Sustainable Management of Rainwater through Integrated Watershed Approach for Improved Rural Livelihoods

Suhas P. Wani[1] and Y.S. Ramakrishna[2]

[1]*International Crops Research of Institute for Semi-Arid Tropics, Patancheru, Andhra Pradesh, India*

[2]*Central Research Institute for Dryland Agriculture, Hyderabad, Andhra Pradesh, India*

Abstract

Rainwater, an essential resource for growing food also plays an important role in providing livelihood support for rural people in the rain-fed regions. Eighty percent of the world's agricultural land is rain-fed and contributes to about 60 percent of the global food production. An insight into the rain-fed regions shows a grim picture of water-scarcity, fragile ecosystems 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, poor infrastructure and inappropriate policies. The current rainwater use efficiency for crop production is low ranging between 30 and 45 %; thus annually about 300-800 mm of seasonal rainfall goes unproductive, lost either as surface run-off or deep drainage. The challenge, therefore, is to improve rural livelihoods through efficient and sustainable rainwater management technologies for increasing rain-fed productivity and thereby contribute to food and livelihood security. Watershed as an entry point acts as a beginning to address the issues of sustainable rainwater management for improving livelihoods. An innovative integrated farmer participatory consortium watershed management model developed by ICRISAT along with NARS partners is a holistic model unlike the earlier watershed approaches which were sectoral with emphasis only on the soil and water conservation measures. The integrated watershed approach uses new science tools, links on-station research to on-farm watersheds, provides technical backstopping through consortium of institutions with convergence of livelihood-based activities. The core theme of the model is sustainable natural resource management for increasing the farm productivity and improving the rural livelihoods. The approach covers issues starting with conservation of natural resources and ensures increased productivity and incomes through convergence of all necessary activities to achieve the good. In order to ensure equity for women and landless people, emphasis is put on development of common property resources as well as establishing micro-enterprises. This integrated watershed approach enables to have 'win-win' situations for sustaining productivity and improving livelihoods as it includes convergence of activities at various levels thus enhancing community participation and creating income-generating options. Successful results from on-farm integrated watersheds are discussed. However, the challenge is to scale up the approach to larger areas on sustainable basis. Lessons learnt from past watershed experiences are that we need to focus

on issues such as keeping the community interest for participation; institutions to continue activity for maintenance after the project activity ceases; maintaining the link between the watershed and supporting institutions for technical backstopping, appropriate policies for groundwater use and common property resources and innovative ways to merge common wastelands. Thus the lessons learnt from the integrated watershed management can help re-engineer suitable roadmaps for maximizing returns to investment on watershed programs. With ever changing policies and economies, improved institutional and policy support mechanisms in partnership with stakeholders especially the farmers, market links for products, value addition products for rural areas, infrastructure and suitable ways to meet the challenges for the target areas need to be addressed.

Introduction

Rainwater, a scarce and critical resource for growing food and providing livelihood support for rural populations, is under threat particularly in the arid and semi-arid regions of the world. Rainfed agriculture that constitutes the livelihood base for the vast majority of rural inhabitants (about 75 percent of the poor in south Asia, and about 80 percent of the population in east Africa) in the developing countries is a source of food security, and livelihoods. It is estimated that about 80 percent of the world's agricultural land is rainfed, contributing to about 60 per cent of the global food production. Rainfall in the semi-arid tropics (SAT) generally occurs in short torrential downpours. Most of this water is lost as run-off, eroding significant quantities of precious top soil. The current rainwater-use efficiency for crop production is low ranging from 30 to 45 percent; thus annually about 300-800 mm of seasonal rainfall goes unproductive, lost either as surface run-off or deep drainage. An insight into the rain-fed regions shows 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, poor infrastructure and inappropriate policies.

The ever-growing problems as burgeoning population, poverty, lack of improved varieties, poor knowledge base on improved farm technology, resource poor farmers, low farm productivity and income levels constitute major threat for progress towards sustainable development more so in the SAT. The SAT regions of the world, covering parts of 55 developing countries has over 1.4 billion population of whom 350 million are classified as rural poor (Ryan and Spencer, 2001). It is estimated that over the next 15 years most of the projected 1.1 billion increase in global population (from 6.1 billion in 2000 to 7.2 billion in 2015) will be in the developing countries (United Nations, 2001). A recent report published by the United Nations Population Fund projects a grim picture of constraints to sustainable development in the future for the countries experiencing rapid population growths (UNFPA, 2003). One billion of the world's poorest people living in SAT regions will be affected by water scarcity (Seckler *et al*. 1998; Ryan and Spencer, 2001). Uncertainty in rainfall and poor socio-economic condition of the farmers prevent them from making heavy investments in agriculture. To save the crops from drought during rainy season and to meet the water needs of the post-rainy season crop, farmers resort to groundwater exploitation resulting in recession of groundwater levels due to inadequate groundwater recharging facilities.

The poverty of Asia's poor is both a cause and a consequence of accelerating soil degradation and declining agricultural productivity. The challenge, therefore, is to develop sustainable and environment-friendly options to manage natural resources in this fragile ecosystem to increase the farm productivity and incomes of millions of poor farmers who are dependent on the natural resources for their survival. The way forward to address this gigantic task is by sustainable management of rainwater and other natural resources in a manageable land unit, which is a watershed.

Large Yield Gaps for Rain-fed Crops Between Potential and Current Productivity

Current productivity of rainfed crops in the SAT hovers around 1.0 t/ha. However, number of studies have shown that productivity of rainfed farming systems could be doubled or in some situations like in west Africa could even be quadrupled through adoption of improved soil, water, crop and nutrient management options (Rockstorm, 2004; Wani, 2004).

Crop growth simulation models in an integrated watershed management approach provide an opportunity to simulate the crop yields in a given climate and soil environment that can be used for yield gap and constraint identification. ICRISAT researchers have adopted DSSAT v 3.0 a soybean crop growth model to simulate the potential yields of soybean crop in Vertisols grown at different benchmark locations. Mean simulated yield obtained for a location was compared with the mean observed yield for a period of five years to calculate the yield gap. The results (Table 1) showed that there is a considerable potential to bridge the yield gap between the actual and potential yield through adoption of improved resource management technologies (Singh *et al.*, 2001).

Table 1. Simulated soybean yields and yield gap for the selected locations in India

Location	Mean simulated yields (kg ha^{-1})	Mean observed yield[1] (kg ha^{-1})	Yield gap (kg ha^{-1})
Primary zone			
Raisen	3050	-	-
Betul	2370	860	1510
Guna	1695	840	855
Bhopal	2310	1000	1310
Indore	2305	1120	1180
Kota	1250	1010	240
Wardha	3000	1040	1960
Secondary zone			
Jabalpur	2240	900	1350
Amaravathi	1620	940	680
Belgaum	1990	570	1420

[1] Mean of reported yields for five years.

Using the CROPGRO models of soybean and chickpea sequential system the potential yields, yield gap and water balance of the soybean-chickpea sequential system for selected benchmark sites showed that the average potential productivity of the soybean-chickpea system under rain-fed system ranged from 1390 to 4590 kg/ha across sites and yield gap of 200 to 3300 kg/ha for the system indicating the potential to increase productivity with improved management. Water balance analysis showed that on an average 35 to 70 percent of rainfall was used by the crop as evapotranspiration, whereas 25 to 40 percent was lost as surface run-off indicating the need for water harvesting for supplemental irrigation or recharging of groundwater (Singh *et al*., 2002).

Watersheds for Grey to Green Revolution

A watershed, a land unit to manage water resources is also a logical planning unit for sustainable resource management. Sustainable watershed management is the rational utilization of all the natural resources for optimum production to fulfil the present need without compromising the needs of future generations with minimal degradation of natural resources such as land, water and environment.

Innovative Participatory-Consortium-Approach-Watershed Model

Conventional watershed approaches in the past focussed only on soil and water conservation measures hence did not bring in much productivity gains or contributed to improve the rural livelihoods. A new model for efficient and sustainable management of natural resources in the SAT has emerged from the lessons learnt from long watershed-based research conducted by ICRISAT in partnership with National Agricultural Research Systems (NARSs) (Wani *et al.*, 2003a, d). The important components of the farmer participatory integrated watershed management model are:

- Farmer participatory approach through cooperation and not through contractual mode.
- Use of new scientific tools for management and monitoring of watersheds through linking of on-station and on-farm watersheds.
- A holistic system's approach to improve livelihoods of people and not merely conservation of soil and water compartmental approach.
- A consortium of institutions for technical backstopping of the on-farm watersheds.
- A micro-watershed within the watershed where farmers conduct strategic research with technical guidance from the scientists. Planned gradual shift from contractual mode of participation to consultative and collective mode of participation.
- Low-cost soil and water conservation measures and structures throughout the toposequence to achieve equity.
- 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 farms and private economic gains alongwith community-based soil and water conservation measures for ecosystem services.

- Minimize free supply of inputs for undertaking evaluation of technologies. Farmers are encouraged to evaluate new technologies themselves with empowerment.
- Continuous monitoring, evaluation and refinement of options by the stakeholders.
- Empowerment of community individuals and strengthening of village institutions for managing natural resources.

A Holistic System's Approach

In order to address the farm productivity and dependent rural livelihood issues, the strategy of participatory consortium model is to take the on-station research results to real-world on-farm watersheds for fine-tuning the technologies. The integrated genetic and natural resource management (IGNRM) strategy is a new paradigm to sustain and increase productivity and improve the rural livelihoods. The strategy encompasses integrated water and soil management alongwith integrated crop management. The process begins with the management of soil and water, which eventually leads to the development of other resources for enhancing productivity and incomes. Further scaling-up and scaling-out of the potential technologies are done for greater impact, which aims to create a self-supporting system essential for sustainability and development in the dry regions. As people's participation is critical for sustainable development and management of watersheds, a holistic approach converging the activities, which could improve livelihoods of rural people including landless dependent on natural resources, is adopted (Wani *et al.,* 2003d; Ramakrishna and Osman, 2004).

Increased Productivity through Improved Rainwater-use Efficiency in Rain-fed Regions: Improved *vs* Conventional Systems – Vertisol Watershed

In an improved system with improved soil, water and nutrient management options, the average productivity of maize/pigeonpea or sorghum/pigeonpea systems over 27 years was 4.7 t/ha, which indicates a carrying capacity of 18 persons/ha/yr, whereas the traditional system (post-rainy sorghum) with farmer adopted practices could yield only about 0.95 t/ha and have a carrying capacity of only 4 persons/ha/yr (Fig. 1). Alongwith this higher productivity, the improved system could also sequester more carbon (0.3 t/ha/yr) and improve soil quality (Wani *et al.,* 2003b). Most importantly, in the improved system 67 percent of the rainfall was used as green water (evapotranspiration) by the crops, 14 percent of the rainfall was lost as run-off and 19 percent as evaporation and deep percolation. In the traditional system only 30 percent of the total rainfall was used by the crops, 25 percent was lost as run-off and 45 percent as soil evaporation and deep percolation. The soil loss in improved system was only 1.5 t/ha compared to traditional system where the soil loss was 6.4 t/ha. Moreover, the improved system was gaining 78 kg/ha/yr in productivity indicating the sustainability towards attaining new state of equilibrium.

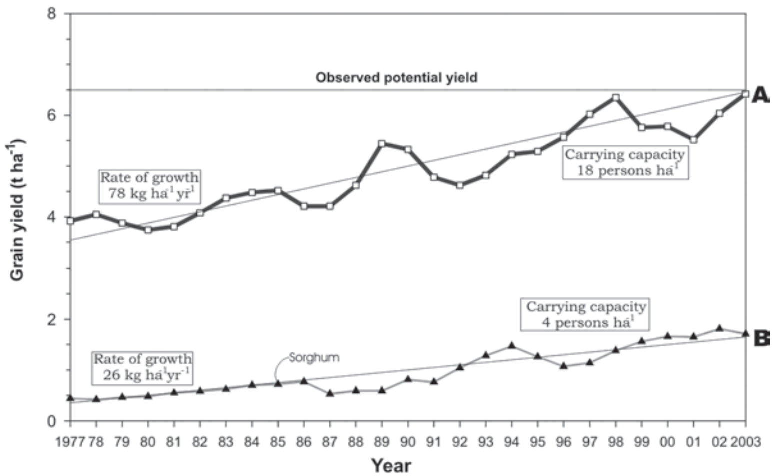

Figure 1. Average grain yields under improved (A) and traditional (B) technologies on a Vertisol watershed at ICRISAT (1977-2003)

Increased Productivity-Vertic Inceptisols Watershed

At ICRISAT, Patancheru, crop productivity and resource use were studied by adopting integrated watershed approach for a soybean-chickpea sequential and soybean+pigeonpea intercrop systems on two landforms [broad bed and furrow (BBF) and flat sowing on contour] and with two soil depths (shallow and medium-deep) at watershed scale on a Vertic Inceptisol. The results show that during 1995-2003 the improved BBF system recorded on an average 0.1 t/ha more grain yield than the flat landform. Increased crop yield of 2.9 t/ha of soybean intercropped with pigeonpea on BBF was recorded compared with 2.63 t/ha in flat landform treatment. The total run-off was higher in the flat land system (23% of the seasonal rainfall) than on the improved system (15% of the seasonal rainfall). The BBF landform treatment stored 15 mm more rainfall in the soil profile than the flat landform treatment enhancing the green water flow and reducing the run-off. The BBF had more deep drainage than the flat land system, especially for the shallow soil. The run-off figure in the flat land system (190 mm), with a peak run-off rate (0.096 m^3/s/ha) compared unfavourably with the BBF system, which had lower run-off (150 mm) and a lower peak run-off rate (0.086 m^3/s/ha). Hence, the BBF system was useful in decreasing run-off and increasing rainfall infiltration and green water use for crop production. The soil loss in flat land system was 2.2 t/ha *versus* 1.2 t/ha in the BBF system (Wani *et al.*, 2003b).

Improved Livelihoods through Convergence

To achieve the goal of improving rural livelihoods and sustainable utilization of existing resources, the roadmap chosen was through convergence of activities in the watersheds, such as agriculture, horticulture, livestock, fisheries, poultry and small enterprises that bring value addition to rural produce. The overall objective of the whole approach being poverty reduction, the new integrated watershed management model fits into the framework as a tool to assist in sustainable rural livelihoods. The convergence approach is to make watershed development to be explicitly linked with rural livelihoods and effective poverty reduction and in the process identify policy interventions at micro, meso and macro levels.

In the new model, emphasis is on to encourage the convergence of people-centric rural development programs at the watershed level. Any project design should encourage a more holistic understanding of the needs and priorities of the poor people in integration with policy and institution structures.

An example of convergence for agriculture related activities in the watershed and its link with other micro-enterprises is shown in Fig. 2 (Wani *et al.*, 2003a).

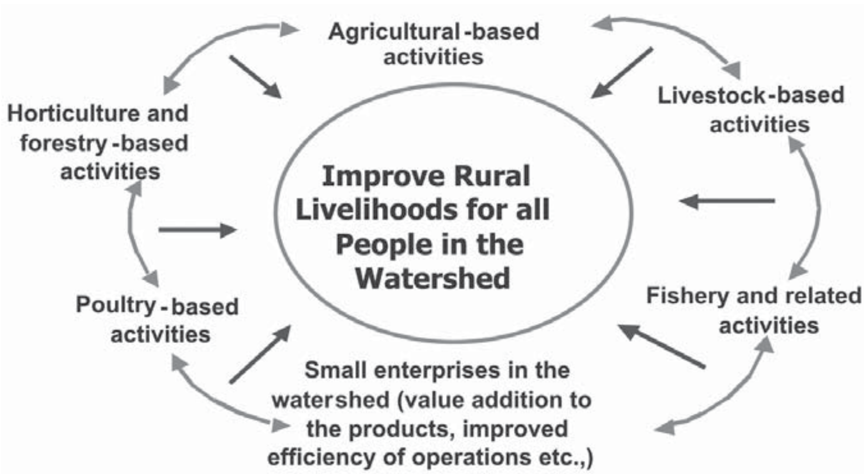

Figure 2. An example of convergence of various activities based on use of natural resources

Convergence can take place at different levels. Convergence at the village level requires facilitation of processes that bring about synergy in all the watershed related activities. An approach is needed to address the equity issues while addressing livelihood options through integrated watershed management. Scope for issues related to suitable processes for change in micro-practices, macro-policies, convergence and knowledge management systems also form part of the program. Socio-economic institution and policy needs to increase adoption of improved options by the rural people are adapted in the convergence approach.

Integrated Water Management

In-situ conservation of rainwater includes landforms (e.g., BBF, ridges and furrows, planting on contours, raised beds and sunken furrows, etc.), tillage, bunding and vegetative barriers, continuous contour trenches and staggered trenches, increased soil organic matter through green manuring, plastic and organic residue mulching, crop residue incorporation and wasteland development. All these activities result in increased water in soil profile and soil conservation.

Ex-situ conservation includes grassed waterways, gully plugging, silt traps, excess water from fields drained out safely, recharging pits, diversion drains, recharging of dead open wells and storage tanks that results in increased water availability for life-saving irrigations to crop plants and enhance groundwater recharge.

Rainwater harvesting results in storing water in above ground tanks, dugout farm ponds, which could be used for life-saving irrigation or increasing recharge of groundwater (Singh and Sharma, 2002). In rainfed agriculture, conjunctive use through supplemental irrigation results in significant increase in crop productivities through substantially enhanced water-use efficiency.

Enhanced Rainwater-use Efficiency (RUE) with Supplemental Irrigation

After storing the rainwater in soil profile through *in-situ* conservation measures the excess water is safely taken out of fields and stored in above ground tanks and dugout farm ponds, which could be used as life-saving irrigation or enhancing groundwater recharge (Osman *et al.*, 2001). In rain-fed agriculture, conjunctive use through supplemental irrigation from harvested run-off water or recharged groundwater results in increasing crop productivities substantially. The green-blue water (rain-fed systems with supplemental irrigation system) continuum proves to be more effective in terms of improving overall water-use efficiency.

Benefits of supplemental irrigation in terms of increasing and stabilizing crop production have been impressive even in dependable rainfall areas of both Alfisols and Vertisols. Good yield responses to supplemental irrigation were obtained on Alfisols in both rainy and post-rainy seasons at ICRISAT on-station watershed. The average irrigation water productivity, WP (ratio of increase in yield to depth of irrigation water applied) varied with the crop, e.g., for sorghum it was 14.9 kg/ha-mm and for pearl millet 8.8 to 10.2 kg/ha-mm. On Vertisols the average additional gross returns due to supplemental irrigation were about INR* 830 per ha for safflower, INR 2400 per ha for chickpea and INR 3720/ha for chillies. In the sorghum + pigeonpea intercrop, two irrigations of 40 millimetres each, gave an additional gross return of Rs 3950/ha. The largest additional gross return from the supplemental irrigation was obtained by growing tomatoes (INR 13870/ha).

At Bhopal, India, supplemental irrigation with stored rainwater along with improved landform treatment increased RUE and productivity. Water-use efficiency of chickpea was higher under BBF (11.37 kg/ha-mm) than flat on grade (FOG) land treatment, which was 8.65 kg/ha-mm. The grain yield of soybean in sole soybean treatment was 1830 and 1580 kg ha^{-1} in BBF and FOG land treatments, respectively. Thus BBF registered 15.8 percent higher soybean grain yield than FOG. Similarly, grain yield of maize in sole maize treatment (3640 kg ha^{-1}) under BBF was 11.8 percent higher than the same treatment (3250 kg ha^{-1}) under FOG land configuration. In soybean/maize and soybean/pigeonpea intercropping systems, grain yield of soybean and maize were also higher in BBF than FOG (Misra, 2004).

Bright Spot: Benchmark Watersheds

Adarsha (Model) watershed, Kothapally in Andhra Pradesh and other benchmark watersheds established by ICRISAT led consortium in Madhya Pradesh,

*(INR=Indian Rupees, IUSD = 45 INR).

Rajasthan and Gujarat in India and northern Vietnam, northeast Thailand and south China are excellent examples of convergence. This model of watershed management with technical backstopping is being evaluated by ICRISAT, DPAP, CRIDA, NRSA and non-governmental organization (MV Foundation, BAIF and others) with the participation and involvement of farmers at Kothapally in Andhra Pradesh. This is the best option to scale-up the benefits of watershed programs through appropriate convergence and technical backstopping provided by ICRISAT-led consortium. The income-generating activities in integrated watershed management approach through convergence mode includes village seed banks through self-help groups, value addition through seed material, product processing such as *Daal* (pulses) making, poultry feed, animal feed, grading and marketability, poultry rearing for eggs and meat production and local hatching to provide chicks, and quality compost preparation through vermi-composting using cow dung, fodder waste and weeds locally. These activities are income-generating options for landless and women groups, which in turn bring increased incomes, improve the rural livelihoods in a sustainable way in the participatory approach and address the equity issues in the watershed mainly for landless, marginal farmers' groups and women groups who could benefit from the watersheds. The issues of equity for all in the watershed call for innovative approaches, institutions and policy guidelines for equitable use of water resources. Alongwith the water use the equity issues concerning sustainable use of common property resources in the watersheds also need to be addressed.

Integrated Nutrient Management (INM)

The importance of leguminous green manures such as *Gliricidia* in maintaining soil and crop productivity is widely accepted. Comparative evaluation of decomposition of *Gliricidia* and pigeonpea plant residues showed that the leaves of *Gliricidia* decomposed faster than pigeonpea plant parts (leaves, stem and roots). Highest N mineralization (119 mg N kg^{-1} soil) occurred with the *Gliricidia* leaf surface application to soil compared to the *Gliricidia* stems (93 mg N kg^{-1} soil) during 150 days of incubation. Along with *in-situ* generation of organic matter, use of crop residue compost, biofertilisers such as *rhizobia* for legumes, inclusion of legumes and need based application of deficient nutrients are used as INM package.

In Tad Fa Watershed, northeastern Thailand, application of chemical fertilizers to cash crops is a common practice to harvest decent yields. Since chemical fertilizers are one of the costliest inputs and there is not much scope to use farmyard manure (FYM) (as farm animals are replaced by farm machines), use of legumes in the cropping system is a viable alternative or supplement source to overcome nutrient constraints. In order to recommend suitable legumes in cropping systems so that farmers can reduce fertilizer N application, rice bean (*Vigna umbellata*), black gram (*Vigna mungo*), sword bean (*Canavalia gladiata*) and sunnhemp (*Crotolaria juncea*) were evaluated for quantifying nitrogen fixation and the benefits of legumes using ^{15}N abundance method and ^{15}N isotope dilution method on farmer's fields at Ban Koke Mon located near Ban Tad Fa where ICRISAT benchmark watershed is situated. The cropping systems of Ban Koke Mon are similar to those of Ban Tad Fa.

The results showed that the actual realized benefits from legumes in terms of increased N uptake by a succeeding maize crop varied from 5.3 to 19.3 kg N ha^{1} whereas the expected benefits from legumes through biological nitrogen fixation and soil N sparing effect over a maize crop varied from 15 to 64 kg N ha^{-1} (Table 2). These results of strategic research revealed that for quick benefits for succeeding maize crop farmers would be benefitted by growing legumes, such as rice bean, sunnhemp and black gram.

In Than Ha watershed, Hoa Binh province of Vietnam, farmers could reduce 95 to 120 kg N ha^{-1} without sacrificing the maize yield due to inclusion of legumes in the system and application of 10 t FYM ha^{-1}. *Gliricdia* loppings from the plants on bunds provided 30 kg N ha^{-1} yr^{-1} in India and 50 kg N ha^{-1} yr^{-1} in Vietnam.

Table 2. Amount of nitrogen fixed (kg ha^{-1}), net N benefit expected, total N uptake by a succeeding maize crop and N benefit realized from the legumes in the maize-based systems

Crop	N fixed by legume (kg ha^{-1})	Net N benefit expected[1] (kg ha^{-1})	Total N uptake by succeeding maize (kg ha^{-1})	N benefit realized from legume over maize[2] (kg ha^{-1})	Expected benefit from BNF+N saving benefit[3] (kg ha^{-1})
Rice bean	20	2	75.9	19.1	15
Sunhemp	90	31	76.1	19.3	44
Sword bean	104	51	62.1	5.3	64
Black gram	27	8	68.9	12.1	21
Maize	-	-13	56.8	-	-

1. Net N benefit: N_2 fixed –seed N.
2. Total N uptake by succeeding maize –total N uptake by maize grown after maize.
3. Net N benefit + soil N depleted by maize in column 3.

Source: Wani *et al.*, 2003a.

Baseline characterization of soils in different benchmark watersheds indicated that these soils are not only thirsty but also hungry for micronutrients, such as zinc (Zn), boron (B) and secondary nutrients sulphur (S) in addition to primary plant nutrients such as N, P and K.

Successful demand driven interventions and farmer participatory evaluation of B and S nutrient amendments studies in farmers' fields in Guna district, Madhya Pradesh (India) showed that S application at the rate of 30 kg ha^{-1} increased yields of soybean by 34 percent over the recommended N and P doses alone and with B and S application yield increase ranged from 22 to 53 percent over control. Higher grain yields (48% over control with B+S application) of chickpea were recorded over control with residual effect of B, S and B+S application treatments (Table 3).

In Lalatora (Vidisha, Madhya Pradesh) in order to increase the RUE, micronutrient amendments were targeted for increasing crop production at farmers' level. During 2001, the RUE of soybean was 1.6 kg/mm of rainwater under farmers

Table 3. Residual effect of B, S and B+S nutrient amendments applied to soybean on grain and straw yield of chickpea in watershed of Guna district, Madhya Pradesh, India during post-rainy season 2002-2003

Treatment	Yield ($t\ ha^{-1}$)		Increase over control (percent)	
	Grain	Straw	Grain	Straw
Boron(0.5 kg B ha^{-1})	1.61	1.66	54	10
Sulphur(30 kg S ha^{-1})	1.76	1.92	68	27
Boron + Sulphur(same as above)	1.55	1.79	48	18
Control(farmer's practice)	1.05	1.51	-	-

input condition, while it was 2.0 kg/mm of rainwater (i.e., 25% more productivity for the rain-fed systems in Madhya Pradesh) where micronutrients were applied. Application of B, S, and B+S increased soybean yields by 34-40 percent over the best-bet option treatment based on recommended fertilizer doses, which served as control without amendments. The economic analyses of these on-farm trials showed that application of B and S gave the benefit of USD 572-584 per hectare. The benefit-cost ratio was up to 1.8 for amendment addition, while it was 1.3 for control.

Integrated Pest Management (IPM) of Pigeonpea and Cotton in Kothapally Watershed

Integrated pest management was adopted to optimise crop productivity in the watershed. *Helicoverpa*, a major pest on chickpea, pigeonpea and cotton was monitored using pheromone traps. Effective indigenous methods like shaking pod borers from pigeonpea and using them for pest management, pest tolerant varieties and bio-control measures using *Helicoverpa* nuclear polyhedrosis virus (HNPV) were adopted. Studies conducted showed that in 65 percent of the 17 cases of the farmers' field trials, integrated pest management recorded higher crop yields (3.47 t ha^{-1}) over farmer's practice (2.33 t ha^{-1}) along with substantial reduction in investments in IPM plots.

Improved Crop Varieties

ICRISAT's adoption of integrated genetic management model include, short and extra-short duration crop varieties such as HHB 67 pearl millet hybrid and ICP 88039 pigeon pea that enable double cropping with mustard, chickpea and wheat in northern India. Better rooting and leaf-size pattern bred into drought tolerant varieties with conventional methods gave 10-40 percent higher grain yield. The approach includes drought resistant crops/varieties, use of high value crops such as medicinal plants for increased productivity and income with available water resources.

Micro-enterprises

The provision of training and development to farming communities in micro-enterprises forms a better way to reduce migration to urban areas for seeking employment during off-farm season. Selection of micro enterprises can be based on the locally available resources and technical backstopping for training the farmers. Some such technologies include

- Vermicomposting: Providing training to women farmers can empower them.
- Preparation of bio-fertilizers.
- Village-based seed banks.
- Livestock-based activities: Improved fodder production can improve the livestock productivity, improved breed and animal health enhance productivity and incomes.
- Fisheries and related activities: When excess rainwater is available the farmers can go in for fish or prawn culture in the water ponds/ channels. This option can be made available to the landless people in the rural communities.
- Poultry-based activities: Agro-wastes, for instance, where maize cultivation is taken up, can be diverted for poultry feed alongwith other supplemental food. Rearing of improved genotypes like broilers can increase the returns and improve the livelihood options.
- Horticulture and forestry-based activities: Teak planting, pomegranate and custard apple cultivation along the bunds and marginal lands can enhance farm incomes.

Village-based Seed Banks

One of the critical issues for increasing crop productivity is availability of good quality seeds to the farmers. The approach adopted was empowering farmers and self-help group (SHG) members under the technical guidance of the consortium partners to operate village-based seed banks where the SHGs buyback the seeds of varieties produced by the farmers using breeders' seeds of selected crop varieties. To cite micro-enterprise activities in the watersheds, under the APRLP-ICRISAT-ICAR project in 2003, two village-based seed banks became operational in Kurnool district, Andhra Pradesh, India that procured 10 tons of seeds of ICGS 11 and ICGS 76 of groundnut crop; 4.5 tons of greengram (MGG 295) and one ton of pearl millet (ICMV 221) in Nalgonda district. Further, seed banks of chickpea, sorghum and pigeonpea that started during 2002 in ADB-Tata funded projects in Madhya Pradesh and Rajasthan are successful examples of empowerment.

Rehabilitation of Common Grazing Lands/Wastelands and Participatory Biodiversity Management

Rehabilitating common grazing lands and wastelands is one of the important activities under watershed management. *Annona* spp. (custard apple) plantation on the bunds, *Gliricidia* saplings planted along the borders of the wasteland can serve as live fences. Avenue plantation (timber [teak], fuel, fruit trees) in the watershed villages through afforestation program; and bio-diesel plantation like *Pongamia* spp. and *Jatropha* spp. can help in rehabilitating the common lands through income-generating options. These activities help in rehabilitating common wastelands and enhance possibilities for expanding the income earning potential. Community participation to rehabilitate 45 ha of open grazing land of undulating terrain through stone wall fencing, planting useful grasses, bench terraces, contour trenches and silt-trap pits for *in-situ* soil-moisture conservation in Gokulpura village of Thana watershed, Bundi district, Rajasthan, India under the Tata-ICRISAT-ADB Project led to improved fodder availability and, flora [*Dhaman* (*Cenchrus setigerus*)] grass, the native *Khejri (Prosopis cineraria)* species, Neem (*Azadirachta indica*), Khejada (*Acacia leucopholia*) etc. and fauna [Nilgais (wild cow)], rabbits, hares, a host of bird species) rehabilitation.

Impact of Integrated Watershed Interventions

Appropriate technology options and scientific and technical backstopping by the consortium of institutions through the integrated watershed management model developed by ICRISAT-led consortium have yielded good results at different benchmark locations in Asia. The success is mainly because of good participation by the farmers and due to tangible economic benefits to individuals equitably through technically backstopped holistic approach. The impact assessment was based on the parameters discussed below.

Increased Productivity

In the on-farm Kothapally Adarsha (Model) watershed, (Ranga Reddy district, Andhra Pradesh), farmers evaluated improved crop management practices (INM, IPM and soil and water management) along with researchers. Farmers obtained high maize yield ranging from 2.2 to 2.5 times with improved technologies as compared to the yields of sole maize (1.5 t ha^{-1}) in 1998 (Table 4). In case of intercropped maize with pigeonpea, improved practices resulted in increased maize yield (3.1 t ha^{-1}) compared with farmers' practices where the yields were 2.0 t ha^{-1}. In case of sorghum the adoption of improved practices increased yields by three-folds within one year. Yield of intercropped pigeonpea with improved management practices increased by five times in 2003 (Wani *et al.,* 2003d). Similar results were reported from other benchmark watersheds in India, Thailand and Vietnam (Wani *et al*., 2003a)

Table 4. Average yields with improved technologies in Kothapally Adarsha Watershed, 1999–2003

Crop	Baseline yield (1998)	Yield (kg ha^{-1}) 1999	2000	2001	2002	2003
Sole maize	1500	3250	3750	3300	3480	3921
Intercrop maize	-	2700	2790	2800	3083	3129
(Farmers' practice)		700	1600	1600	1800	1950
Intercrop pigeonpea	190	640	940	800	720	949
(Farmers' practice)	-	200	180	-	-	-
Sole sorghum	1070	3050	3170	2600	2425	2288
Intercrop sorghum	-	1770	1940	2200	-	2109

Shift in Cropping Pattern and Crop Diversification for Increasing Incomes

Investments in crop technologies and integrated watershed management interventions have brought a shift in cropping pattern and increased yields. During 1998–2002, more pronounced impacts in terms of shift in cropping pattern and increased yields were observed in a 500-ha Kothapally Adarsha Watershed. In this watershed, the farmers grow a total of 22 crops, and a remarkable shift has occurred in the cropping patterns from cotton (200 ha in 1998 to 100 ha in 2002) to a maize/pigeonpea intercrop (40 ha in 1998 to 180 ha in 2002). This shift has increased productivity and incomes of the farmers as well as diversified the cereal-based systems using legumes (Wani *et al.*, 2003a, d). Crop diversification with inclusion of higher value crops such as vegetables, medicinal and aromatic plants have a greater market and make the systems more remunerative.

Improved Greenery

An increase in vegetation cover was observed through satellite imageries. Vegetative cover in Kothapally Adarsha Watershed during November-December increased from 129 ha in 1996 to 200 ha in 2000.

Improved Groundwater Levels

Groundwater level in the village significantly improved (around 3 m) in Adarsha Watershed, Kothapally as against untreated watershed areas where water levels were continuously declining (Wani *et al.*, 2003c).

Reduced Run-off and Soil Loss

Run-off was 12 percent of the total rainfall (Fig. 3) in the undeveloped watershed while it was only 6 percent in the developed watershed where soil and water conservation measures were undertaken.

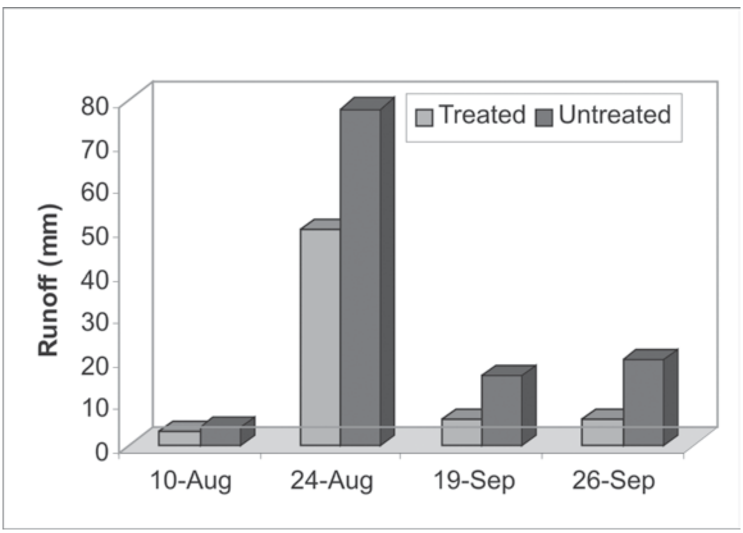

Figure 3. Run-off losses in the untreated and treated sections of Adarsha Watershed, Kothapally, 2001

Increased Incomes

The impact of integrated watershed management interventions on poverty and livelihoods of rural communities at on-farm watersheds in Adarsha Watershed, Kothapally, India clearly showed that average net returns per hectare for dryland cereals, pulse and other crops almost doubled. Adoption of the improved varieties not only increased crop yields, but also enhanced the economic profitability of other soil and water conservation investments, which may otherwise be economically less attractive to farmers. Average household income from crop production activities within and outside the watershed was INR 15400 and INR 12700 respectively. The average per capita income was INR 3400 in Adarsha Watershed and INR 1900 outside the watershed. This shows a significant impact of watershed intervention activities (initiated in 1999) towards poverty reduction in Kothapally Watershed through increased incomes for the poor. The average income from agricultural wages and non-farm activities were INR 17,700 and INR 14,300 within and outside the watershed, respectively. The increased availability of water (and hence supplementary irrigation) and better employment opportunities in watershed development related activities have contributed to diversification of income opportunities and reduced vulnerability to drought and other shocks (Wani *et al.*, 2003d).

Because of the serious drought, the average household incomes declined in 2002-03 cropping season as compared to 2001-02 in both the developed and untreated watershed villages. However, the decline in crop income was more pronounced in the untreated watershed areas as compared to developed watershed areas. The data showed that income from crop production activities in the untreated watershed villages declined by about 70 percent while it declined only by 25 percent in Adarsha (Model) watershed. This indicates that watershed management activities have significantly reduced household vulnerability to drought and enhanced the resilience of livelihoods. The effect of watershed management programs was more in the case of dryland cereals and pulses – the crops supported through ICRISAT and partners. The decline of crop production due to drought was generally compensated by increased income from non-farm activities. The change in livestock income due to the drought was not significant.

Scaling-up and Scaling-out

These micro-level studies have been critically reviewed and analysed for upscaling the interventions to stipulate the macro-level picture of the watershed benefits and people's participation. Based on the success of the participatory consortium watershed management model at Kothapally; three districts of the Andhra Pradesh Rural Livelihoods Programme (APRLP), three districts of Madhya Pradesh and Rajasthan, northeastern Thailand, north Vietnam and southern China with support from APRLP-DFID, Sir Dorabji Tata Trust, India and Asian Development Bank (ADB), the Philippines have selected this model for scaling up the benefits in nucleus and satellite watersheds. In the target ecosystems, project-implementing agencies (PIAs) were selected based on their strengths and knowledge base available in the system. Nucleus watersheds were selected for development and critical monitoring as the sites for undertaking action research. An innovative model with a consortium of institutions, as opposed to single institution approach, for technical backstopping was initiated (Fig. 4.) for project implementation (Wani *et al*., 2003c). All the partners have worked in partnership with each other to manage the watershed sustainably.

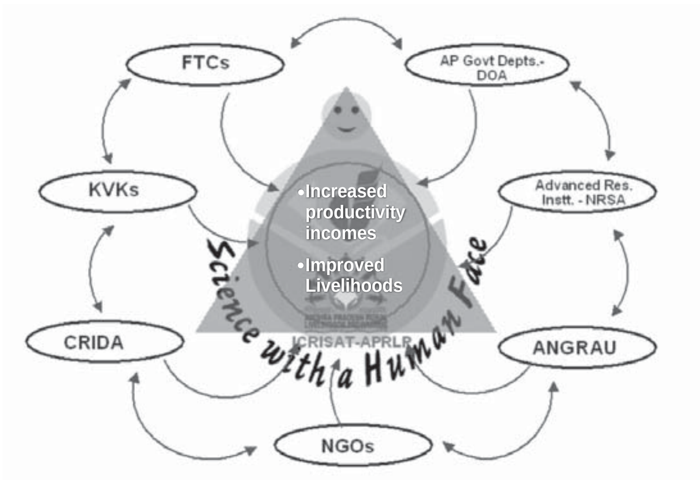

Figure 4. Farmer participatory ICRISAT-APRLP consortium for integrated watershed development. (FTC : Farmer Training Centre, KVK : Krishi Vigyan Kendra (Farmer Science Centre), ANGRAU: ANGR Agricultural University, NRSA: National Remote Sensing Agency, DoA: Department of Agriculture)

A successful partnership based on strong commitment with state and local agencies, community leaders and people is desirable. It was recognized that to shift the community participation from contractual to consultative and collegiate mode, tangible private economic benefits to individuals are must. Such tangible benefits to individuals could come from *in-situ* rainwater conservation and translating through increased farm productivity by adopting Integrated Genetic of Natural Resource Management (IGNRM) approach. Adopting the principle that 'users pay' provided no subsidies for investments on individual's farms for technologies, inputs and conservation measures. Once the individuals could realize the benefits of soil and water conservation they came forward to participate in community activities in the watershed through various organized groups.

Up-scaling Strategy for Increased Household Incomes

Unlike other Asian countries, the landholdings of Vietnamese farmers are very small. In the Thanh Ha watershed, Vietnam, the average family holding in drylands is around 0.5 to 1 ha. Efforts have been made to identify appropriate crops and crop combinations in various seasons for enhanced household incomes and food security in the backdrop of systems sustainability, soil health and potential for large-scale adoption and adaptation. For example, maize, groundnut and soybean combination gave higher incomes in spring while maize and groundnut, and maize and soybean crop combination in autumn-winter season. Crop performance differences were significant across the seasons. Spring season was more favourable in terms of grain yields and associated income gains than the autumn-winter season. Again, among the crops soybean performed better in spring and summer as compared to winter season.

Soils in the sloping land being highly vulnerable to erosion and land degradation, their influence on crop productivity and profitability is quite evident. From field studies, the grain yields of soybean, groundnut, mungbean, and maize based on the location on the toposequence in the landscape watershed have been delineated (Fig. 5 and 6).

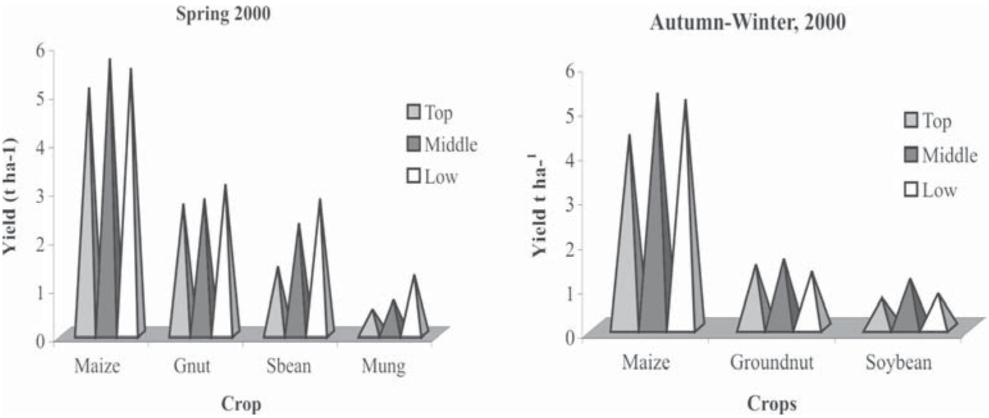

Figure 5. Influence of toposequence on crop productivity

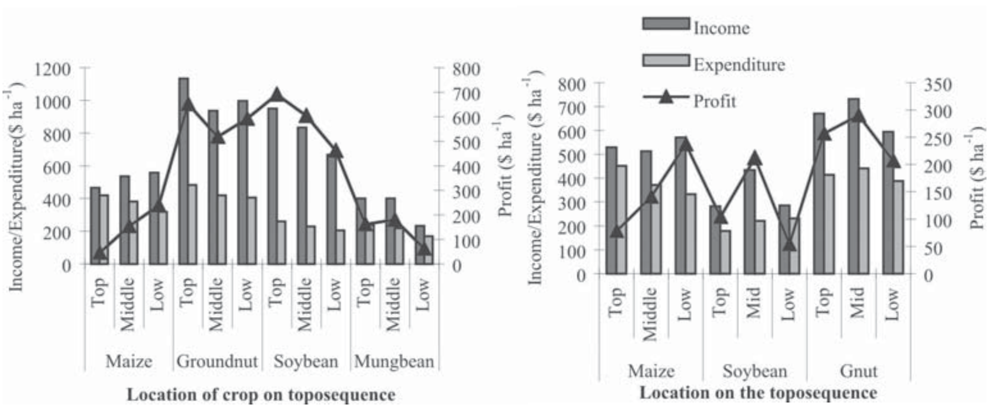

Figure 6. Influence of toposequence on crop profitability, spring and autumn-winter, 2000

In general, higher grain yields and farm incomes were obtained in the lower and middle part of the toposequence compared to the top due to lower degradation and better soil fertility. Farmers are incurring higher expenditure due to higher fertilizer usage on top of the toposequence. Among the crops groundnut can be grown successfully on top, mid and lower part of the toposequence while mungbean and soybean need high level of management on top of the toposequence for obtaining good yields. This kind of information would assist in appropriate land use planning and development of targeted nutrient management technologies for systems resilience and increased household incomes (Wani *et al*., 2003a).

At present ICRISAT-led consortium is developing scaling-up methodology for the integrated watershed management model in 190 villages in India, China, Thailand and Vietnam with the financial support from the development investors, such as ADB, Sir Darobji Tata Trust, DFID and NARSs.

New Initiatives

Sustainability through Empowerment

Empowerment of stakeholders through capacity building is very critical in participatory integrated watershed management. In this model emphasis is on capacity building of all the stakeholders (farmers, partners, NGOs, government departments and policy makers) to facilitate the scaling-up of the benefits from the nucleus and satellite watersheds in the target districts. The strategy adopted in this module for scaling-up is depicted in Fig. 7. The nucleus watershed PIAs and farmers serve as trainers to the rest of the watersheds in a given agro-ecosystem for rapid extension of technologies.

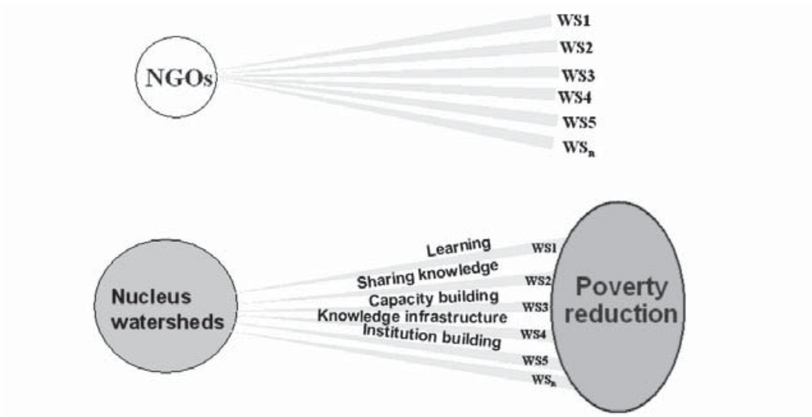

Figure 7. Knowledge transfer within the institution and the region

Mass Capacity Building Efforts

Farmers' days, field days and farmer awareness programs are important activities for effective dissemination of on-station and on-farm technologies to a wide range of farmers in the watersheds. Specialized training courses/programs on participatory watershed management, tropicultor training, use and maintenance of hydrological equipment, seed treatment and *Rhizobium* inoculation methods, integrated pest and disease management, training project personnel on socio-economic survey methods in community watersheds, information and communication technology, action learning for community mobilization, income-generating options and improving livelihoods like training of SHGs, women, youth and landless households in vermicompost preparation, *dhal* mill for milling pigeon pea are a part of this consortium model. Preparation of training materials, information brochures, bulletins, pamphlets on various watershed-based technologies, in English and regional languages and their distribution in all the nucleus watersheds. Website for the APRLP-DFID-ICRISAT project, TATA-ICRISAT-ICAR and ADB-ICRISAT projects are launched with selected datasets to be put on the website and the site is updated as and when new information is available.

ICT-enabled Farmer-centered Learning Systems for Knowledge Exchange

Modern information and communication technologies (ICTs) are intelligent options for facilitation of flow of information and knowledge to masses for upscaling the benefits. In the watersheds, community centres managed by the PIAs are functioning as a Rural Information Hub (RIH) connecting participating villages (or groups of villages, as the case may be) and also with other internet connected web sites. Each RIH centre has a computer and a suitable connectivity device (e.g. modem or VSAT technology). It is operated or managed by rural group (women or youth SHGs). To site a case, taking advantage of the established connectivity with Adarsha Society in Addakal (Mahabubnagar district), a 'distance learning program' was launched by ICRISAT.

Supporting Strategies for Improving Productivity and Rural Livelihoods – Challenges Ahead

There are two levels of challenges faced by the farmers/stakeholders that need to be properly addressed. First challenge is to increase the productivity levels and the second is to look beyond subsistence livelihoods. Our strategies need to be refined and innovative ways need to be adopted to increase productivity whilst sustaining natural resources in the rainfed areas. The approach needs integration of natural resources management with socio-economic and life support systems to look beyond plus some emerging issues of concern as categorized below:

Building Partnerships

Different groups and locations have conflicting objectives with respect to their investment priorities and enterprise choices. These need to be converted into opportunities. The action of all the farmers in the watershed should converge in such a way that the positive externalities are maximised, and negative ones are minimised. To achieve this, the community or stakeholders have to develop their own rules, which resolve their conflicting objectives. It is believed that better organised and effective people's participation would yield higher benefits.

Common Property Resources (CPR)

Equity issues of water: Competitive extraction of groundwater is leading to disastrous consequences that need to be administered through appropriate policy mechanisms, collective arrangements for groundwater use with the support of local governing bodies, state government officials and technical backstopping by scientists.

Rehabilitation of common wastelands: Innovative ways to manage common wastelands by planting saplings of useful species and diversification such as bio-diesel, medicinal and aromatic plants along the roads, field bunds and *nalas* needs to be adopted for additional support to rural livelihoods. Adoption of such initiatives by resource poor farmers in the local region even at small scale can improve the economic welfare and quality of the local and global environment.

Balancing Demand and Supply of Water

Balancing the water demand for all the purposes, such as agriculture, domestic, industry, recreational and environment purposes is a critical issue. There is an urgent need to increase water-use efficiency in agriculture and also reduce the water demand for domestic uses by adopting innovative options and increasing awareness and capacity building efforts.

Choice of Crops

Efficient utilization of existing natural resources is possible by crop zoning based approach, crop intensification, rational choice of crops and crops that are cash generating like soybean crop and medicinal and aromatic plants. As groundwater extraction is dictated by the cropping pattern, appropriate cropping systems and patterns need to be adopted for drylands where water is very scarce natural resource. Crop diversification with legume (pulses) has long-term sustainable benefits to the soil system by restoring the soil organic matter and thereby the water holding capacity in the soils.

Appropriate Policies for Groundwater Use

Water-Energy-Agriculture-Nexus

Power failures at critical irrigation dates coupled with the attitude that agricultural crops with more water supplies yield more gains make farmers irrigate crops more frequently and use water inefficiently. By ensuring quality and timely supply of electricity, over-pumping of precious groundwater can be minimized. This calls for efficient irrigation management through efficient irrigation systems, pricing electricity, efficient pumps and crops that use water efficiently. The concept of water-energy-agriculture nexus needs to be adopted for rational and sustainable use of this limiting resource. Policy options for groundwater harvesting, issues like borewells, use of working strategies and maintenance need to be addressed.

Administered Price Policy for Dryland Crops

The farmers are inclined more towards the water-intensive crops like wheat and rice over coarse cereals or pulses as these crops are favoured by procurement and pricing policies. A regulation needs to be worked out for minimum support price operations for dryland crops.

Value Addition Products in Rural Areas and Market Links for Products

There is a need to investigate and explore a range of opportunities through on-farm and off-farm activities to encourage and promote village level micro-enterprises such as vermicompost technology, giving value addition to agricultural produce (e.g. pigeon pea, *dhal* mill, extraction of oils from medicinal plants, scope for food processing, infrastructure development, etc.) to help the landless, educating youth and women to ensure a more equitable sharing of the benefits of watershed management projects. Further, promoting pathways for market links for rural produce through institutional and policy support shall be of great help.

Conclusion

The current model of ICRISAT-led consortium's integrated watershed management through its efficient rainwater management have very high potential for bringing favourable changes in drylands of the SAT. On-farm watersheds managed through community participation could sustain productivity of drylands and preserve the quality of the land resources and environment in the SAT. Holistic systems approach through integrated watershed management can result in sustainable and increased farm productivity and improve the livelihoods of rural poor in the dry regions.

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