13. Integrated Water Resource Management for Increasing Productivity and Water Use Efficiency in the Rain-fed Areas of India

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Abstract

Climate variability is the major cause of fluctuations in food production in the semi-arid tropical (SAT) regions of India leading to food insecurity, malnutrition and poverty. Although the total amount of rainfall in the SAT regions is adequate to meet the water requirements of the crops and cropping systems, its erratic distribution results in periods of excess and deficit water availability, leading to low productivity and degradation of natural resources. Therefore, an integrated water resources management approach comprising *in-situ* water conservation, harvesting of excess water in ponds and groundwater recharging and its efficient use through appropriate supplemental irrigation methods, improved crop varieties and cropping systems, balanced nutrition of crops, crop diversification and intensification with high value crops and crop protection is needed to produce more food and income per unit of rainfall. The paper describes the achievements made by ICRISAT in collaboration with its partners in enhancing crop productivity and rainfall use efficiency by implementing improved technologies in on-station and on-farm community watersheds in India.

Keywords. Rain-fed agriculture, community watersheds, integrated genetic and natural resource management, food security, rural livelihoods.

Introduction

Water is the inherently limiting resource in the semi-arid tropics (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 increased 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 that are dependant mainly upon natural resources can be farfetched. Water is the key factor and through efficient and sustainable management of water resources, entry could be made to break the nexus (Wani et al. 2003). In rain-fed 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, and nutrient and pest management practices.

This paper describes an integrated water resource management approach adopted by ICRISAT to enhance the goal of increasing crop production and improving rural livelihoods through sustainable and efficient use of water resources in rain-fed areas of India and elsewhere.

An Integrated Approach for Enhancing Productivity and Water Use Efficiency

ICRISAT has adopted an integrated genetic and natural resource management (IGNRM) approach to enhance agricultural productivity in rain-fed areas, which is a powerful integrative strategy of enhancing agricultural productivity. ICRISAT has learnt that converging different agro-technologies at field level showed greater impact on agricultural productivity and water use efficiency in the farmers' holdings and rather than compartmentalized testing of individual technologies. This was achieved through adoption of integrated watershed management approach, which 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 to alleviate poverty. In our on-station and on-farm research, integrated package of technologies were evaluated on watershed scale in India. The contribution of both individual and combined effects of improved technologies on productivity enhancement and water use efficiency is presented here.

Enhancing Productivity and Water Use Efficiency in Watersheds

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 basic component of land and water management for conserving 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 bed 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 per cent. BBF system helps for safe disposal of excess water through furrows when there is high intensity rainfall with minimal soil erosion, while 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 per cent) and permeable soils, where farming operations such as ploughing, sowing are carried out along the contour. The system helps to reduce the velocity of runoff by impounding water in series of depressions and thus decrease 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 per cent slope. It consists of 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 moderate slope (0.2-0.4 per cent). It comprises 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 35 per cent yield increase in soybean during rainy season and yield advantage of 21 per cent in chickpea during postrainy season when compared with the farmers' practice. Similar yield advantage was recorded in maize and wheat rotation under BBF system (Table 1). Yield advantage of 15 to 20 per cent was recorded in maize, soybean and groundnut with conservation furrows on Alfisols over farmers' practices of Haveri, Dharwad and Tumkur watersheds in Karnataka (Table 2). Yield advantage in terms of rainfall use efficiency (RUE) were also reflected in cropping system 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 to 8.2 to 8.9 kg ha^{-1} mm^{-1} with flat on grade system of cultivation on Vertisols (Table 3).

Table 1. Effect of land configuration on productivity of soybean and maize-based system in the watersheds of Madhya Pradesh, 2001-05.

Watershed location	Crop	Grain yield (t ha^{-1})		
		Farmer's practice	BBF system	% Increase in yield
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 2. Effect of improved land and water management on crop productivity in Sujala watersheds of Karnataka during 2006-07

Watershed	Crop	Grain yield (t ha^{-1})		
		Farmers' practice	Conservation furrows	% increase in yield
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 3. Rainfall use efficiency of different cropping systems under improved land management practices in Bhopal, Madhya Pradesh, India

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

- = Sequential system; / = Intercrop system.

Water Harvesting and Groundwater Recharge

In medium to high rainfall areas, despite following the *in-situ* moisture conservation practices, rainfall runoff due to high intensity storms or water surplus after filling up the soil profile, does exists. 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 postrainy season. For example, in Adarsha watershed in Kothapally village in Andhra Pradesh various types of water harvesting structures were built with the participation of farmers (Fig. 1). Water harvesting in these structures resulted in increase in groundwater levels (Fig. 2). 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 postrainy season crop 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 number of farmers than the large size structures, which benefit only a few farmers.

Figure 1. Water harvesting structure in Adarsha watershed Kothapally, Andhra Pradesh.

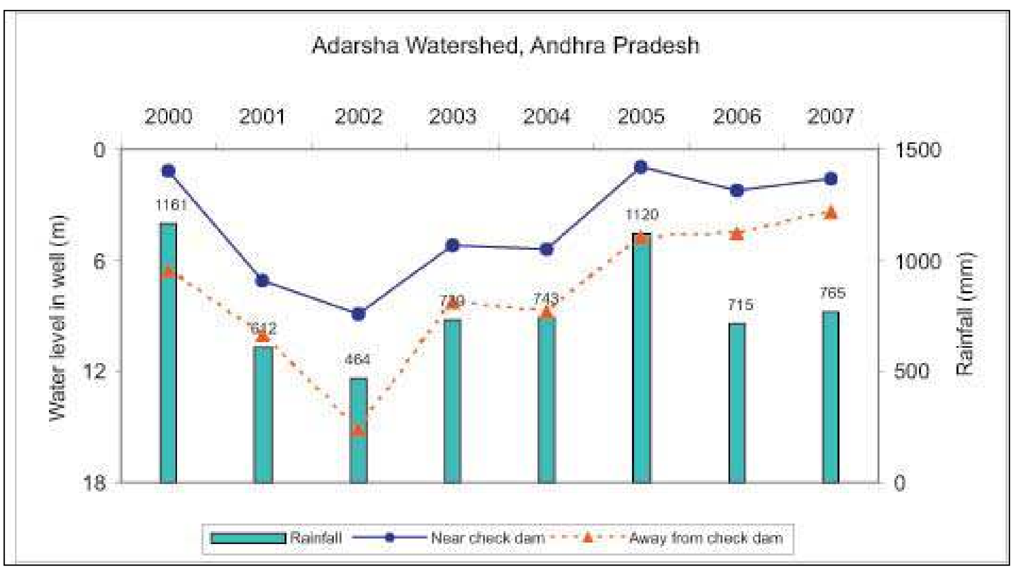

Figure 2. Impact water harvesting structures on groundwater levels in Adarsha watershed, Kothapally, Andhra Pradesh.

Efficient Use of Supplemental Irrigation Water

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 in two parts – first, the conveyance of water from its source to the field and second, application of water in the field.

Conveyance of Water to the Field*:* In the most SAT areas, the water is carried to cultivated fields by open channel, which are usually unlined and therefore, a large amount of water is lost through seepage. On SAT Vertisols, generally there is no need of lining the open field channels as the seepage losses in these soils are low mainly due to very low saturated hydraulic conductivity in 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.

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 to narrow ridge and furrow, the BBF saved 45% of the water without affecting crop yields. Compared to 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 to that in uncultivated furrows. Shallow cultivation in moderately cracked furrows before the application of irrigation water, reduce the water required by about 27% with no significant difference in chickpea yields (Table 4).

Table 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

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 find out the most appropriate land surface configuration for the application of supplemental water. The wave-shape broad-beds and furrows with checks at every 20 m length along the furrows, was found to be most appropriate for efficient application of supplemental water and increasing crop yields. It was observed that the moisture distribution across the beds was uniform, in case of wave-shape broad-beds with checks compared to normal broad-bed and furrow (BBF) system. The sorghum yield in wave-shape broad-beds with checks was higher at every length of run compared to normal BBF (Table 5). It was found that when irrigation water was applied in normal BBF system on Alfisols, the center of the broad-bed remained dry. The centre 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). It was found that the narrow ridge and furrow system performed better than BBF system both in terms of uniform water application and higher crop yields. Therefore, for Alfisols, the wave-shape 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.

Table 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-shape 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

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 farm lands. 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 and Sharma, 2007). Implementation of these improved irrigation techniques can be used to save water, energy and increase crop yields. However, currently the use of these improved irrigation methods are limited, primarily due to the high initial cost. Favourable government policies and the availability of credit are essential for popularizing these irrigation methods.

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 rain-fed systems. Recent trials during rainy season conducted across Kolar and Tumkur districts of Karnataka, India, revealed that mean yield advantage of 52 per cent 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 farmers' management (Table 6). 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 per cent 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, due to improved management that included balanced application of nutrients.