTIONS THROUGH INTEGRATED WATERSHED APPROACH

To maximize the benefits from soil and water conservation interventions, a more integrated approach is needed. In rainfed agriculture, where water is a highly variable production factor, risk reduction through integrated soil and water management is a key to unlocking the potential of managing crops, soil fertility, and pests and allowing for diversification. For rainfed agriculture, watershed provides a logical hydrological scale for effectively managing soil erosion, rainfall, runoff, and groundwater. Results from the several integrated watershed programs clearly indicated excellent opportunities of implementing soil and water conservation, water harvesting, groundwater recharging, and supplemental irrigation at the watershed scale. The key advantage of this approach is that these interventions can be implemented both at farmers' field level as well as community level. Also, the watershed-based community organizations and institutions assist in sustainable management of soil conservation and water harvesting structures.

Although the integrated watershed program includes multi-faceted activities, soil and water conservation, water harvesting, groundwater recharging and its efficient utilization have been the key components of most watershed programs in India and other Asian countries. Results from some key watershed programs with reference to these aspects are discussed.

In Asia, ICRISAT in partnership with the national agricultural research systems (NARS) has developed an innovative and up-scalable consortium model for managing watersheds holistically (Wani *et al.*, 2003). The approach uses rainwater management as an entry point activity starting with in-situ conservation of soil and rainwater, harvesting the excess runoff, and groundwater recharging and converging the benefits of stored rainwater into increased productivity by using improved cultivars and suitable nutrient, pest, and land and water management practices. The consortium strategy brings together institutions from the scientific, non-government, government, and farmers' groups for knowledge management. Convergence allows integration and negotiation of ideas among actors. Cooperation enjoins all stakeholders to harness the power of collective actions. Capacity building engages in empowerment for sustainability. This approach of integrated and participatory watershed development and management has emerged as the cornerstone of rural development in the SAT. It ties together the biophysical notion of a watershed as a hydrological unit with the social aspect of community and its institutions for sustainable management of land, water, and other resources. At ICRISAT benchmark watersheds in India, Thailand, Vietnam, and China, community- and farmer-based soil and water conservation interventions control soil loss and improve the surface and groundwater availability. Findings in most of the watershed sites reveal that open wells located near water harvesting structures have significantly higher water levels compared to those away from the structures. Improved water availability in the watershed not only resulted in increased crop productivity but significant shift in area under cultivation took place towards high-value cereals, cash crops, vegetables, flowers, and fruits.

At Kokriguda watershed, Koraput district, Orissa, India various soil and water conservation measures were implemented to improve the water availability and control soil erosion. Water Users' Association was constituted to maintain the various structures. Open wells registered water table rise by 0.32 m and crop yields increased by 15% in finger millet to 38% in upland paddy. Due to these interventions, area under remunerative crops like vegetables increased from 2 to 35 ha, conveyance efficiency from 23 to 95%, and overall irrigation efficiency from 20 to 43% (Patnaik *et al.*, 2004). In Rajiv Gandhi Watershed program in Madhya Pradesh, India, over 0.7 million water harvesting structures were constructed. The program ran on a mission mode and had over 19% peoples' contribution in monetary terms. There has been 59% increase in irrigated area and 34% decrease in wasteland area where the mission has worked. Agricultural production in the project villages increased by 37% during rainy season and by 30% during postrainy season. Over 3000 villages have reported accretion in groundwater. At Fakot in Tehri Garhwal district, India, a 370-ha watershed was treated with various water harvesting and soil conservation measures. Consequently, paddy and wheat yields increased by 1.65 t ha^{-1} and 1.93 t ha^{-1} respectively. These measures considerably reduced runoff and soil loss from 42.0 to 0.7% and 11.0 to 2.7 t ha^{-1}, respectively. The benefit-cost ratio considering 25 years project life has been worked out as 2.71 at 12% discount rate (Sharda and Juyal 2007).

7.4 STRATEGIES FOR IMPROVING ADOPTION OF SOIL AND WATER CONSERVATION PRACTICES BY FARMERS

Despite being effective in increasing crop yield and having positive effects on soil quality, the adoption of most improved soil and water conservation practices is limited.

Farmers do not operate as independent decision-makers, but rather are subjected to and influenced by a variety of factors. Thus many a times, the decision to adopt and use soil and water conservation practices is made not only in the context of personal and family circumstances, but also in response to government policies, institutional arrangements, community attitudes, and customs.

In seeking workable conservation prescriptions, research institutions, governments, and aid agencies should cooperate closely and fully with local farmers, extension personnel, and community leaders. Such an approach permits information exchange about what already works well, what might work well, and what would be required to make proposed new soil and water conservation techniques feasible and acceptable. Some of the key points, which can facilitate the greater adoption of soil and water conservation techniques, are:

- *Participatory research and demonstration:* Participatory research and demonstrations are very useful to show potential adopters that soil and water conservation technologies and techniques are appropriate for farming systems employed in their community. Field demonstrations are also useful to show potential adopters the type of technical skills they must possess to effectively implement recommended soil and water conservation programs on their farm. Before farmers adopt the technology, it must be adequately demonstrated in terms of its benefits as well as its limitations. Farmers must have enough time to assess the improved technology and compare this with what they have become familiar and have been practicing for a long time.
- *Increased emphasis to rainwater management:* In addition to soil conservation emphasis should be given to rainwater management. This will enhance the adoption of soil and water conservation practices by farmers, as this will provide both short- and long-term benefits to the farmers.
- *Short-term and visible benefits to farmers:* Profitability is assessed in the context of financial return to investment, savings in time and labor, modifications needed in the management of farm activities to integrate innovations, increased risk of failure associated with adoption, and many other factors. Unless the economic return associated with adoption is high enough to compensate adopters for all of these costs, farmers will not adopt any recommended technologies. They evaluate all soil and water conservation technologies and techniques in the context of short- and long-term return to investment. Conservation practices that produce short-term benefits will be more readily adopted than those that produce long-term benefits. The recommended technologies or practices should be able to provide farmers with sufficient benefits, especially cash benefits. This should also be adequately addressed and explained to farmers.
- *Selecting the right technologies with full technical and other assistance:* The right soil and water conservation technology which gives farmers both short- and long-term benefits should be identified. Also, all the assistance and other help should be provided in effectively implementing the technology. For example, if BBF system is recommended, the appropriate implement for BBF making and planting should be provided.
- *Encourage more farmer-to-farmer transfer:* This can facilitate the adoption of new soil and water conservation technologies.

- *Government policy to promote adoption:* Government policy has a very important role to play in the adoption of new practices. For example, in China, terracing has been promoted by the government as the main soil and water conservation practice for which subsidies are provided. In India, contour bunding was promoted by the government during 1974–89.
- *Increased farmers' perception of environmental problems and their effects:* Perception of soil erosion does not mean that farmers are motivated to reduce it. Farmers, without assistance, cannot be expected to know that the erosion of fine, nutrient-rich particles of soil reduces soil fertility. Farmers' awareness of environmental problems has been one of the most important factors to affect adoption and continued use of soil and water conservation technologies and techniques at the farm level. Efforts should be made to increase the awareness of soil erosion, efficient utilization of water and its effects, both on-site and off-site.
- *Improved farmers' perception of the recommended technology:* Lack of access to information about problems and possible solutions can prevent adoption of soil and water conservation technologies and techniques because potential adopters are not informed of alternatives to the existing production systems.
- *Technology which reduces risk:* Small farmers tend to avoid adopting technologies and techniques that increase the level of risk. Efforts should be made to recommend the technology, which reduces risk.
- *Integrated watershed approach:* Implementation of soil and water conservation practices in integrated watershed mode for greater impact and increased adoption.
- *Training and capacity building:* This is important for effective implementation of technology in the fields.

7.5 CONCLUSIONS

Fast deterioration of natural resources is one of the key issues, threatening sustainable development of rainfed agriculture as most rainfed regions are facing multifaceted problems of land degradation, water shortage, acute poverty, and escalating population pressure. Improved and appropriate soil and water management practices are most important for sustainable and improved livelihoods in the rainfed areas. This is because other technological interventions such as improved varieties, fertilizers, etc. are generally not so effective where soil is degraded and water is severely limited. For in-situ soil and land water conservation practices such as contour cultivation, conservation furrows, tied ridges, scoops, BBF system, contour bunding, graded bunding, field bunding, compartmental bunding, vegetative barriers, and tillage systems, considerable body of research knowledge and experiences exist. The real challenge is to identify appropriate technologies, implement and execute strategies for different rainfed regions with different socioeconomic, soil, crop, rainfall, and topographic conditions.

Physical erosion-control measures have been effectively used in the past and the need for them will continue in the future too. However, if emphasis is first placed on rainwater management, the need for physical conservation works can be greatly reduced and many of the problems faced in the past could be overcome. Evidence shows that this approach improves the adoption of soil and water conservation practices by farmers as it provides both short- and long-term benefits.

Conservation tillage or zero tillage is probably one of the most effective systems for soil and water conservation. However, the performance of this practice in many rainfed regions has been poor. In addition to its poor performance, there are also several constraints (demands of crop residues for animal feed, high cost of new tools and equipment, and high level of management) to adoption of no-till farming, clearly indicating that there is need for more research on how these tillage systems will perform in short- and long-term on different soil types. So far results indicate that for rainfed regions minimum tillage appears better compared to no-till farming.

Studies have indicated that water harvesting and supplemental irrigation systems make a lot of difference through enhanced water use efficiency and these systems are affordable even for small-scale farmers. However, policy frameworks, institutional structures, and human capacities similar to those for full irrigation infrastructure are required to be successfully applied for water harvesting and supplemental irrigation systems in rainfed agriculture. Due to the high initial cost, favorable government policies and the availability of credit may be essential for popularization of efficient irrigation system. Impressive benefits have been reported from supplemental irrigation both in terms of increasing and stabilizing crop productivity from many rainfed regions of Asia and Africa. The best response to supplemental irrigation was obtained when water was applied at the critical stage of crop growth. Even small amounts of water applied at critical growth stage were highly beneficial. To get the maximum benefits from supplemental irrigation, other improved inputs such as responsive cultivars and fertilizers must be used. Majority of the soil and water conservation projects have in the past had narrow focus and now a more holistic approach of integrated watershed management is required to ensure sustainability and overall improvement in livelihoods. Integrated watershed management approach enables to have "win-win" situations for sustaining productivity, controlling land degradation, and improving livelihoods of the community. Some successful watershed development models, e.g., "consortium model for managing watersheds holistically" have high potential in conserving soil and water and bringing favorable changes in rainfed areas for sustainably improving livelihoods.

The adoption of soil and water conservation practices is still a major problem in most rainfed regions. Clearly these technologies require greater and sustained support from the implementing agencies than generally required for other improved agricultural technologies, viz., crop varieties, fertilizers, etc. Finally, farmers, scientists, policy makers, and government must work together to enhance the adoption of soil and water conservation technologies for producing adequate amounts of food, feed, and fiber, and to meet the challenge of sustaining the natural resource base.

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