CONSERVATION FARMING

Enhancing Productivity and Profitability of Rainfed Areas

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In-situ Water Management: Key to Rural Prosperity and Sustainable Development through Watershed Management in Rainfed Areas

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Introduction

Over the past 20 years, the proportion of the world's hungry people has declined from one-fifth to one-sixth, while the absolute number of hungry people has fallen slightly. The problem is acute in Asia, where most of the 852 million poor in the world who are malnourished live, particularly in India (221 million) and China (142 million (Sanchez et al. 2005). Agriculture is the main source of livelihood for more than 75% of the poor in Asia, who are mostly concentrated in rainfed areas. It is estimated that about 80 per cent of the world's agricultural lands are rainfed, contributing to about 60 percent of the global food production. The status of rainfed agriculture determines the well being and poverty of millions of these people.

Water is a very scarce and critical natural resource and a major constraint to growing food crops and providing livelihood support to rural populations in rainfed regions of the developing world. Rainfall in the semi-arid tropics (SAT) generally occurs in short torrential downpours. Most of the water is lost as runoff, eroding significant quantities of precious topsoil. Current rainwater-use efficiency for crop production is low, ranging from 30 to 55 per cent; meaning that annually a large percentage of seasonal rainfall is lost either as surface runoff or deep drainage. Groundwater levels are depleting in the region and most rural rainfed areas are facing water scarcity and drinking water shortages in the summer.

Adding to the problem is land degradation, whose extent has greatly increased in recent times due to burgeoning population and better ways of exploiting natural resources. Rainfed regions thus present a grim picture of water scarcity, fragile ecosystems, drought and land degradation due to soil erosion by wind and water, low rainwater-use efficiency, high population pressure, poverty, low investments in water use efficiency measures and inappropriate policies (Rockström et al. 2007).

Though governments have assigned priority to rainfed farming, actual improvements in productivity and incomes have been far from satisfactory. Over the past three decades, systematic research efforts by national and international agricultural research institutions have led to the development of useful technologies in standard crop husbandry, appropriate choice of crops, varieties and cropping systems. However, the inability to conserve rainwater during times of abundance is the root of nonsustainable rainfed farming and livestock husbandry.

In-situ moisture conservation is a vital component of improved rainfed crop production technology. While earlier efforts focused on the construction of bunds across slopes to control erosion and reduce soil loss, rather than on increasing crop yields through additional moisture conservation, the emphasis has shifted towards improving moisture through field-based practices such as land surface configuration, tillage, amendments, etc. However, *in-situ* moisture conservation practices alone may not greatly benefit farmers.

Maximum benefits can accrue from moisture conservation practices provided they are implemented in an integrated watershed framework adopting a holistic and integrated genetic and natural resource management (IGNRM) approach (Wani et al. 2002a). This paper discusses the result of ICRISAT's promising *in-situ* moisture and *ex-situ* conservation practices as crucial components of integrated watershed management leading to improved productivity and reduced land degradation of SAT soils.

In-situ Water Management Strategies

The great variability in rainfall in the SAT has a paradoxical twist to it. Poor infiltrability of most soils lead to water shortages as well as destructive floods. Recent cases of extreme events leading to high runoff, soil loss and flash floods damaging the land resource base and reducing productivity have been reported. In Kurnool in Andhra Pradesh, June 2007 saw about 420 mm of rainfall as against a normal monthly rainfall of 77 mm. Similarly, very heavy rainfall events were recorded in Mumbai and Hyderabad (Fig. 1) during this decade. As a result of high runoff and soil loss, there is a need to identify soil and water management strategies which can conserve resources and increase their use efficiency. Research on *in-situ* soil and water management systems at ICRISAT research station and on-farm watersheds has resulted in the development of improved management practices, some of which are discussed.

Moisture Conservation on SAT Vertisols

Vertisols in the SAT represent a vastly underutilized soil resource. Double cropping on these soils can lead to better resource utilization and efficiency. However, due to their sticky

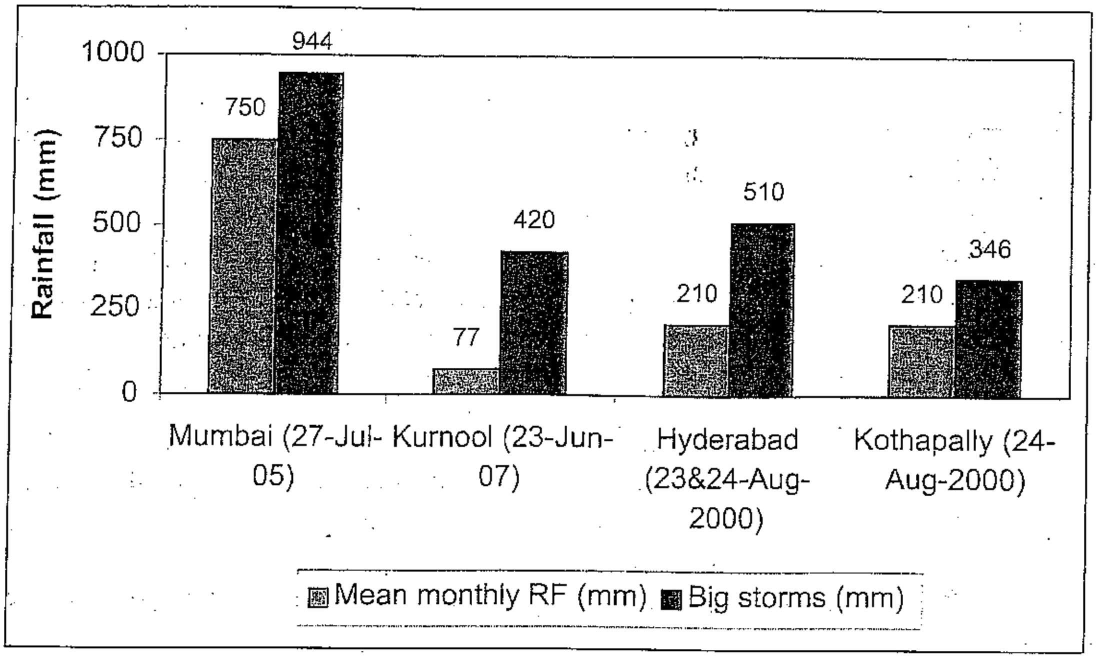

Fig. 1. Extreme rainfall storms at various locations in India

nature when wet and hardness during dry periods, these soils are traditionally kept fallow during the rainy season and cropped during the postrainy season. Our recent studies using satellite imagery and ground truthing revealed that 2.0 m ha Vertsols are kept fallow during the rainy season in Madhya Pradesh (Wani et al. 2002b).

An improved package of land and water management practices to increase the productivity of Vertisols has been developed at ICRISAT (Kampen 1982 and El-Swaify et al. 1985), whose essential components are:

- Land smoothing and installation of drains to ensure effective surface drainage and runoff disposal from the field;
- A well-designed, semi-permanent or permanent broad-bed furrow (BBF) system;
- Performing primary tillage operations for both postrainy and rainy season crops immediately after harvesting the previous season's crop, when the soil has adequate moisture and is friable; and
- Shallow cultivation of land (only beds) whenever effective rainfall (<20 mm) is received.

These *in-situ* land and water management practices alleviate the physical constraints of Vertisols. They improved soil aeration and workability, reduced soil erosion and runoff and facilitated safe disposal of excess runoff. Combined with other improved crop management practices, it resulted in high stable crop yields (Fig. 2). Compared to traditional systems, the improved system also reduced runoff, peak runoff rate, soil loss and produced higher grain yield per unit of water (Table 1). Some of the salient results of the long-term Vertisols studies (1976-2006) at ICRISAT are:

- Average productivity over the last 30 years in the improved system has been 5.1 t ha^{-1} compared to 1.1 t ha^{-1} in the traditional system;
- The improved system's carrying capacity of about 21 persons ha^{-1} yr^{1} exceeds that of the traditional system (4.6 persons ha^{1} yr^{-1});
- The improved system sequestered more carbon (335 kg ha^{-1} y^{-1}) leading to improved soil and environment quality;
- It saw 71% of the rainfall being used for crop production as against only 36% in the traditional system; and
- Mean annual soil loss in the improved system was only 1.5 t ha^{-1} compared to 6.4 t ha^{-1} under the traditional system (Wani et al. 2003a, in press).

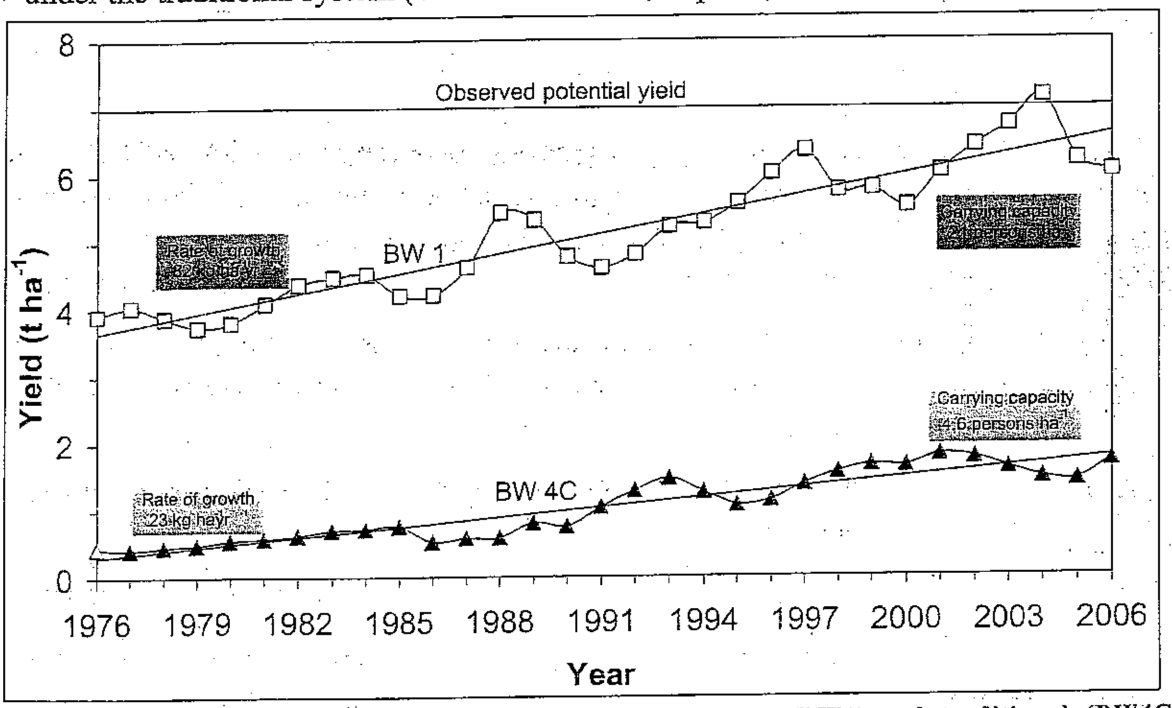

Fig. 2. Three-year moving average of grain yield under improved (BW1) and traditional (BW4C) technologies on Vertisol watersheds at ICRISAT, 1976-2006

Moisture Conservation on SAT Alfisols

Alfisols cover about one-third of the land in the SAT. Despite their importance in food production, their productivity has remained low and unstable owing to climate- and soil-related constraints. Moisture conservation on Alfisols is hindered by poor soil structure leading to surface sealing and crusting, low-water holding capacity, and argillic horizon. The dry soil

Table 1: Effect of improved and traditional technologies on runoff, soil loss, rainfall productivity and rainfall use efficiency (1974-2006)

Parameters	Improved Management	Traditional management
Mean seasonal rainfall (mm)	780	780
Mean seasonal runoff (mm)	102	178
Mean runoff as % of rainfall	12	21
Peak runoff rate ($m^3 s^{-1} ha^{-1}$)	0.18	0.22
Mean annual soil loss ($t ha^{-1}$)	1.51	6.46
Production per unit rainfall ($kg mm^{-1}$)	5.6	1.2
Rainfall used by crops (%)	71	38
Carbon lost through soil loss ($kg ha^{-1}$) during last 33 years	198	853

makes seedbed preparation very difficult until the rains soften the soil. Combined, these factors leave a very narrow 'window of opportunity' for successful establishment of crops. Furthermore, farmers in the SAT usually have very limited resources at their disposal.

There are clear indications, however, that most SAT Alfisols possess a much high productivity potential than currently obtained through traditional farming. The results of promising research on *in-situ* soil and water management systems for improving productivity are discussed below.

For Alfisols with slopes of more than 2.0%, a modified contour bund system has been found to be ideal. A traditional contour bund is modified by installing gated outlets in the lower field sections, land smoothing and planting on grade instead of on contour. This allows runoff water to be stored above the bund for a certain period and then released at the desired rate through the gated outlet (Fig. 3). Most of the erosional sediments are deposited so that relatively sediment-free water drains through the outlet and releasing excess water

Fig. 3. A traditional (left) and modified contour bund with a gated outlet

Table 2: Comparison of grain yield, runoff and soil loss from modified and traditional contour bund systems, ICRISAT

Land management system	Crop	Grain yield ($t\ ha^{-1}$)	Runoff (mm)	Soil loss ($t\ ha^{-1}$)
Modified contour bund	Sorghum/	3.02		
	pigeonpea	0.97	160	0.92
	Pearl millet/	2.73		
	pigeonpea	1.01		
Traditional contour bund	Sorghum/	2.52		
	pigeonpea	0.71	75	0.97
	Pearl millet/	2.23		
	pigeonpea	0.73		

considerably reduces waterlogging. This system consistently produced higher crop yields (35% higher than the traditional system) and reduced runoff and soil loss (Table 2) at ICRISAT.

For lands with slopes less than 2.0%, contour cultivation with conservation furrows or dead furrows at 5-m intervals were found to be quite effective in reducing runoff and soil loss and in increasing crop yields. Raised land configurations (BBF and narrow ridge and furrow) offered no particular advantages over contour cultivation in terms of runoff, soil loss and yield.

Scoops have been found effective in improving *in-situ* soil and water conservation in SAT Alfisols (Fig. 4). The equipment used to make small scoops or pits on the soil surface is simple, inexpensive and can easily be made with local material. Scoops serve the purpose of providing more time for rainwater to infiltrate into the soil and also to reduce soil loss by trapping eroded sediments that would otherwise be lost from the field. A study conducted at ICRISAT revealed that scoops reduced seasonal runoff by 69% and soil loss by 53% compared to flat land surfaces. Pearl millet yield increased by 42% over the control.

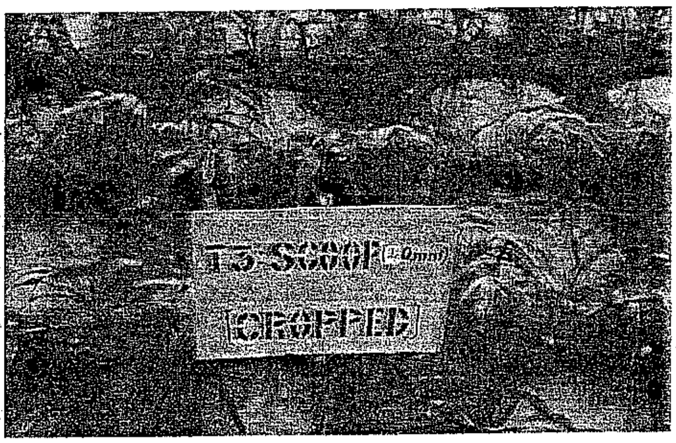

Fig. 4. Scoops on Alfisols with a sorghum crop

Off-season tillage on Alfisols should be done whenever feasible to increase rainwater infiltration and reduce weeds. It minimizes the evaporation of stored water by a mulching effect and allows the acceleration of planting operations, thereby permitting earlier sowing and extension of the growing season. Experiments at ICRISAT reveal that in most of the years, off-season tillage has been effective in improving soil moisture and increasing crop yields.

In the long term, a farming systems design with assured generation and maintenance of favorable structural conditions would be critical to the successful use of Alfisols. The incorporation of beneficial organic matter can achieve favorable soil organic matter content and in turn a better structure in SAT Alfisols. The use of organic matter as surface mulch and its incorporation into the soil in subsequent years has been useful in achieving favorable rainfall infiltration, reducing soil erosion and achieving structural stability. Studies conducted at ICRISAT reported that a mulch rate of 10 t ha^{-1} reduced seasonal runoff by 74% and soil loss by 80% compared with a no mulch treatment. Yields of sorghum and pigeonpea increased significantly with this treatment (Cogle and Rao 1994).

Prioritized *In-situ* Water Conservation Practices for Different Rainfall Regions

The suitability of an *in-situ* soil and water management practice depends upon soil, topography, climate, cropping system and farmer's resources. Based on our experience, general guidelines on the suitability of different *in-situ* soil and water conservation practices under different rainfall conditions are given in Table 3.

Ex-situ Water Conservation Practices

Ex-situ water conservation practices are crucial in improving surface and groundwater availability in rainfed areas. After *in-situ* conservation measures the excess water to be taken out safely from fields, the excess runoff needs to be harvested and stored in a watershed to enhance groundwater recharge or be used as supplemental irrigation. Of the various water harvesting structures (Fig. 5) tried out in on-farm watersheds as part of ICRISAT's integrated watershed management approach, low-cost structures (Fig. 6) were found to be economical and effective in improving groundwater (Wani et al. 2003b). Following are some characteristics of low-cost structures:

- In most situations, small earthen structures have been found to be most economical for recharging groundwater. The unit cost of water storage in small earthen check dams ranged between Rs 12 and Rs 52 per cu. m, compared to between Rs 38 and Rs 92 per cu.m in masonry structures.

Table 3: Rainfall-based prioritized *in-situ* soil and water conservation measures

Seasonal rainfall (mm)			
<500	500-700	750-1000	>1000
• Contour cultivation with conservation furrows • Ridging • Sowing across slopes • Mulching • Scoops • Tied ridges • Off-season tillage • Inter-row water harvesting system • Small basins • Contour bunds • Field bunds • Khadin	• Contour cultivation with conservation furrows • Ridging • Sowing across slopes • Scoops • Tide ridges • Mulching • Zingg terrace • Off-season tillage • BBF • Inter-row water harvesting system • Small basins • Modified contour bunds • Field bunds • Khadin	• BBF (Vertisols) • Conservation furrows • Sowing across slopes • Tillage • Lock and spill drains • Small basins • Field bunds • Vegetative bunds • Graded bunds • Nadi • Zingg terrace	• BBF (Vertisols) • Field bunds • Vegetative bunds • Graded bunds • Chos • Level terraces

Fig. 5. An earthen check dam at Lalatora watershed, Madhya Pradesh, India

Fig. 6. A low-cost mini percolation tank (earthen structure) at Adarsha watershed, Kothapally, Andhra Pradesh

- A greater number of small and medium earthen structures than masonry structures could be constructed with the project money, benefiting more wells and farmers (equity of benefits).
- Small earthen structures are easy to construct and maintain by the local community, thereby improving the sustainability of the structures. Most masonry structures need the help of engineers.

In India, heavy investments are being made in the construction of groundwater recharging structures through various watershed programs. Currently, masonry type structures are being constructed which are expensive and difficult to maintain. Low-cost structures can play a vital role in recharging groundwater.

Indigenous *In-situ* Moisture Conservation Practices

There is great potential in using some of the promising indigenous *in-situ* moisture conservation technologies in the rainfed SAT. Many of them are based on long-term experiences of farmers and tested over centuries as traditional technologies. These practices are eco-friendly, cost effective, easy to implement, acceptable to user groups and can also be integrated with other improved natural resource management practices. Among the conservations practices for rainfed areas are the use of loose stone water weir, stone bund on hill slope, vegetative barrier with Agave, sand mulching, nala check with soil filled in cement bags, sand bags as gully check, conservation bench terrace, gravel mulching, loose boulders checks, etc.

An Innovative Watershed Management Model

A new consortium watershed management model for the efficient management of natural resources and improving rural livelihoods has emerged from ICRISAT's experiences in on-farm watershed-based research with its partners. The consortium approach revolves around four Es (empowerment, equity, efficiency and environment), which are addressed by adopting specific strategies prescribed by four Cs (consortium, convergence, cooperation and capacity building). The consortium strategy brings together institutions — scientific, non-government and farmers groups - for knowledge management convergence. Cooperation enjoins all stakeholders to harness the power of collective action. Capacity building engages in empowerment for systems sustainability (Wani et al. 2006).

The model uses a participatory, multi-disciplinary and multi-institutional approach with the aim of exploiting the synergies of various partners for the benefit of all the stakeholders, including farmers. It is characterized by site-specific solutions, a consortium of institutions for technical backstopping, continuous monitoring and evaluation by stakeholders, community and women empowerment and environmental protection. It has facilitated the exchange of knowledge and technologies among partners. Implementing integrated watershed management practices at several locations in Asia has resulted in reduced land degradation and improved rural livelihoods through increased incomes (Wani et al. 2003b).

The approach begins with the implementation of *in-situ* and *ex-situ* soil and water management practices leading to improved moisture in the fields and greater availability of groundwater (Fig. 7). Water availability stabilizes crop productivity at increased yield levels, the area under cultivation improves, cropping intensity increases and there is diversification with vegetables and high-value crops.

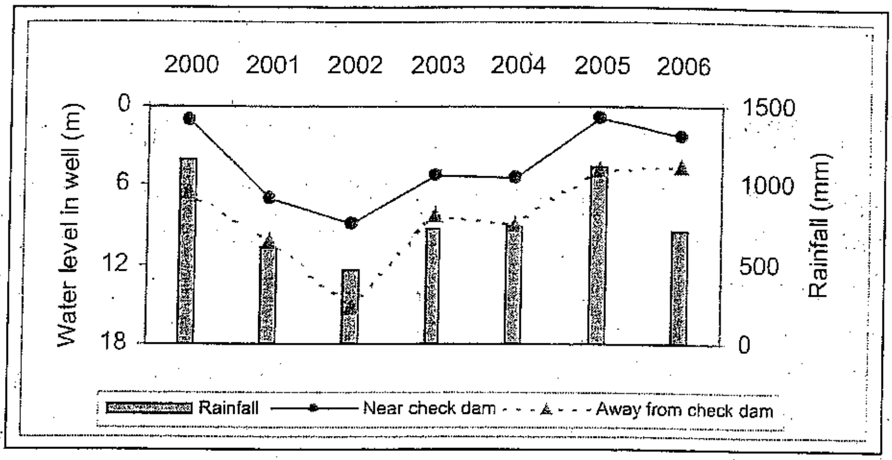

Fig. 7. Groundwater level at Adarsha watershed, Kothapally during 2000-06

For example at Kothapally watershed in Andhra Pradesh, the number of farmers growing cash crops and high-value crops increased substantially after the watershed program was implemented (Fig. 8) (Shiferaw et al. 2006). It also provided employment opportunities to local people in the watershed area, improved water availability which increased the area under double cropping and also enhanced crop productivity largely due to the adoption of integrated soil, water, nutrient and pest management options. Enhanced cropping intensity and diversification generated extra off-season employment in the village, resulting in substantially less migration. Crop diversification with more water-efficient crops helped farmers move away from crops with high water requirement. Thus moisture conservation activities essentially provided the foundation for other improved watershed interventions.

In Kothapally, currently about 100 farmers collectively send 10 tons of fresh vegetables everyday to retail vendors in Hyderabad and obtain Rs 2000 more per ton than the prevailing

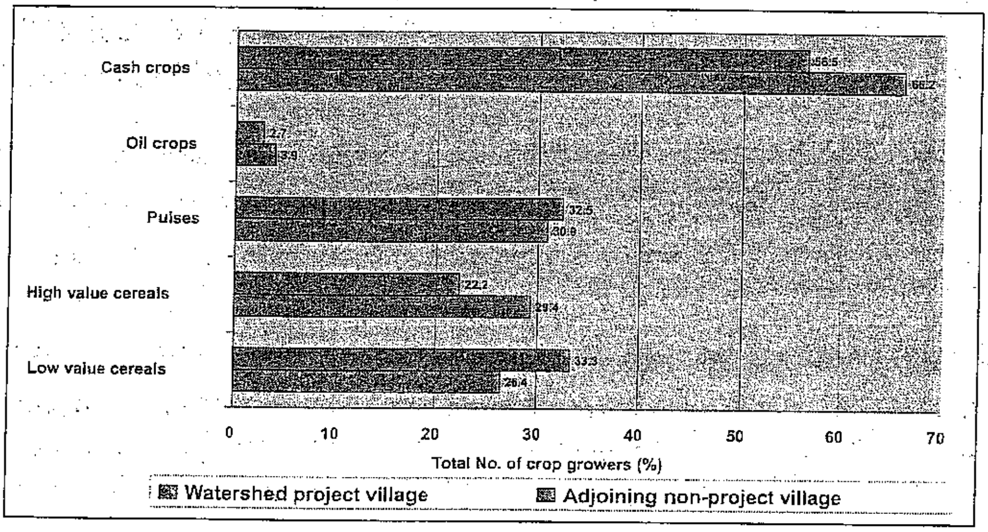

Fig. 8. Effect of watershed management on commercialization of production, Kothapally, AP, India

wholesale price (Wani et al. 2006). Farmers in the developed watershed marketed more produce and earned more incomes through the sale of surplus produce. Watershed development benefited farmers not only during normal rainfall years but also during drought years. In fact, during the 2002 drought year, the total amount as well as the value of produce marketed (Rs 15,500) was significantly higher compared to that in the non-project village (Rs 9,500).

Conclusion

Rainwater harvesting in conventional watershed programs have been skewed in favor of rich farmers. In order to improve community participation through tangible economic benefits to small and marginal farmers, *in-situ* rainwater conservation measures have been found very effective. However, such conservation is futile unless it is combined with a holistic IGNRM approach for an efficient convergence of good cultivars with soil, water, nutrient and pest management options. ICRISAT's innovative consortium approach to managing community watersheds has built collective action by addressing equity issues using field-based rainwater management and low-cost water harvesting structures throughout the toposequence in a watershed. By converging biophysical interventions with suitable social measures, good community-based organizations (CBOs) not only enhanced the tangible economic and environmental benefits for farmers but also improved the sustainability of watershed programs. *In-situ* rainwater management proved to be an important key for the sustainable development of rainfed areas through integrated watershed management approach.

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