Chapter 12

Integrated watershed management for increasing productivity and water-use efficiency in semi-arid tropical India

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ABSTRACT

Poverty, food insecurity, and malnutrition are pervasive in the semi-arid tropics (SAT) of South Asia, including India. In rural areas, most of the poor make their livelihoods on the use of natural resources, which are degraded and inefficiently used. This is because of the inadequate traditional management practices of managing agriculture as well as the fact that resulting crop yields are much below the expected potential yields. ICRISAT in the early 1970s initiated research on watersheds for integrated use of land, water, and crop management technologies for increasing crop production through efficient use of natural resources, especially rainfall that is highly variable in the SAT and is the main cause of year-to-year variation in crop production in India. Improved watershed management on Vertisols more than doubled crop productivity, and rainfall-use efficiency increased from 35% to 70% when compared with traditional technology. After many years of implementing and evaluating these improved technologies in on-farm situations, many lessons were learned and they formed part of the integrated watershed management model currently being pursued by ICRISAT in community watersheds in rural settings. This watershed model is more holistic and puts rural communities and their collective actions at center stage for implementing improved watershed technologies with technical backstopping and convergence by consortium partners. We describe here the achievements made in enhancing crop productivity and rainfall-use efficiency by implementing improved technologies in on-farm community watersheds in India.

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12.1 INTRODUCTION

South Asia alone accounts for almost all (236 of 237 million) of rural poor living in the semi-arid tropics (SAT) of Asia and about 63% of the rural poor in the SAT worldwide. This also indicates that about 50% of abject poverty in South Asia is concentrated in the SAT (ICRISAT, 2006). Along with pervasive poverty, degradation of agro-ecosystems and declining sustainability are the major concerns of agricultural development in many poor regions of the world where livelihoods depend on exploitation of natural resources. This is especially the case in arid and semi-arid areas where water scarcity, frequent droughts, soil degradation, and other biotic and abiotic constraints lower agricultural productivity and resilience of the system (Shiferaw & Bantilan, 2004). This is further complicated by a policy environment often biased toward high potential regions and incentive systems that discourage adoption of water-saving crops and technologies adapted to dryland areas (Shiferaw, Wani & Nageswara Rao, 2003).

Water is the inherently limiting resource in the SAT for agricultural production on which the human and animal populations are dependent. Erratic rainfall results in widely fluctuating production, leading to production deficit and causing land degradation through soil erosion and reduced groundwater recharge. Population growth accompanied by the heightened demand for natural resources to produce food and to meet needs of the other sectors of the economy further exacerbates the existing problems. Thus, a process of progressive degradation of resources sets in, which intensifies with every drought and the period following it. If not checked timely and effectively, it leads to permanent damage manifested as loss of biodiversity and degradation of natural resources (Wani et al., 2006). Unless the nexus between drought, land degradation, and poverty is addressed, improving the livelihoods dependent mainly upon natural resources can be difficult. Water is the key factor and, through efficient and sustainable management of water resources, entry could be made to beak and not to break the nexus (Wani et al., 2003). In rainfed regions, this would mean enhancing the supply of water through soil and water conservation, water harvesting in ponds, and recharging the groundwater and on the demand side, enhancing its efficient use by adopting integrated soil-, water-, crop-, nutrient- and pest-management practices.

In this paper, we describe the ICRISAT approach of integrated watershed management in rainfed areas of India to enhance the goals of increasing crop production and improving rural livelihoods through sustainable and efficient use of land and water resources.

12.2 OPPORTUNITIES FOR ENHANCING CROP PRODUCTIVITY IN RAINFED REGIONS OF INDIA

The dominant rainfed crops in India are sorghum, pearl millet, pigeonpea, chickpea, soybean, and groundnut. Some area is also under rainfed rice, rainfed wheat, mustard, rapeseed and cotton. Substantial yield gaps exist between current (farmers') and experimental or simulated potential yields (Figure 12.1). The farmers' average yield is 970 kg ha^{-1} for *kharif* sorghum, 590 kg ha^{-1} for *rabi* sorghum, and 990 kg ha^{-1} for pearl millet. Simulated rainfed potential yield in different production zones ranged from 3,210 to 3,410 kg ha^{-1} for *kharif* sorghum, 1,000 to 1,360 kg ha^{-1} for *rabi* sorghum, and 1,430 to 2,090 kg ha^{-1} for pearl millet. Total yield gap (simulated rainfed potential yield – farmers' yield) in production zones ranged from 2,130 to 2,560 kg ha^{-1} for *kharif* sorghum, 280 to 830 kg ha^{-1} for *rabi* sorghum, and 680 to 1040 kg ha^{-1} for pearl millet. These gaps indicate that productivity of *kharif* sorghum can be increased 3.0 to 4.0 times, of *rabi* sorghum 1.4 to 2.7 times, and of pearl millet 1.8 to 2.3 times from their current levels of productivity (Murty et al., 2007).

For legumes, the farmers' average yield is 1,040 kg ha^{-1} for soybean, 1,150 kg ha^{-1} for groundnut, 690 kg ha^{-1} for pigeonpea, and 800 kg ha^{-1} for chickpea. Large spatial and temporal variation in yield gap was observed for the four legumes. The yield gaps for the production zones ranged from 850 to 1,320 kg ha^{-1} for soybean, 1,180 to 2,010 kg ha^{-1} for groundnut, 550 to 770 kg ha^{-1} for pigeonpea, and 610 to 1,150 kg ha^{-1} for chickpea. The results showed that on average the productivity of legumes and oilseeds can be increased 2.3 to 2.5 times their current levels of productivity under rainfed situations. Supplemental irrigation would further increase these yields (Bhatia et al., 2006). Similarly, the national average yield gap relative to simulated rainfed potential yields was 2,560 kg ha^{-1} for rainfed rice, 1,120 kg ha^{-1} for cotton, and 860 kg ha^{-1} for mustard. Such large yield gaps could not be estimated for rainfed wheat because of large percentage of irrigated area in all states (Aggarwal et al., 2008). Whether these biophysical estimates of yield gaps can be abridged economically remains to be quantified, but it gives the scope of increasing crop productivity to meet the future food needs of the country.

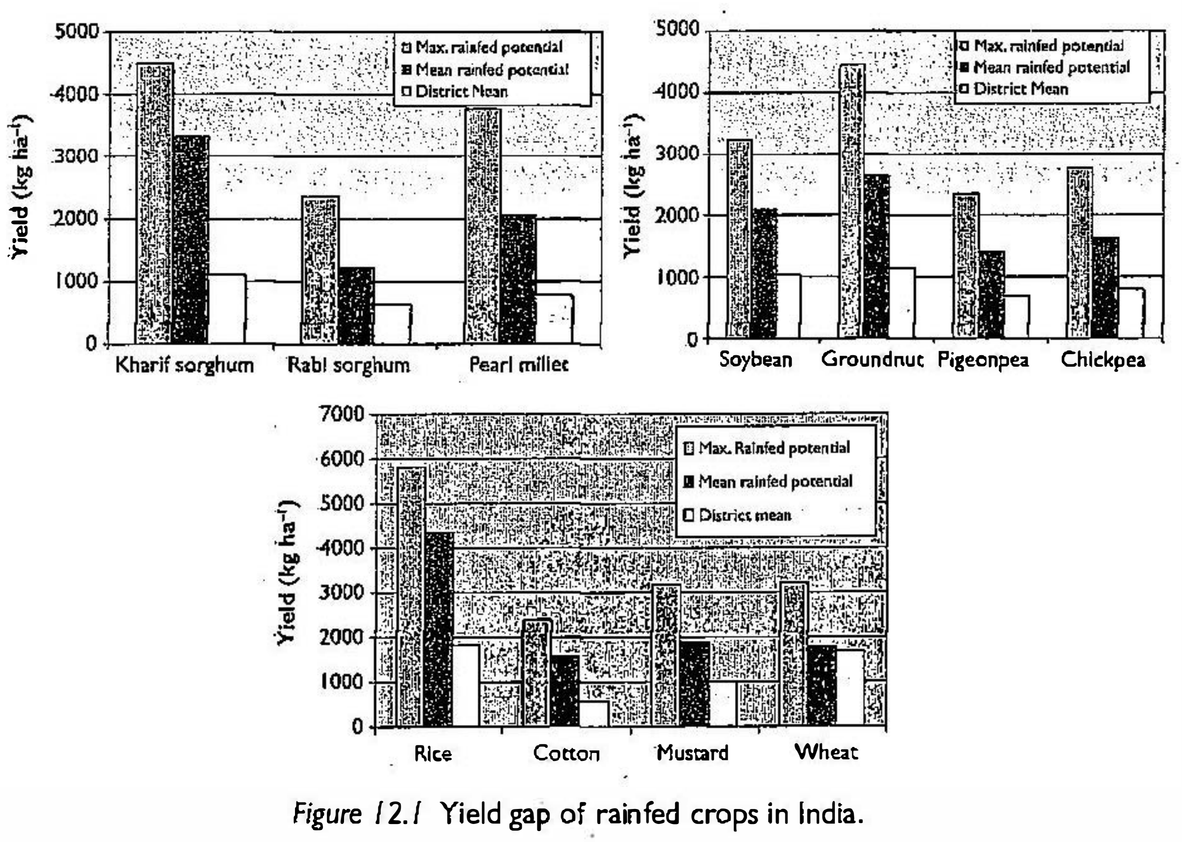

Figure 12.1 Yield gap of rainfed crops in India.

12.3 THE IGNRM APPROACH OF ICRISAT FOR RAINFED AGRICULTURE

ICRISAT has adopted an integrated genetic and natural resource management (IGNRM) approach to enhance agricultural productivity in rainfed areas, which is a powerful integrative strategy of enhancing agricultural productivity. While addressing the core issue of rural development, this approach maximizes synergies among the disciplines of natural resource management, crop improvement, and social sciences, along with people's empowerment through capacity-building measures (Twomlow et al., 2008). ICRISAT has learned that converging different agro-technologies at field level showed greater impact on agricultural productivity in the farmers' holdings than did compartmentalized testing of individual technologies. This was achieved through adoption of an integrated watershed management approach that is holistic in nature to achieve the desired goals of enhancing productivity, reducing land degradation and protecting the environment, which ultimately results in increased economic benefit to rural communities and in alleviating poverty. In our on-stations and on-farm research, the integrated package of technologies was evaluated on watershed scale at various sites in India. The contribution of both individual and combined effects of improved technologies on productivity enhancement and water-use efficiency is presented here.

12.4 ON-STATION WATERSHEDS: TECHNOLOGY DEVELOPMENT AND EVALUATION

12.4.1 Enhancing productivity and resource-use efficiency on Vertisols

The Patancheru area, where ICRISAT is located in India, typifies a SAT climatic environment. The rainy season here begins in June and ends in early October, however, the rains during the month of June, at the time of sowing of crops, are unstable and wide variations are noted in the onset of the rainy season. During the rainy season, the amount and distribution of the rains vary widely.

In 1973, ICRISAT developed a set of Vertisol watersheds at its Patancheru farm. This approach to natural resource management was based on the strategy that, if the land were properly graded and the seedbed prepared in such a way that the rainwater were given enough opportunity time to seep into the soil, the crop-growing season would be secure against water deficits. Grassed waterways were laid out in the watershed hydrological units, so that when heavy rains are received, the water does not stagnate in the field but is safely conducted through the furrows and grassed waterways to the dugout tanks or small reservoirs. These water reservoirs were strategically located in a series to capture most of the surface runoff. These agricultural watersheds have been used to gain insight into the climatic variability impacts on rainfed agriculture production options for sustaining crop yields.

Two Vertisol watersheds were used to evaluate the impact of SAT climate on alternate methods of soil and water conservation and crop productivity under a standard set of agronomic management practices. In the improved watershed-based technology (A), the land was cultivated ahead of the season and prepared to graded BBF system. The rainy season crop was sown in the dry seed bed prior to the on-set of the rainy season; two crops were grown per year in a rotation, which consisted of maize (95 days to maturity) followed by chickpea (120 days to maturity) in year 1, and sorghum (105 days to maturity) intercropped with pigeonpea (210 days to maturity) in year 2. The crops were planted on the graded broad-beds (105 cm wide). Each broad-bed was separated by a furrow (45 cm wide). A standard rate of fertilizers to add 60–80 kg N per ha and 40 kg P_2O_5 per ha was applied every year. All other crop management practices were maintained at the same level throughout the course of this long-term experiment. Under the traditional technology (B) treatment, the seed-bed was kept flat, one crop, either sorghum or chickpea, and was grown during the post-rainy season on conserved soil moisture on the land maintained as fallow during the rainy season. No chemical fertilizers were applied; only farmyard manure was incorporated at 10 t/ha every two years. Farmers in the Patancheru area follow this traditional farming system on the Vertisols. The study has been conducted across the past 30 years, and the following salient results have been obtained.

In the improved system, the two-crop yields were consistently more than 4.7 t/ha, whereas in the traditional system, the average yield across the years was 0.9 t/ha (Figure 12.2). Because of progressive improvements in the soil quality in the improved system, the two-crop yields increased at the rate of 82 kg/ha/year, whereas in the traditional system, the yields increased at 23 kg/ha/year.

The improved system utilized, on average, 67% of seasonal rainfall received as compared with 30% in the traditional management system and endured the climatic risks (seasonal rainfall variability); furthermore, the soil erosion was 1.5 t/ha as against the 6.4 t/ha observed in the traditional system (Table 12.1).

The carrying capacity of the improved system rates at 21 persons/ha/year, compared with 4.6 persons/ha/year under the traditional system. The improved system had no deleterious effects on soil quality, addressed the issues of building up water resources, and is labor intensive.

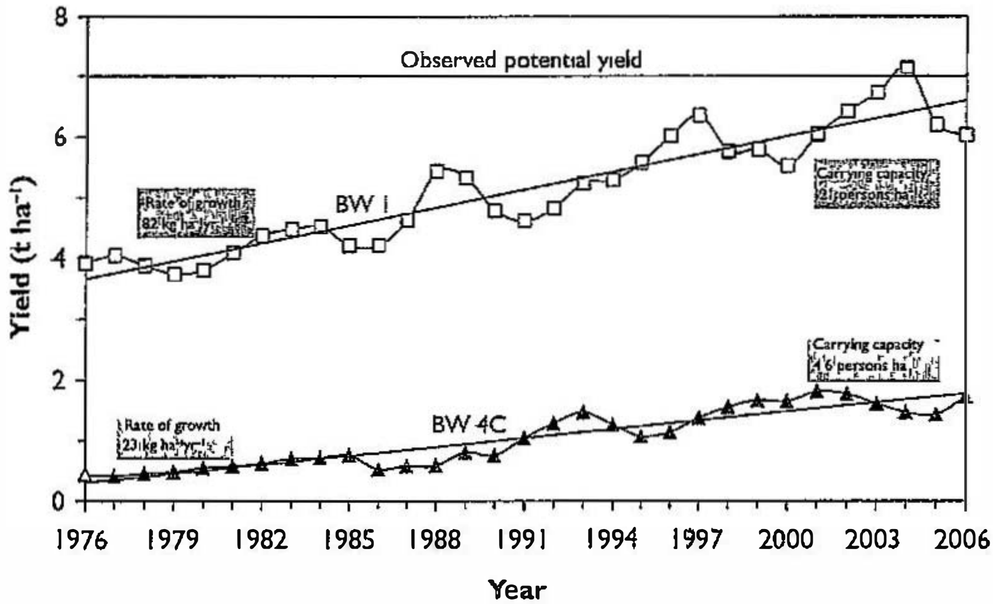

Figure 12.2 Three year moving average of sorghum and pigeonpea grain yield under improved management and on farmers' fields in a deep Vertisol catchment, Patancheru, India.

Table 12.1 Annual water balance and soil loss for traditional and improved technologies in Vertisol watersheds, ICRISAT center, 1976/77 to 1983/84

	Water balance component (mm)				
Farming systems technology	*Annual rainfall*	*Water used by crops*	*Water lost as surface runoff*	*Water lost as bare soil evaporation and deep percolation*	*Soil loss (t/ha)*
Improved system					
Double cropping on †BBFs	904	602 (67)[a]	130 (14)	172 (19)	1.5
Traditional system					
Single crop in post-rainy season and cultivation on flat	904	271 (30)	227 (25)	406 (45)	6.4

Note: [a]Figures in parentheses are amounts of water used or lost expressed as percentage of total rainfall
†BBF = Broad-bed and furrow system

Significant positive changes were observed in the soil physical properties under improved management compared with the traditional technology. Organic C content, which is a good indicator of soil quality, was significantly higher for improved management than for traditional management. The total soil organic C (SOC) content in the top 60 cm soil depth contained 6 t more SOC per ha for the improved management watershed than in the traditional management (27.4 vs. 21.4 t/ha) watershed and this difference was reduced to 1.4 t/ha for the 60–120 cm soil depth for these fields. Similar differences were observed with respect to total N and available P contents, especially for the 60 cm soil depth for these management treatments.

12.4.2 Enhancing productivity and resource use efficiency on Vertic Inceptisols

Out of 72 M ha of black soils in India, Vertic Inceptisols occupy about 60 million hectare (M ha) mostly in the states of Madhya Pradesh, Maharashtra, and Andhra Pradesh (Sehgal & Lal, 1988). These soils have similar physical and chemical properties as the Vertisols, except that these are shallower (depth of black soil material), lighter in texture, and have low to medium available water-holding capacity (100–200 mm plant extractable water). Annual rainfall in Central India, where these soils predominate, varies from 750 to 1300 mm with almost 80% received from June until September (Singh, 1997). Because of their location in toposequence, major constraints for crop production on these soils are a high run-off of rainwater and associated soil erosion and depletion of nutrients and beneficial organisms, all leading to a decline in crop productivity. Under such biophysical conditions, farmers find soybean as the most suitable crop in the region. During past two decades, soybean has been introduced on these soils, and currently some 6.0 million ha area is under this crop. However, the productivity of the crop has stagnated at less than 1.0 t/ha. Therefore, for sustainable increase in crop yields of soybean-based systems, it is essential that suitable land management and agronomic practices be introduced to minimize land degradation and to use natural resources efficiently for crop production. Because the Vertic Inceptisols are relatively shallow in depth, the focus of the technology for these soils was to recharge the groundwater through land management and harvesting of excess rainfall in percolation tanks. Integrated nutrient management practices (legumes in the system, bio-fertilizers, and chemical fertilizers) were followed to meet the nutrient needs of the crops and to minimize the pollution of surface and ground waters.

At ICRISAT, Patancheru, we evaluated the long-term effects of improved vis-à-vis traditional management of a Vertic Inceptisol on the productivity of two soybean-based cropping systems, surface runoff and soil erosion, and balance of organic carbon and other nutrients in the soil. Improved management comprised sowing on BBF landform with *Gliricidia* [*Gliricidia sepium* (L.)] grown on graded field bunds between plots; the pruned materials were added to the soil during the cropping season along with the addition of composted crop residues of soybean, chickpea, and pigeonpea at the start of the season (Figure 12.3). Traditional management comprised of flat landform with sowing along the graded field bunds. No organic matter was added to this treatment except the additions through natural leaf senescence and roots. The two cropping systems evaluated from 1996/97 to 2003/04 were soybean-chickpea sequential (SB-CP) and soybean/pigeonpea intercrop (SB/PP) systems, except during the first year (1995/96 season) when only SB-CP was grown in all the four hydrological units.

Improved management of the Vertic Inceptisol decreased surface runoff by 24%–27% and soil loss by 44%–47% as compared with the traditional management (Table 12.2). Water use by the two crops ranged from 50% to 100% of seasonal rainfall across years. Surface runoff and deep drainage water was captured in surface tanks, which resulted in an increase in water level in dug wells – this water was used to provide irrigation to horticultural crops (Figure 12.4). Overall rainfall-use efficiency on watershed basis was greater than 50% in most years.

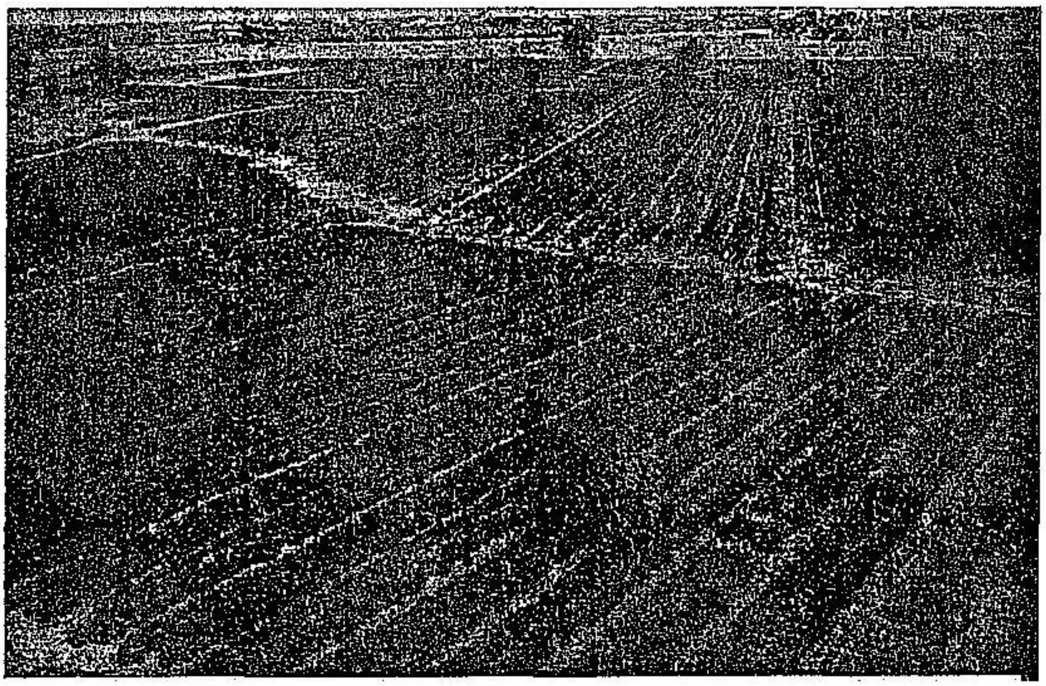

Figure 12.3 Vertic Inceptisol watershed (BW7 watershed) at ICRISAT center, Patancheru.

Table 12.2 Mean seasonal rainfall, surface runoff, and soil loss in the improved and traditional management treatments during 1996/97 to 2003/04 cropping seasons.

Stat	Rainfall (mm)	Surface runoff (mm)		Water use (mm)*		Soil loss (t ha^{-1})	
		Imp.	Trad.	Imp.	Trad.	Imp.	Trad.
Medium depth							
Mean	751	131	179	515	509	1.9	3.6
Range	401–1062	0–477	0–641	395–563	400–565	0–6.5	0–12.0
Shallow depth							
Mean	751	126	166	482	481	1.9	3.4
Range	401–1062	0–489	0–588	400–565	388–558	0–6.7	0–110.1

*From 1995 to 2001. Imp. = Improved; Trad. = Traditional.

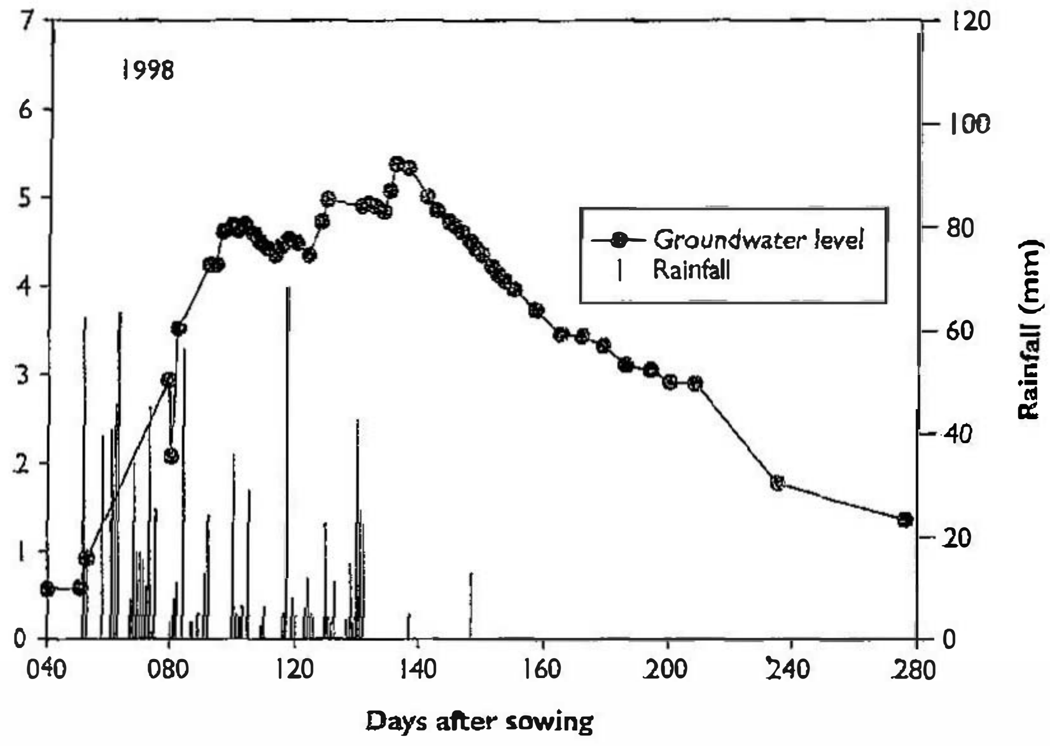

Figure 12.4 Rainfall and groundwater levels in the BW7 watershed during 1998 season.

As the watershed area was cleared of vegetation at the start of the watershed experiment, it had high levels of soil organic carbon (SOC) in the soil profile. Because of rapid decline in SOC in the initial years of the experunent, the productivity of both the cropping systems for biomass and grain yield declined across time; however, the decrease in productivity of the SB/PP system was less than that of the SB-CP system in both the management treatments. In the last three years of the study, total grain yield productivity of SB-CP system was 21% higher on the medium-deep soil and 9% higher on the shallow soil with improved management than with traditional management (Table 12.3). Total grain yield of the SB/PP inter-crop system was marginally higher by 4%–7% with improved management on both the soil types. Across

Table 12.3 Total grain yield of soybean-chickpea sequential and soybean/pigeonpea intercrop systems in the improved and traditional management treatments during the first three and the last three years of study. Each data point is mean of three years.

	Soybean + Chickpea (kg/ha)		*Soybean + Pigeonpea (kg/ha)*	
Soil depth	*Traditional*	*Traditional*	*Improved*	*Improved*
	1995/96 to 1997/98 season		1996/97 to 1998/99 season	
Medium depth	2750	2710	2000	2180
Shallow depth	2520	2360	2100	2030
SEd	111.7		123.3	
	2001/02 to 2003/04 season			
Medium depth	2170	1780	1780	1710
Shallow depth	1400	1290	1690	1590
SEd	129.7		143.5	

SEd = Standard error of the difference between means.

eight years of cropping, organic carbon (OC), total N, and available P content of the soil declined in all the treatments; and in 2002, the extractable sulfur (S), zinc (Zn), and boron (B) in the soil were found to be deficient. After eight years of cropping, improved management retained 2.0 t ha^{-1} more SOC compared with the traditional system, and SB/PP system retained 2.4 to 6.4 t ha^{-1} more OC compared with the SB-CP system in the medium-deep soil, but not in the shallow soil. The conclusion was that for improving and stabilizing productivity of the soybean-based cropping systems on Vertic Inceptisols – in addition to improved land and water management – more balanced nutrition of crops through additions of organics and inorganics, including application of micronutrients, would be required than the low input practice evaluated in this study.

12.4.3 Efficient use of supplemental irrigation water

In the SAT regions, water is a scarce resource, and the amount of water available for supplemental irrigation is generally limited. Once the surplus water has been harvested in surface ponds or the groundwater is recharged, its efficient use is important for increasing crop productivity in a sustainable manner. Efficient use of water involves both the timing of irrigation to the crop and efficient water application methods. Broadly, the methods used for application of irrigation water can be divided into two types, viz., surface irrigation systems (border, basin, and furrow) and pressurized irrigation systems (sprinkler and drip). In the surface irrigation system, the application of irrigation water can be divided into two parts: first, the conveyance of water from its source to the field and, second, application of water in the field.

12.4.4 Conveyance of water to the field

In most SAT areas, the water is carried to cultivated fields by open channel, which is usually unlined and therefore a large amount of water is lost through seepage.

On SAT Vertisols, generally there is no need to line the open-field channels, as the seepage losses in these soils are low mainly due to very low saturated hydraulic conductivity in the range of 0.3 to 1.2 mm hr^{-1} (El-Swaify et al., 1985). On Alfisols and other sandy soils having more than 75% sand, the lining of open-field channel or use of irrigation pipes is necessary to reduce the high seepage water losses. The uses of closed conduits (plastic, rubber, metallic, and cement pipes) are getting popular especially with farmers growing high-value crops, viz., vegetables and horticultural crops.

12.4.5 Efficient application of supplemental water on SAT Vertisols

Formation of deep and wide cracks during soil drying is a common feature of SAT Vertisols. The abundance of cracks is responsible for high initial infiltration rates (as high as 100 mm hr^{-1}) in dry Vertisols (El-Swaify et al., 1985). This specific feature of Vertisols makes efficient application of limited supplemental water to the entire field a difficult task. Among the various systems studied at ICRISAT, the BBF system was found to be most appropriate for applying irrigation water on Vertisols. As compared with narrow ridge and furrow, the BBF saved 45% of the water without affecting crop yields. Compared with narrow ridge and furrow and flat systems, the BBF system had higher water application efficiency, water distribution uniformity, and better soil-wetting pattern. Studies conducted to evaluate the effect of shallow cultivation in furrow on efficiency of water application showed that the rate of water advance was substantially higher in cultivated furrows as compared with uncultivated furrows. Shallow cultivation, in moderately cracked furrows before the application of irrigation water, reduced the water required by about 27% with no significant difference in chickpea yields (Table 12.4).

12.4.6 Efficient application of supplemental water on SAT Alfisols

On Alfisols, surface irrigation on flat cultivated fields results in very poor distribution of water and high water loss. At ICRISAT research station, Patancheru, India, experiments were conducted to determine the most appropriate land surface

Table 12.4 Grain yield of chickpea in different treatments, Vertisols, ICRISAT center.

Treatment	*Mean depth of water application (cm)*	*Grain yield (kg ha^{-1})*
No supplemental irrigation	0	690
One supplemental irrigation on uncultivated furrows	6.3	920
One supplemental irrigation on cultivated furrow	4.6	912
SEM		19
CV%		5.55

configuration for the application of supplemental water. The wave-shaped broad beds and furrows with checks at every 20 m length along the furrows were found to be the most appropriate for efficient application of supplemental water and increasing crop yields. The moisture distribution across the beds was uniform in the case of the wave-shaped broad-beds with checks compared with normal BBF system. The sorghum yield in wave-shaped broad-beds with checks was higher at every length of run compared with normal BBF (Table 12.5). We found that when irrigation water was applied in normal BBF system on Alfisols, the center of the broad-bed remained dry. The center row crop did not get sufficient irrigation water, resulting in poor crop yields. In another experiment on Alfisols, normal BBF system (150 cm wide) was compared with narrow ridge and furrow system (75 cm wide). We found that the narrow ridge and furrow system performed better than BBF system both in uniform water application and higher crop yields. Therefore, for Alfisols, the wave-shaped broad-bed with checks in furrow is the most appropriate land surface configuration for efficient application of supplemental irrigation water, followed by narrow ridge and furrow system.

The improved surge flow irrigation method can also be used for improving the performance of furrow irrigation. This system saves water, uses less energy, and improves water productivity. With proper planning and design, surge flow system can be extensively used for efficiently irrigating high-value crops grown using the ridge and furrow landform (Singh, 2007). The modern irrigation methods, viz., sprinklers and drip irrigation, can play vital roles in improving water productivity. These irrigation systems are highly efficient in water application and have opened up opportunities to cultivate light textured soils with very low water-holding capacity and in irrigating undulating farmlands. The technology has also enabled regions facing limited water supplies to shift from low-value crops with high water requirements, such as cereal, to high value crops with moderate water requirements, such as fruits and vegetables (Sharma & Sharma, 2007). Implementation of these improved irrigation techniques can save water, energy, and increase crop yields. However, currently the use of these improved irrigation methods is limited, primarily because of the high initial cost. Favorable government policies and the availability of credit are essential for popularizing these irrigation methods.

Table 12.5 Sorghum grain yield (t ha^{-1}) as affected by the water distribution in different surface irrigation systems on Alfisols.

Length of run (m)	*Normal BBF*†	*Wave-shaped broad beds with checks in furrow*
0	2.07	2.52
20	2.38	3.91
40	2.56	4.42
60	3.06	4.54
80	3.26	4.53
100	3.08	4.42

†BBF = Broad bed and furrow system.

12.4.7 Conjunctive use of rainfall and limited irrigation water

Stewart, Musick, and Dusek (1983) developed a limited irrigation dryland system (LID) for the efficient use of limited irrigation water for crop production. The objective of the LID concept was to maximize the combined use of growing-season rainfall, which varies for any given year, with a limited supply of irrigation water. This system was studied at ICRISAT research center, Patancheru, India, for rainy season sorghum on Alfisols. Results demonstrated the usefulness of LID system in the application of limited water under uncertain and erratic rainfall conditions. The LID system increased both the crop yields and water-application efficiency (WAE) during the two years of study (Table 12.6).

12.4.8 Crop responses to supplemental irrigation

Srivastava and colleagues (1985) studied the response of post-rainy season crops to supplemental irrigation grown after maize or mung bean on a Vertisol. The highest WAE was recorded for chickpea (5.5 kg mm^{-1} ha^{-1}), followed by chillies (4.0 kg mm^{-1} ha^{-1}), and safflower (2.0 kg mm^{-1} ha^{-1}) (Table 12.7). They concluded that one pre-sowing irrigation to the sequential crops of chickpea and chillies was profitable on Vertisols. Average additional gross returns due to supplemental irrigation were about Rs 1630 ha^{-1} for safflower, Rs 7900 ha^{-1} for chickpea, and Rs 14600 ha^{-1} for chillies.

Impressive benefits have also been reported from supplemental irrigation to rainy and post-rainy season crops on Alfisols at the ICRISAT center (El-Swaify et al., 1985; Pathak & Laryea, 1991). The average water-application efficiency (WAE).for sorghum (14.9 kg mm^{-1} ha^{-1}) was more than that for pearl millet (8.8 to 10.2 kg mm^{-1} ha^{-1}) (Table 12.8). An intercropped pigeonpea responded less to irrigation and its average WAE ranged from 5.3 to 6.7 kg mm^{-1} ha^{-1} for both sorghum/pigeonpea and pearl millet/pigeonpea intercrop systems. Tomatoes responded very well to water application with an average WAE of 186.3 kg mm^{-1} ha^{-1} (Table 12.8).

For the sorghum/pigeonpea intercrop, two irrigations of 40 mm each gave an additional gross return of Rs 9750 ha^{-1}. The highest additional gross return from supplemental irrigation was obtained by growing tomato (Rs 58300 ha^{-1}). These results

Table 12.6 Effect of irrigation on sorghum (CSH6) yield (kg ha^{-1}) on different sections of the slope, Alfisols, ICRISAT center, 1985–1986.

	Upper section 0–20 m		*Middle section 20–40 m*		*Lower section 40–60 m*		*Average yield*		*WAE[b] (kg mm^{-1} ha^{-1})*	
	1985	*1986*	*1985*	*1986*	*1985*	*1986*	*1985*	*1986*	*1985*	*1986*
Rainfed	1058	2220	1618	2110	1710	2140	1659	2150	–	–
Full irrigation[a]	3716	3404	3516	3200	2960	3458	3390	3352	6.9	7.5
LID system	3413	3090	2600	2710	2000	2110	2671	2636	12.1	9.2

[a]5 irrigations totaling 250 mm and 4 irrigations totaling 130 mm were applied during 1985 and 1986, respectively, on full irrigation and LID (upper section) treatments on area basis.
[b]Water-application efficiency (WAE) = increase in yield due to irrigation/Depth of irrigation.

Table 12.7 Response of sequential crops to supplemental irrigation on a Vertisol watershed, ICRISAT center, 1981–85.

	Mean yield (kg ha^{-1})		
Cropping system	*Supplemental irrigation*	*Increase due to irrigation*	*Water application efficiency (mm kg^{-1} ha^{-1})*
1. Maize + chickpea sequential	1540	493	5.6
2. Mung + chillies sequential	1333	325	4.1
3. Maize + safflower sequential	1238	165	2.1

Table 12.8 Grain-yield response (t ha^{-1}) of cropping systems to supplemental irrigation on an Alfisol watershed, ICRISAT, Patancheru, 1981–82.

One irrigation turn of 40 mm	*Increase due to irrigation*	*WAE† (kg ha^{-1} mm^{-1})*	*Two irrigations 40 mm each*	*Increase due to irrigation*	*WAE (kg ha^{-1} mm^{-1})*	*Combined WAE (kg ha^{-1} mm^{-1})*
Intercropping systems						
Pearl millet			Pigeonpea			
2.353	0.403	10	1.197	0.423	5.3	6.8
	Sorghum			Pigeonpea		
3.155	0.595	14.9	1.22	0.535	6.7	9.4
Sequential cropping systems						
Pearl millet			Cowpea			
2.577	0.407	10.2	0.735	0.425	5.3	6.9
Pearl millet			Tomato			
2.215	0.35	8.8	26.25	14.9	186.3	127.1

†WAE = Water-application efficiency.

indicate that on Alfisols, significant returns can be obtained from relatively small quantities of supplemental water.

It is interpreted from the above studies that on Alfisols, the best results from the limited supplemental irrigation were obtained during the rainy season. On Vertisols in medium to high rainfall areas, pre-sowing irrigation for post-rainy season crops was found to be the most beneficial. The best responses to supplemental irrigation were obtained when irrigation water was applied at the critical stages of crop. To get the maximum benefit from the available water, growing high-value crops, viz., vegetables and horticultural crops, is getting popular even with poor farmers.

12.5 INITIAL ON-FARM EVALUATION OF WATERSHED TECHNOLOGIES AND LESSONS LEARNED

Based on impressive successes, with on-station watersheds using new technologies for double cropping on Vertisols, researchers expected that this approach could be 'transferred' to farmers' fields, thereby enhancing the productivity of rainfed systems. The whole process evolved around the 'demonstration' of the technology package and of its possible benefits under farmers' conditions. The Vertisol technology package was demonstrated in the village watersheds. It included land smoothing, drain construction, introduction of the BBF system, use of a bullock-drawn Tropicultor, summer cultivations, dry seeding, and the use of appropriate nutrient and pest-management options along with improved high-yielding crop varieties. Yields in the improved watershed were compared with those in the traditional farmers' system. The trials performed during 1981/82 confirmed that on-farm yields could be similar to those from on-station operational research watersheds. With improved management, sorghum/pigeonpea intercrop system produced higher grain yields (1.9 t ha^{-1}) and net returns of Rs. 3838 ha^{-1} $year^{-1}$ compared with those from the traditional farmers' fields, which recorded 0.55 t ha^{-1} of grain yield and net returns of Rs. 1234 ha^{-1} $year^{-1}$. Similar on-farm evaluations were done at several locations in Maharashtra, Gujarat, Madhya Pradesh, Karnataka, and Andhra Pradesh.

However, subsequent evaluation of these watersheds after 15 years revealed that, in most of them, the farmers went back to their normal practices and that only selected components of the technology package were continued. As part of the watershed evaluation exercise, hundreds of farmers were interviewed and a multidisciplinary team of scientists analyzed the process, farmers' responses and possible reasons for the low adoption of the technology package. Several constraints affected the adoption of technology and higher adoption rates were observed in assured high-rainfall Vertisol areas. From many years of experience of working with watershed technologies, the major lessons learned were: mere on-farm demonstration of technologies by scientists does not guarantee their adoption by farmers; a higher degree of farmers' participation through a consultative to cooperative mode from the planning to evaluation stage is needed; a consortium of organizations is needed for technical guidance, as no single organization can provide support to all the problems of a watershed; a holistic systems approach through the convergence of different activities is needed and it should improve farmers' livelihoods and not merely conserve soil and water in the watershed; efficient technical options are needed to manage natural resources for sustaining systems; appropriate technology applications to address region-specific constraints need to be identified and simple broad recommendations do not help; individual farmers should first realize tangible economic profits from the watersheds; and involvement of women and youth groups is essential, as they play an important role in decision making in the families (Wani et al., 2001).

12.6 CURRENT MODEL OF INTEGRATED WATERSHED MANAGEMENT FOR ENHANCING PRODUCTIVITY AND EFFICIENT USE OF NATURAL RESOURCES

Based on the lessons learned from the extensive watershed-based research and initial on-farm evaluation of watershed technologies, ICRISAT scientists articulated a new model of implementing watershed-based interventions to enhance crop productivity and efficient management of natural resources (Wani et al., 2003). The important components of the new integrated watershed management model are as follows:

- The farmer participatory approach through cooperation and not through the contractual agreement with the farmers. The factors that promote collective action by the community are: the program be demand driven and provide tangible benefits to the individual farmers; initial entry into the watersheds or villages should be knowledge-based to enhance agricultural productivity; and practices that promote equity, equal partnership, shared vision, and trust should be encouraged. Transparency in the use of financial resources, social audit and good local leadership would enhance cooperation and collective action.
- The use of new scientific tools for management and monitoring of watersheds.
- Linking of on-station research watersheds with on-farm community watersheds for technology transfer and for addressing the emerging technical issues.
- A holistic farming systems approach to improve livelihoods of people and not merely conservation of soil and water.
- A consortium of institutions for technical guidance on the on-farm watersheds.
- A micro-watershed within the watershed where farmers conduct strategic research with technical guidance from the scientists.
- Minimize free supply of inputs for undertaking on-farm evaluation of technologies.
- Low-cost soil- and water-conservation measures and structures.
- The amalgamation of traditional knowledge and new knowledge for efficient management of natural resources.
- Emphasis on individual farmer-based conservation measures for increasing productivity of individual farmers along with community-based soil- and water-conservation measures.
- Continuous monitoring and evaluation by stakeholders.
- Empowerment of community of individuals and strengthening of village institutions for managing natural resources.

Since 1999, using the new integrated watershed management model, we have initiated new on-farm watersheds in India. Various interventions made in various community watersheds to enhance productivity and resource-use efficiency are presented.

12.7 ENHANCING PRODUCTIVITY AND WATER USE EFFICIENCY IN ON-FARM COMMUNITY WATERSHEDS

12.7.1 In situ soil and water conservation

Implementation of the type of land- and water-management system depends on the characteristics of the soil, climate, farm size, capital, and availability of human and power resources. Land smoothening and forming field drains are the basic components of land and water management for conservation and safe removal of excess water. Broad-bed and furrow (BBF) system is an improved *in situ* soil and water conservation and drainage technology for the Vertisols. The system consists of relatively flat beds approximately 100 cm wide and shallow furrow about 50 cm wide laid out in the field with a slope of 0.4% to 0.8% (Figure 12.3). The BBF system helps safely dispose of excess water through furrows when there is high intensity rainfall with minimal soil erosion; at the same time, it serves as land surface treatment for *in situ* moisture conservation. Contour farming is practiced on lands having medium slope (0.5%–2%) and permeable soils, where farming operations, such as plowing and sowing, are carried out along the contour. The system helps reduce the velocity of runoff by impounding water in a series of depressions and thus decreasing the chance of developing rills in the fields. Contour bunding is recommended for medium to low rainfall areas (<700 mm) on permeable soils with less than 6% slope. It consists of a series of narrow trapezoidal embankments along the contour to reduce and store runoff in the fields. Conservation furrows is another promising technology in red soils receiving rainfall of 500–600 mm with a moderate slope (0.2%–0.4%). It comprises a series of dead furrows across the slope at 3–5 m intervals, where the size of furrows is about 20 cm wide and 15 cm deep.

On-farm trials on land management of Vertisols of central India revealed that BBF system resulted in a 35% yield increase in soybean during rainy season and yield advantage of 21% in chickpea during post-rainy season when compared with the farmers' practice. Similar yield advantage was recorded in maize and wheat rotation under BBF system (Table 12.9). Yield advantage of 15% to 20% was recorded in maize, soybean, and groundnut with conservation furrows on Alfisols over farmers' practices of Haveri, Dharwad, and Tumkur watersheds in Karnataka (Table 12.10). Yield advantage in rainfall-use efficiency (RUE) were also reflected in cropping systems involving soybean-chickpea, maize-chickpea, soybean/maize-chickpea under improved land management systems. The RUE ranged from 10.9 to 11.6 kg $ha^{-1} mm^{-1}$ under BBF systems across various cropping systems compared with 8.2 to 8.9 kg $ha^{-1} mm^{-1}$ with flat-on-grade system of cultivation on Vertisols (Table 12.11).

Table 12.9 Effect of land configuration on productivity of soybean and maize-based system in the watersheds of Madhya Pradesh, 2001–05 (BBF = Broad Bed and Furrow).

Watershed location	*Crop*	*Farmer's practice*	*BBF system*	*% Increase in yield*
Grain yield (t ha^{-1})				
Vidisha and Guna	Soybean	1.27	1.72	35
	Chickpea	0.80	1.01	21
Bhopal	Maize	2.81	3.65	30
	Wheat	3.30	3.25	16

Table 12.10 Effect of improved land and water management on crop productivity in Sujala watersheds of Karnataka during 2006–07.

Watershed	*Crop*	*Farmers' practice*	*Conservation furrows*	*% Increase in yield*
Grain yield (t ha^{-1})				
Haveri	Maize	3.57	4.10	15
Dharwad	Soybean	1.50	1.80	20
Kolar	Groundnut	1.05	1.22	16
Tumkur	Groundnut	1.29	1.49	15

Table 12.11 Rainfall use efficiency of different cropping systems under improved land management practices in Bhopal, Madhya Pradesh, India.

Cropping system	*Flat-on-grade*	*Broad-bed and furrow*
Rainfall-use efficiency (kg ha^{-1} mm^{-1})		
Soybean-chickpea	8.2	11.6
Maize-chickpea	8.9	11.6
Soybean/maize-chickpea	8.9	10.9

'-' = Sequential system.
'/' = Intercrop-system.

12.7.2 Water harvesting and groundwater recharge

In medium to high rainfall areas, despite following the *in situ* moisture conservation practices, rainfall runoff caused by high intensity storms or water surplus after filling up the soil profile does occur. This excess water needs to be harvested in surface ponds for recycling through supplemental irrigation or to recharge the groundwater for later use in the post-rainy season. Various types of water-harvesting structures were built in Adarsha watershed in Kothapally village in Andhra Pradesh with the participation of farmers (Figure 12.5). Water harvesting in these structures resulted in increased groundwater levels (Figure 12.6). Additional water resource thus created was used by the farmers in providing supplemental irrigation to the crops especially to provide come-up irrigation to the post-rainy season crops, such as chickpea, or to grow high-value crops, such as vegetables. Small and well-distributed water-harvesting structures in the watershed area provided equity and benefited more farmers than the large-sized structures that benefit only a few farmers.

12.7.3 Improved crop varieties and cropping systems

The adoption of improved varieties always generates significant field-level impact on crop yield and stability. The yield advantage through the adoption of improved varieties has been recognized undoubtedly in farmer participatory trials across India under rainfed systems. Recent trials during rainy season conducted across Kolar and Tumkur districts of Karnataka, India, revealed that mean yield advantage of 52% in finger millet was achieved with high-yielding varieties like GPU 28, MR 1, HR 911, and L 5 under farmers' management (traditional management and farmers inputs) compared with use of local varieties and farmer management (Table 12.12). These results showed the efficient use of available resources by the improved varieties reflected in grain yields under given situations. However, yield advantage of 103% was reported in finger millet due to improved varieties under best-bet management practices (balanced nutrition including the application of Zn, B, and S, and crop protection). Similarly, use of improved groundnut variety ICGV 91114 resulted in pod yield of 2.32 t ha^{-1} under farmer management compared with local variety with similar inputs. The yields of improved varieties further improved by 83% over the local variety with improved management that included balanced application of nutrients.

Figure 12.5 Water-harvesting structure in Adarsha watershed Kothapally, Andhra Pradesh.

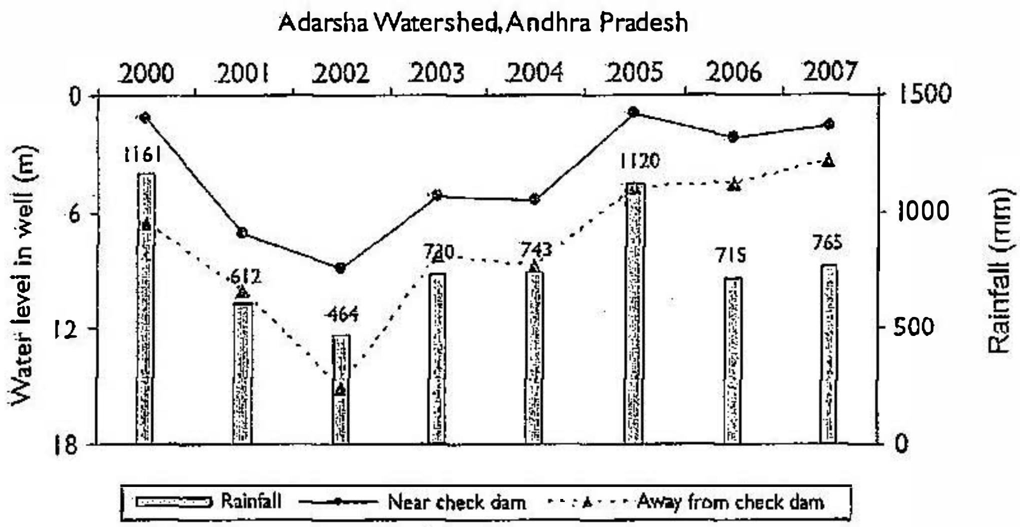

Figure 12.6 Impact of water-harvesting structures on groundwater levels in Adarsha watershed, Kothapally, Andhra Pradesh.

12.7.4 Integrated nutrient management

Low fertility is one of the major constraints responsible for the low productivity under rainfed system besides water scarcity. The deficiency of N and P among the nutrients is regarded as an important issue in soil fertility-management programs. However, ICRISAT-led watershed program across the subcontinent provided the opportunity to diagnose and understand the widespread deficiencies of secondary nutrients, such as S, and micronutrients, such as B and Zn, in the soils of rainfed areas (Sahrawat et al.,

Table 12.12 Effect of improved varieties of finger millet and groundnut under different levels of management in Kolar and Tumkur districts, Karnataka during 2005.

Finger millet yield (t ha⁻¹)			*Groundnut yield (t ha⁻¹)*		
Variety	*Formers' practice*	*Improved mgmt.*	*Variety*	*Farmers' practice*	*Improved mgmt.*
Local	1.97	–	TMV 2 (local)	1.38	1.74
GPU 28	3.00	3.68	JL 24	1.92	2.80
MR 1	2.83	3.93	ICGV 91114	2.32	3.03
HR 911	2.90	3.66			
L 5	3.20	4.65			
Mean	3.00	4.00		1.88	2.52
% increase over local variety	52	103		36	83

2007). An on-farm survey across various states revealed that out of 1,926 farmers' fields, 88% to 100% were deficient in available S; 72%–100% in available B and 67%–100% in available Zn (Table 12.13).

On-farm trials evaluated the response of crops to the application of S and micronutrients at the rate of 30 kg ha^{-1} S, 0.5 kg ha^{-1} B, and 10 kg ha^{-1} Zn. The study revealed 79% yield advantage in maize, 61% in castor, 51% in greengram, and 28% in groundnut compared with the yield levels without application of S and micronutrients (Table 12.14). Impressive economic gains due to improved soil-fertility management to the extent of Rs 5948 and Rs 4333 ha^{-1} in maize and groundnut, respectively, were also reported from ICRISAT-led watershed program across Andhra Pradesh (Table 12.15). Addition of micronutrients and S substantially increased productivity of crops and thus resulted in increased rainfall-use efficiency (RUE). RUE of maize for grain yield under farmer inputs of nutrients was 5.2 kg mm^{-1} compared with 9.2 kg mm^{-1} with S, B, and Zn application over and above the farmer nutrient inputs; respective values in the same order of treatment were 1.6 kg mm^{-1} and 2.8 kg mm^{-1} for groundnut and 1.7 kg mm^{-1} and 2.9 kg mm^{-1} in mung bean. However, addition of recommended dose of N and P along with S, B, and Zn in legumes further increased agricultural productivity, RUE, and incomes of the farmers (Table 12.16).

12.7.5 Integrated pest management

Integrated pest management (IPM) is an effective and environmentally sensitive approach to pest management that relies on a combination of available pest suppression techniques to keep the pest populations below the economic thresholds. In other words, IPM is a sustainable approach to managing pests by combining biological, cultural, physical, and chemical tools in a way that minimizes economic, health, and environmental risks. New IPM products and methods are developed and extended to producers to maximize yields. On-farm trials on IPM were evaluated in Bundi watershed, Madhya Pradesh, which clearly demonstrated that IPM encompassing suitable varieties, clean cultivation, scouting through pheromone traps, use of NPV against

Table 12.13 Magnitude of deficiency of micronutrients in the soils of various states in India (Sahrawat et al., 2007)

	% of Deficient fields		
Locations	*Zn*	*B*	*S*
Kurnool (Andhra Pradesh)	81	92	88
Dewas (Madhya Pradesh)	100	96	100
Bundi (Rajasthan)	67	72	72
Bharuach (Gujarat)	85	100	40
Gurgaon (Haryana)	89	93	60
Tirunelveli (Tamil Nadu)	100	100	100

Table 12.14 Effect of sulfur and micronutrient amendments in different field crops

	Crop yield (kg ha^{-1})		
Crop	*Control*	*Sulfur + micronutrients*	*% Increase over control*
Maize	2800	4560	79
Green gram	770	1110	51
Castor	470	760	61
Groundnut pod	1430	1825	28

Table 12.15 Yield and economic returns in response to application of nutrients in maize and groundnut in Andhra Pradesh

	Maize		*Groundnut*	
Treatment	*% Yield increase over FP*	*Economic returns (Rs ha^{-1})*	*% Yield increase over FP*	*Economic returns (Rs ha^{-1})*
Farmer's practice (FP)	–	13931	–	12490
FP+S	26	17228	12	13660
FP+Zn	33	17479	27	14780
FP+B	33	18354	20	14850
FP+S+B+Zn	49	19429	48	16830
FP+S+B+Zn+N+P	75	21766	78	19520

Table 12.16 Effect of micronutrient application on rainfall use efficiency in various field crops in Andhra Pradesh and Madhya Pradesh, India

	Rainwater use efficiency (kg mm^{-1} ha^{-1})	
Crop	*Farmers' practice*	*Farmers' practice + micronutrients*
Andhra Pradesh (Kurnool, Mahabubnagar and Nalgonda districts)		
Maize	5.2	9.2
Groundnut	1.6	2.8
Mung bean	1.7	2.9
Sorghum	1.7	3.7
Madhya Pradesh (Vidisha district)		
Soybean	1.4	2.7

lepidopteron pests, and installing bird perches resulted in yield advantage of 18% and increased net returns by 39% in green peas compared with practice of chemical control alone (Table 12.17).

12.7.6 Crop intensification: A case study from guna watershed, Madhya Pradesh

The practice of fallowing Vertisols and associated soils in Madhya Pradesh has decreased after the introduction of soybean. However, estimates are that about 2.02 M ha of cultivable land is still kept fallow in Central India, where there is a vast potential for having crop during *kharif* season. However, the survey indicated that the introduction of *kharif* crop delays the sowing of post-rainy crop and frequent waterlogging of crops during *kharif* season, which is a major problem forcing farmers to keep the cultivable lands fallow. Under such situations, ICRISAT demonstrated the avoidance of water logging during initial crop growth period on Vertisols by preparing the fields to BBF along with grassed waterways. Simulation studies using SOYGRO model showed that early sowing of soybean in seven out of 10 years was possible by which soybean yields can be increased three-fold along with appropriate nutrient management. Hence, evolving timely sowing with short-duration soybean genotypes would pave the way for successful post-rainy-season crop where the moisture carrying capacity is sufficiently high to support successful post-rainy-season crop. Yield maximization and alternate crops can be focused on post-rainy season, as there is assured moisture availability in Vertisol regions. On-station research was initiated with Indian Institute of Soil Science (IISS), Bhopal, to address issues related to soil, water, and nutrient management practices for sustaining the productivity of soybean-based cropping systems in Madhya Pradesh. Then, the conceptual best-bet options were scaled up in farmers' fields, and yield advantages to the tune of 30% to 40% over the traditional system were recorded.

On-farm soybean trials conducted by ICRISAT involving improved land configuration (BBF) and short-duration soybean varieties along with fertilizer application (including micronutrients) showed a yield increase of 1,300 to 2,070 kg ha^{-1} compared with 790 to 1,150 kg ha^{-1} in Guna, Vidisha and Indore districts of Madhya Pradesh. Similarly, soybean varieties evaluated were Samrat, MAUS 47, NRC 12, Pusa 16, NRC 37, JS 335, and PK 1024, out of which performance of JS 335 was better in Guna watershed of Madhya Pradesh. Increased crop yields (40%–200%) and incomes (up to 100%) were realized with landform treatment, new varieties, and other best-bet management options.

Table 12.17 Effect of IPM on crop productivity and net returns in green peas, Bundi watershed, Rajasthan.

Technology	*Cost of cultivation (Rs ha^{-1})*	*Cost of pest management (Rs ha^{-1})*	*Yield (t ha^{-1})*	*Net returns (Rs ha^{-1})*
Farmers' practice	8520	1800	3.53	10870
IPM	7800	1080	4.16	15070

12.7.7 Crop diversification with supplemental irrigation

The primary constraints to food security in developing countries are low productivity per unit area, shrinking land and water sources available for cropping, and escalating costs of crop production. Under these circumstances, crop diversification can be a useful means to increase crop output under different settings of available resources either through broadening the base of the system by adding more crops coupled with efficient management practices or replacing traditional crops with high-value crops. Crop diversification allows realization of the real value of improved water availability through watershed programs either through growing high-value crops like vegetables or a larger number of crops with supplemental irrigation. However, crop diversification takes place automatically from traditional agriculture to high-value/commercial agriculture at the field level once the water availability is improved. On-farm survey in Ringnodia watershed in Madhya Pradesh revealed the spread of high-value crops like potato, coriander, garlic, etc., and an increase in net income from farming activities once the scope for supplemental irrigation was established in the watershed (Table 12.18).

12.7.8 Crop diversification with chickpea in rice fallows

It is estimated that about 11.4 M ha of rice fallows are available in India. The amount of soil moisture remaining in the dry season after rice crop is usually adequate for raising a short-duration legume crop. Despite low yields, legumes grown after rice due to progressively increasing biophysical stresses, their low-cost of production, and higher market prices often result in greater returns to the farmer. Thus, the twin benefits of income and nutrition could be realized from legumes rather than from rice in spite of moderate yields of legumes. Introduction of early-maturing cool-season chickpea in the rice fallows by addressing the crop establishment constraints should certainly improve cropping intensity and sustainability of the system. Main constraints to the production of legumes in rice fallows are low P in the soil, poor plant establishment, low or absence of native rhizobial population, root rot, and terminal drought. On-farm trials in eastern states of India on early-maturing chickpea in rice fallows with suitable best-bet management practices revealed that chickpea grain yields in the range of 800–850 kg ha^{-1} can be obtained.

Table 12.18 Crop diversification with high-value crops with supplemental irrigation in Ringnodia watershed, Madhya Pradesh.

Crops	*Area covered (ha)*	*Yield (t ha^{-1})*	*Net income (Rs ha^{-1})*
Potato	8.3	17.5	29130
Onion	1.0	25.2	42000
Garlic	1.5	7.6	15750
Hybrid tomato	1.5	66.8	55000
Coriander	2.9	6.1	12700

Table 12.19 Effect of seed priming with sodium molybdate on the performance of chickpea in rice fallows with residual moisture.

	Chickpea yield (kg ha^{-1})		
States	*Control*	*Seed priming with mo*	*Yield advantage (%)*
Madhya Pradesh	814	917	12.7
Uttar Pradesh	2053	2207	7.5
Orissa	284	323	13.7
Jharkhand	664	663	–
West Bengal	309	317	2.6

Table 12.20 Effect of short-duration rice varieties in the rice + rice fallow chickpea system in rainfed uplands.

State	*Varieties*	*Yield (kg ha^{-1})*	*Yield advantage* (%)*
Bihar	Kalinga 3, Vandana, Tulasi	032	144
Eastern Uttar Pradesh	NDR 118, Narendra 97	3613	75
Orissa	Nilagiri, Chandeswari, Vandana	2940	125

*Over check or traditional varieties.

Molybdenum (Mo) deficiency is considered rare in most agricultural cropping areas. However, our on-farm research since 2002 has suggested that in the acid soils of rice fallows, Mo is relatively unavailable, and nodulation, growth, and yield of chickpea can be improved by providing small amounts of Mo (Kumar Rao et al., 2008). The study revealed that seed priming with sodium molybdate resulted in a yield advantage of 2.6% to 13.7% in rice fallow chickpea compared with control (Table 12.19). It is assumed that residual soil moisture after the harvest of rice in target regions could be 100 mm in the soil profile and hence moisture-use efficiency of rice fallow chickpea was calculated to be in the range of 8.0 to 9.0 kg ha^{-1} mm^{-1}.

In a few cases, delayed harvest of rice affects the sowing of chickpea and its grain yield due to terminal drought. Hence to address this issue, on-farm trials were conducted with sowing of short-duration rice varieties during the rainy season. The results showed that sowing of Kalinga 3, Vandana, and Tulasi in Bihar, NDR 118 and Narendra 97 in eastern UP, and Nilagiri, Vandana, and Chandeswari in Orissa resulted in increased rice grain yield and facilitated timely sowing of chickpea in rice fallows (Table 12.20).

12.8 CONCLUSIONS

Rainfed environments in India have great potential to contribute to increasing agricultural production as evidenced by the large yield gaps between potential and actual yields realized by the farmers. ICRISAT and its consortium partners across years of experience have developed the integrated watershed management approach, which has demonstrated promising results in enhancing crop productivity and efficient use of natural resources under both on station and on-farm watersheds with local community participation. The major contributions to productivity enhancement came from adoption of improved crop varieties and integrated nutrient management and their interaction with soil and water conservation practices. Integrated pest management practices contributed toward reducing the cost of production and protecting the environment. Water harvesting in ponds and recharging of groundwater supported production of high-value crops with supplemental irrigation. Crop diversification and intensification took place automatically at field level once the water availability was established, which in turn enhanced the system productivity and rainfall-use efficiency. The adoption of this new approach to technology development and adoption needs to be promoted to benefit a large number of farmers.

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