Lead Papers

4th
World Congress on Conservation Agriculture
4-7 February 2009, New Delhi, India

Innovations for Improving Efficiency, Equity and Environment

4th
World Congress on
CONSERVATION AGRICULTURE
New Delhi, India

Development, Integration and Dissemination of Resource Conservation Options through Community Watershed Approach

Suhas P. Wani[1*], T.K. Sreedevi[1], P.K. Joshi[2] and B. Venkateswarlu[3]

[1]*International Crops Research Institute for the Semi-Arid Tropics, Patancheru, 502 324, Andhra Pradesh, India*

[2]*National*

[3]*Central Research Institute for Dryland Agriculture, Santosh Nagar, Hyderabad, 500 059, Andhra Pradesh, India*

*(*Email: s.wani@cgiar.org)*

Dryland areas in the tropics are hot spots of poverty as well as severe land degradation and water scarcity. In order to achieve the food security for millions of rural poor, it is critical to enhance the productivity of rainfed agriculture through conservation of natural resources such as water and land. The Comprehensve Assessment of Water for Food and Water for Life has demonstrated that potential of rainfed agriculture of doubling the productivity can be harnessed by adopting integrated approach through watershed management. Assessment of watershed impacts in India revealed that watershed approach can be applied in all rainfed areas with suitable modifications of interventions or economically beneficial and rainfed agriculture can be upgraded by enhancing the effectiveness of 68% of the watershed projects which are performing below average. The new paradigm for unlocking the potential of rainfed agriculture is by adopting community watershed management approach as a business model through convergence and linking of farmers to the markets, efficient use of conserved natural resources for enhancing the productivity by adopting IGNRM approach and improving community participation through capacity building and ensuring tangible economic benefits. Capacity building has been identified as a weakest link for scaling-up the watershed programs and national strategy for quality capacity building measures through consortium of quality service providers with suitable quality indicators is recommended. Conservation agriculture can be operationalized through watershed approach for improving the livelihoods of rural poor by unlocking the potential of rainfed agriculture.

Key words: Community Watershed, Resource conservation, Rainfed agriculture, integrated approach, Livelihood, scaling-up.

To meet the millennium development goal of halving the number of poor people by 2015 and achieve food security for the ever growing population along with increasing incomes in the world with the prevailing status of available natural resources *viz*; land and water and the associated impacts of global warming is a challenging task. Sixty per cent of the food insecure people in the world live in South Asia and sub-Saharan Africa. Recently completed Comprehensive Assessment of Water for Food and Water for Life revealed that it is possible to produce required food – but it is probable that today's food production and environmental trends, if continued, will lead to crises in many parts of the world (Molden, 2007). The assessment has also indicated that the world's available land and water resources can satisfy future demands by taking appropriate steps.

The comprehensive assessment has also highlighted the importance of rainfed agriculture (Molden, 2007, Rockstrom et al; 2007)) that varies regionally (95% in sub-Saharan Africa, 60% in South Asia, and 90% in Latin America) but produces most food for poor communities in developing countries. Despite large strides made in improving productivity and environmental conditions in many developing countries, a great number of poor families in Africa and Asia still face poverty, hunger, food insecurity and malnutrition, where rainfed agriculture is the main agricultural activity. These problems are exacerbated by adverse biophysical growing conditions and the poor socioeconomic infrastructure in many areas in the semi arid tropics (SAT). The importance of rainfed sources of food weighs disproportionately on women, given that approximately 70% of the world's poor are women (WHO, 2000). Agriculture plays a key role for economic development (World Bank, 2005) and poverty reduction (Irz and Roe, 2000), with evidence indicating that every 1% increase in agricultural yields translates to 0.6 to 1.2% decrease in the percentage of absolute poor (Thirtle *et al.*, 2002). Agriculture will continue to be the backbone of economies in Africa and South Asia in the foreseeable future. Substantial gains in land, water and labour productivity as well as better management of natural resources are essential to reverse the downward spiral of poverty and environmental degradation. Renewed effort and innovative R&D strategies are needed to address these challenges in rainfed areas.

Rainfed Agriculture in Need of Natural Resource Conservation Technologies

An insight into the inventories of natural resources in rainfed regions shows a grim picture of water scarcity, fragile environments, drought and land degradation due to soil erosion by wind and water, low rainwater use efficiency

(35-45%), high population pressure, poverty, low investments in water use efficiency (WUE) measures, poor infrastructure and inappropriate policies (Wani *et al.*, 2003b; Rockström *et al.*, 2007). Drought and land degradation are interlinked with poverty, hunger and water stress (Falkenmark, 1986) and the "hot spot" of malnourished countries in the world hosted in semiarid and dry subhumid hydroclimates in the world (Figure1), i.e. savannahs and steppe ecosystems, where rainfed agriculture is the dominating source of food, and where water constitutes a key limiting factor to crop growth (SEI, 2005). The global assessment showed that 57% of the total area of drylands occurring in two major Asian countries namely China (178.9 million ha) and India (108.6 million ha) are degraded (UNEP, 1997). To break this unholy nexus between drought (water scarcity), poverty and land degradation to meet the MDG of halving the number of food insecure poor by 2015 resource conservation technologies need to be urgently developed and scaled-up through appropriate dissemination.

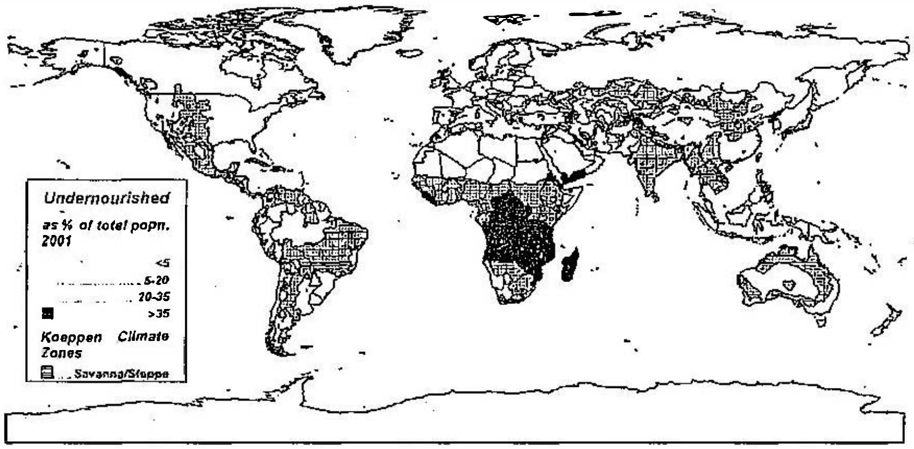


Figure 1. The prevalence of undernourished in developing countries (as percentage of population 2001/2002 (UNStat, 2005), together with the distribution of semiarid and dry subhumid hydroclimates in the world, i.e. savannah and steppe agro-ecosystems. These regions are dominated by sedentary farming subject to the world's highest rainfall variability and occurrence of dry spells and droughts

Conservation agriculture[1] systems are one of the most important strategies to enhance soil productivity and moisture conservation. Non-inversion systems, where conventional ploughs are abandoned in favour of ripping, sub-soiling and no-tillage systems using direct planting techniques, combined with mulch management, builds organic matter and improves soil structure. Conservation agriculture is practised on approximately 40% of rainfed agriculture in USA, and has generated an agricultural revolution in several countries in Latin America (Derpsch, 1998, 2005; Landers *et al.*, 2001). Large-scale adoption of conservation agriculture systems is experienced among small-scale rainfed and irrigated farmers cultivating rice and wheat on the Indo-Gangetic plains in Asia (Hobbs *et al.*, 2002).

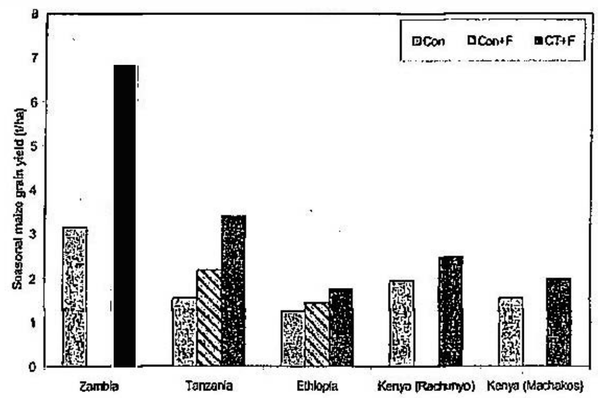
Conservation agriculture is of key importance in efforts of upgrading rainfed agriculture through conservation soil and water among the world's resource-poor farmers. It reduces traction requirements (by tractors, or animal draught power), which saves money and is strategic from a gender perspective, as it generally gives women, particularly in female-headed households, a chance to carry out timely and effective tillage. A challenge is to find alternative strategies to manage weeds, particularly in poor farm households where herbicides are not an option. Furthermore, conservation agriculture can be strengthened in watershed areas. Conservation agriculture is a particularly important soil and water management strategy in hot tropical regions subject to water constraints. Soil inversion (using ploughs) in hot tropical environments leads to rapid oxidation of organic matter and increased soil erosion, which can be avoided using conservation agriculture practices.

Converting from ploughing to conservation agriculture using sub-soiling and ripping has resulted in major improvements in yield and water productivity in parts of semiarid to dry subhumid East Africa, with a doubling of

[1]Conservation agriculture, often defined as conservation tillage or conservation farming, includes tillage systems with no-inversion of soil, i.e. without conventional ploughing, and range from no-tillage to minimum tillage and tillage systems aimed at opening the soil for rainfall capture without inversion. These systems include crop rotations and a mulch cover, which according to the convention should allow at least an average 30% cover of the soil throughout the year. For many farming systems in arid, semiarid and dry subhumid tropical regions a permanent mulch cover is difficult to sustain. Despite this difficulty, conservation agriculture systems, often adopted as a strategy for in-situ water harvesting, show much promise, even though difficulties with weed management is a more prominent challenge than when securing a mulch cover. The Comprehensive Assessment has chosen to adopt a wide definition of conservation agriculture focussed on non-inversion tillage for improvement of soil and water management (including sub-soiling, ripping, pitting and no-till systems).

Box 1. Conservation agriculture options in East Africa – a strategy for water and soil productivity improvement

On-farm participatory trials on innovative conservation agriculture in semiarid to dry subhumid Ethiopia, Kenya, Tanzania and Zambia indicate large potentials to substantially improve yields and rainwater productivity of staple food crops, through conservation agriculture. Conservation agriculture involves the abandoning of soil inversion through conventional ploughing (generally mouldboard or disc ploughing), in favour of tillage systems with no turning and with minimum disturbance of the soil. Trials were carried out with farmers during 1999-2003, where yields increased significantly in all countries (see figure below). The conservation agriculture systems maximized rainfall infiltration into the soil, through ripping and sub-soiling. Draught animal traction requirements were reduced drastically (with at least 50%) and limited soil fertilization resources (manure and fertilizer) were applied along permanently ripped planting lines.



Maize yield improvements from conservation agricultural in on-farm trials in Eastern and Southern African countries. A conventional mouldboard ploughing system (Con) is compared with conventional ploughing with added fertilization (Con+F) and conservation agriculture using ripper and sub-soilers combined with fertilizer (CT+F).

Box 2. Efficient use of *in-situ* water harvesting techniques in arid regions

Water harvesting systems using small micro-basins are used to support plants and trees in arid and semiarid environments. Small basins (*Negarim*) have supported almond trees for over 17 years in the Muwaqqar area of Jordan where the mean annual rainfall is 125 mm. The system has proved sustainable over a period of several years of drought (Oweis and Taimeh, 1996).

In the Mehasseh area of the Syrian steppe, with an average annual rainfall of 120 mm, the survival rate of rainfed shrubs is less than 10%, while those that were grown in micro-catchments had a survival rate of over 90%. Shrub survival rate can be improved between 70 and 90% with the introduction of water harvesting interventions (semicircular bunds). In northwest Egypt, with an average annual rainfall of 130 mm, small water harvesting basins with 200 m^2 watersheds support olive trees, and harvesting rainwater from greenhouse roofs can provide about 50% of the water required by vegetables grown inside the greenhouse (Somme *et al.*, 2004).

yields in good years, due to increased capture of rainwater (Box 1). Further increases in grain yield were achieved by applying manure. Compared to irrigation, these kinds of interventions can be implemented on all agricultural lands. Moreover, Eastern and Southern Africa shows a large potential to reduce labour needs and improve yields in small-holder rainfed agriculture with the adoption of conservation agriculture practices (Box 1). Yield improvements range from 20 to 120%, with rainwater productivity improving at 10-40%. *In-situ* water harvesting options also include techniques to concentrate runoff to plants, such as terracing, bunds, ridges, khadins and micro-basins. The productivity of rain in arid environments can be substantially increased with appropriate water harvesting techniques, which concentrate runoff to plants and trees (Box 2).

Rainfed Agriculture – A Large Untapped Potential

Although agricultural production has kept us the space with the increasing global population during the past 40 years large regional variation as well as the large difference between irrigated and rain-fed agriculture exists. In developing countries rainfed grain yields are on average 1.5 t/ha, compared to 3.1 t/ha for irrigated yields (Rosegrant *et al.*, 2002), and increase in production from rainfed agriculture has mainly originated from land expansion.

In view of the historic regional difference in development of yields there exists a vast potential for raised yields in rainfed agriculture, particularly in sub-Saharan Africa and South Asia. In tropical regions, particularly in the

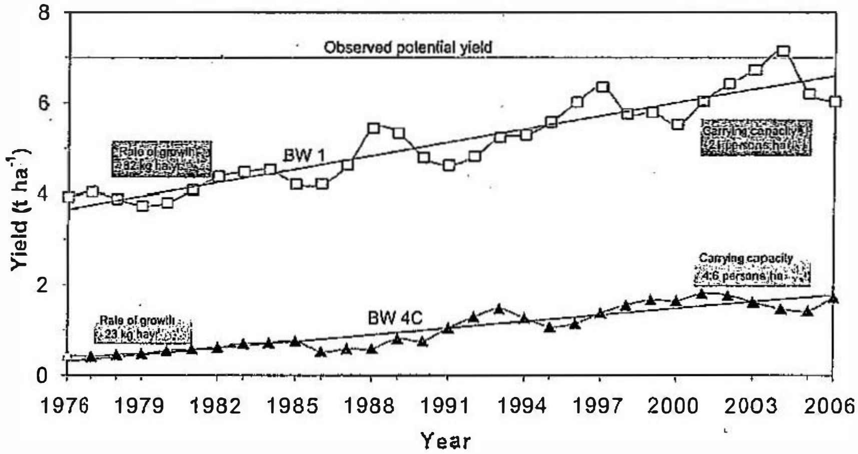


Figure 2. Three-year moving average of sorghum and pigeonpea grain yield under improved and traditional management in a deep Vertisol catchment at Patancheru, India

subhumid and humid zones, agricultural yields in commercial rainfed agriculture exceed 5-6 t/ha (Falkenmark and Rockström, 2000; Wani *et al.*, 2003a, 2003b). At the same time, the dry subhumid and semiarid regions have experienced the lowest yields and the weakest yield improvements per unit land. Here, yields oscillate between 0.5 to 2 t/ha, with an average of 1 t/ha in sub-Saharan Africa, and 1-1.5 t/ha in South Asia, Central Asia and West Asia and North Africa (CWANA) for rainfed agriculture (Falkenmark and Rockström, 2000; Wani *et al.*, 2003a, 2003b).

Evidence from a long-term experiment at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India since 1976, demonstrated the cycle of persistent yield increase through Improved land, water and nutrient management in rainfed agriculture. Improved systems of sorghum/pigeonpea intercrops produced higher mean grain yields (5.1 t/ha) compared to 1.1 t/ha, average yield of sole sorghum in the traditional (farmers') post-rainy system where crops are grown on stored soil moisture (Figure 2). The annual gain in grain yield in the improved system was 82 kg/ha/yr compared with 23 kg/ha/yr in the traditional system. The large yield gap between attainable yield and farmers' practice as well as between the attainable yield of 5.1 t/ha and potential yield of 7 t/ha shows that a large potential of rainfed agriculture remains to be tapped. Moreover, the improved management system is still continuing to provide increase in productivity as well as improving soil quality (physical, chemical and biological parameters) along with increased carbon sequestration of 330 kg C per ha per year (Wani *et al.*, 2003a).

Yield gap analyses carried out by Comprehensive Assessment, for major rainfed crops in semiarid regions in Asia and Africa and rainfed wheat in WANA, reveal large yield gaps with farmers' yields being a factor 2 to 4 times lower than achievable yields for major rainfed crops (Singh *et al.*, 2009). Figure 3 illustrates examples of observed yield gaps in various countries in Africa, Asia and the Middle East and the historic trends present a growing yield gap between farmers' practices and farming systems that benefit from management advances (Wani *et al.*, 2003b).

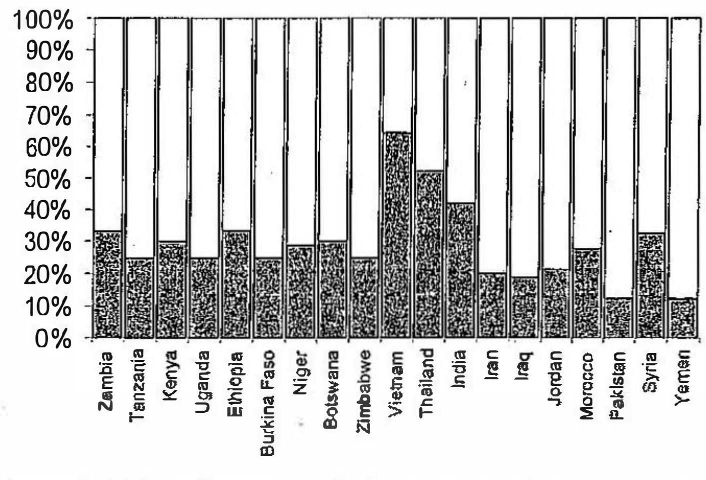


Figure 3. Examples of observed yield gap (for major grains) between farmers' yields and achievable yields (100% denotes achievable yield level, and columns actual observed yield levels). (Source: Derived from Rockstrom *et al.*, 2007)

The difference is largely explained by inappropriate soil, water and crop management options used at the farm level, combined with persistent land degradation. The vast potential of rainfed agriculture needs to be unlocked through knowledge-based natural resource conserving technologies for increasing the productivity and income to achieve food security in the developing world.

The Challenges of Out-scaling in Investments and Policies

Recent reviews of rain-fed agriculture listed the challenges of out-scaling in investments and policies (Ryan and Spencer, 2001, Rockström *et al.*, 2007, Wani et al; 2009, Sreedevi and Wani; 2009). Investments in agricultural research in savannah agroecosystems in the past have generated highly disappointing results (Seckler and Amarasinghe, 2004). A reason for this is the lack of holistic approach as over the past 50 years at farm level has mainly been on crop, soil, or water research. It is only in the past 10-15 years that science and technology development has focused more strongly on water management in rainfed agriculture (on water harvesting and supplemental irrigation in rainfed systems), and on tillage research focused in more explicit terms on water conservation (conservation tillage systems) at the farm scale (Rockström *et al.*, 2007).

Upgrading rainfed agriculture requires that technologies (indigenous or improved) are strongly adapted to local biophysical and socio-cultural conditions accompanied with institutional and behavioural changes (Harris *et al.*, 1991; van Duivenbooden *et al.*, 2000). Adoption of conservation agriculture in several parts of the world was driven by crises, e.g. in USA, as a response to the Dust Bowl in the 1930s, in part of Latin America as a response to an agrarian yield crisis and in Zambia, as a response to droughts. Increased emphasis on watershed management in India is largely to cope with droughts in drought-prone areas, i.e. drylands in India after severe droughts in early 1980s. In rainfed areas the challenges are for many knowledge intensive extension effort along with the widespread limitations of the capacity of local institutions engaged in agricultural development and extension to promote management of rainwater.

New Paradigam in Rainfed Agriculture

For sustaining the economic growth and needed food security we need to have knowledge-based holistic approach converging necessary aspects of natural resource conservation, their efficient use, production functions, income enhancement avenues through value chain and enabling policies coupled with capacity building measures and much needed investments in rainfed areas.

Integrated Genetic and Natural Resource Management (IGNRM)

Traditionally, crop improvement and NRM are two sides of the same coin but were seen as distinct but complementary disciplines. ICRISAT is deliberately blurring these boundaries to create the new paradigm of IGNRM (Twomlow *et al.*, 2006). In essence, plant breeders, NRM and social scientists must integrate their work with that of private and public sector change agents to develop flexible cropping systems that can respond to rapid changes in market opportunities and climatic conditions. Crucially the IGNRM approach looks at various components of the rural economy is participatory, with farmers closely involved in technology development, testing and dissemination. Rather than pursuing a single correct answer, we need to look for multiple solutions tailored to the requirements of contrasting environments and diverse sets of households. In the rainfed areas for improving livelihoods the approach has to be business approach through marketable surplus production through diversified farming systems with necessary market linkages and institutional arrangements.

In much of agricultural research, the multidisciplinary team approach has often run into difficulties in achieving impact because of the perceived disciplinary hierarchy. In Asia the IGNRM approach in Community Watershed Consortium pursues integration of the knowledge and products of the various research disciplines into useful extensions messages for development workers that can sustain increased yields and promote income-generating and sustainable crop and livestock production options for a range of climatic and edaphic conditions (Wani *et al.*, 2006a).

Community Watershed as Growth Engine for Development of Dryland Areas

Watershed, as an entry point should lead to exploring multiple livelihood interventions (Wani *et al.*, 2006a, 2006b, 2008b). The overall objective of the whole approach being poverty elimination through sustainable development, the new community watershed management model fits into the framework as a tool to assist in sustainable rural livelihoods. Watershed management is the integration of technologies within the natural boundaries of a drainage area for optimum development of land, water and plant resources to meet the basic needs of the people and livestock in a sustainable manner through value addition and market linkages.

ICRISAT and the national agricultural research systems (NARSs) in Asia have developed in partnership an innovative and up-scalable consortium model for managing watersheds holistically. In this approach, rainwater management is used as an entry point activity starting with *in-situ* conservation of rainwater and converging the benefits of stored rainwater into increased productivity by using improved crops, cultivars, suitable nutrient and pest management practices and land and water management practices. Conservation of soil and water resources fuel the crop yield increases, diversification and income enhancements. ICRISAT's consortium model for community watershed management espouses the principles of collective action, convergence, cooperation and capacity building (4 Cs) with technical backstopping by a consortium of institutions to address the issues of equity, efficiency, economics and environment (4Es) (Wani *et al.*, 2006a).

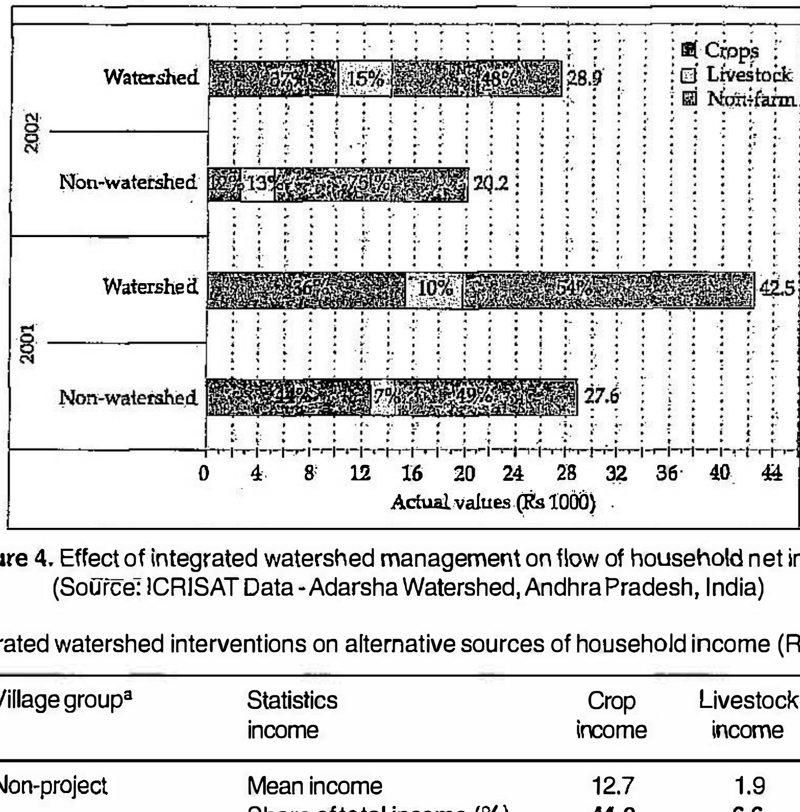


Figure 4. Effect of integrated watershed management on flow of household net income (Source: ICRISAT Data - Adarsha Watershed, Andhra Pradesh, India)

Table 1. The effect of integrated watershed interventions on alternative sources of household income (Rs 1000).

Year	Village group[a]	Statistics income	Crop income	Livestock income	Off-farm income	Household
2001 (average year)	Non-project	Mean income	12.7	1.9	14.3	28.9
		Share of total income (%)	**44.0**	**6.6**	**49.5**	**100.0**
	Watershed project	Mean income	15.4	4.4	22.7	42.5
		Share of total income (%)	**36.2**	**10.4**	**53.4**	**100.0**
2002 (drought year)	Non-project	Mean income	2.5	2.7	15.0	20.2
		Share of total income (%)	**12.2**	**13.3**	**74.5**	**100.0**
	Watershed project	Mean income	10.1	4.0	13.4	27.6
		Share of total income (%)	**36.7**	**14.6**	**48.7**	**100.0**

[a] The sample size is n = 60 smallholder farmers in each group (ICRISAT data).

The IGNRM approach in the community watersheds has enabled communities not only to harness the benefits of watershed management i.e. conservation of natural resources, but also achieve much of the potential from improved varieties from a wider range of crops through efficient and sustainable use of the conserved natural resources. The households' incomes and overall productivity have more than doubled throughout selected benchmark sites in Asia (Figure 4 and Table 1). The benefits not only accrue to landholding households, but also to the landless marginalized groups through the creation of greater employment opportunities.

The Common Features of the Watershed Development Model

Government agencies, development thinkers, donors, researchers and NGOs have gradually learnt from each other, (though some are ahead of the field and others deficient in some aspect or other, principally in people participation or in the science). But generally, nowadays the better models have some or all of the following features in common (Wani *et al.*, 2008a).

- participation of villagers as individuals, as groups or as a whole, increasing their confidence, enabling their empowerment and their ability to plan for the future and for self-determination
- Capturing the power of group action in the village, between villages and from federations, e.g. capturing economies of scale by collective marketing
- Construction of basic infrastructure with contributions in cash or labour from the community
- Better farming techniques, notably the improved management of soil, water, diversifying the farming system and integrating the joint management of communal areas and forest
- Involvement of the landless, often in providing services
- Arrangements for the provision of basic services and infrastructure
- Establishment of village institutions and links with the outside world
- Improved relationships between men and women
- Employment and income generation by enterprise development in predominantly but not exclusively agricultural-related activities.

And sometimes:

- The fusion of research and development (R&D) by capturing the extraordinary power of participatory technology development, including varietal selection with direct links to germplasm collections
- Complete avoidance of corruption so that trust is built and all the benefits pass to the community
- Reduction in distressed migration

Recent Additions to the Watershed Model

- The pragmatic use of scientific knowledge as the entry point rather than money, dole-out of completed by tangible economic benefit from low-cost interventions that generate rapid and substantial returns at low level of risk.
- A broad-based approach to income generation, involving private sector associated with scientific advances and markets; for instance, in the remediation of micro-nutrient deficiencies; in the marketing of medicinal and aromatic plants; with premium payments paid by industrial processors for aflatoxin-free maize and groundnut etc.
- Using new science methodologies to improve performance like remote sensing for monitoring and feedback to farmers, yield gap analysis and rapid assessment of the fertility status of the watershed.
- Building productive partnerships and alliances in a consortium for research and technical backstopping, with the members brought together from the planning stage.
- A concern to create resilience in the watershed and its community to climate change and to events of post-programme intervention.

Where best applied, the model has led to profound farming system changes, improved food self-sufficiency, expanded employment and commerce and enhanced incomes. Where indifferently executed the approach has led, as we shall see in what follows. There is indeed something here analogous to the 'yield gap' exhibited between research station and farmers' yields. Much of the difference can be captured by implementing agencies 'catching up' with best practice. The more recent linking of natural resource science with the private sector, markets and with peoples broader livelihoods in consultation with them, is transforming the dynamic and success rate of development efforts (Wani *et al.*, 2008a).

Broad Overall Conclusions about Watershed Performance and Impact from the Comprehensive Assessment

The watershed approach is a paradigm that works in all rainfed circumstances, has delivered important benefits and impacts and needs to be implemented on a large scale. The difference in result between indifferent and best watershed practice is in part because the watershed approach has been rapidly evolving and the assessment looked at a field in which the goal posts have repeatedly been moved. In part, it is due to deficiencies in execution.

To consolidate and build upon the foundation already laid and universally gain the impact that is possible, the government should undertake some difficult tasks, most noticeably introducing a new 'mind set' or different form of approach that accepts the following (Wani *et al.*, 2008a):

- Watershed development is not just a means to increase production or to conserve soil and water but an opportunity for the fully integrated and sustained development of human and natural resources.
- The approach is valid across various rainfall regimes over vast tracts of India and can contribute in large measure to the simultaneous achievement of government's production environmental and social goals.
- Sustainability and better social impact and equity are very important issues with pro-poor interventions not as a spin-off or after-thought but planned and integrated with the whole.
- There are vast opportunities to reduce costs and increase output by improving the appropriateness and extent of technology.
- There is obvious value in converging Government schemes in the interest of impact and sustainability, rather than a spread of activity; this is particularly important in the case of water and schemes aimed to reach the poor.

Watersheds should be seen as a business model. This calls for a shift in approach from subsidized activities to knowledge-based entry points and from subsistence to gaining tangible economic benefits for the population of the watershed at large. This is being done by productivity enhancement, diversification to high-value enterprises, income-generating activities, market links, public-private partnerships, micro-entrepreneurship and a broad-based community involvement.

Moving forward requires that a lack of capacity to effectively implement programmes be addressed. Implementing agencies need to expand and broaden their capacities and skills; while communities need to strengthen their institutions and their skills. This will require a longer implementation period of seven to eight years with more time spent in preparation and in post-intervention support. It also requires additional funds and more flexibility in using budgets and the engagement of specialist service providers (Wani *et al.*, 2008a).

One of the weakest aspects lies in the generation and dissemination of technology. A big improvement is needed in making appropriate technology and information accessible to the watershed community. The remedy lies in devising technology for the drier and wetter parts of the rainfed area, more participatory development research and in forming consortia, and employing agencies to provide specialist technical backstopping.

There is a crucial need to improve monitoring and evaluation and the feedback of the information obtained to constantly improve performance. Only a few key indicators need to be monitored in all watersheds. At one or two representative watersheds in each district, a broad range of technical and socioeconomic parameters should be measured to provide a scientific benchmark and a better economic valuation of impact than is currently possible (Wani *et al.*, 2008a).

Operationalizing Community Watershed as Growth Engine

Community watershed development programmes are used as growth engines for sustainable development of rainfed areas (Wani *et al.*, 2003b, 2006b, 2008b). However, the major challenge is scaling-up to large areas as successful watersheds remained few and unreplicated (Kerr *et al.*, 2002; Joshi *et al.*, 2005). Recently ICRISAT has developed and evaluated an integrated consortium approach for sustainable development of community watersheds with technical backstopping and convergence (Wani *et al.*, 2002, 2003b). Most farming problems require the IGNRM approach that is participatory, with farmers closely involved in technology development, testing and dissemination. The adoption of this new paradigm in rainfed agriculture has shown that with proper management of natural resources the systems productivity can be enhanced and poverty can be reduced without causing further degradation of natural resource base (Wani *et al.*, 2008b; Rockström *et al.*, 2007). The scaling-up of these innovations with technical support from ICRISAT-led consortium has been attempted in Andhra Pradesh, India through Andhra Pradesh Rural Livelihoods Programme (APRLP) supported by the Department for International Development (DFID), UK; in Karnataka, (India), Sujala watershed programme supported by the World Bank; in three districts of Madhya

Pradesh and Rajasthan with the support from Sir Dorabji Tata Trust (SDTT), Mumbai, India; and four countries in Asia (India, Thailand, Vietnam and China) with the support of Asian Development Bank (ADB), Philippines (Wani et al. 2008b, Sreedevi and Wani 2009).

Knowledge-based Entry Point –widespread Micronutrient Deficiencies in SAT Soils

In the watershed programs to build the rapport with the communities an entry point activity (EPA) is undertaken at the beginning of the program. In the traditional watershed programs generally the EPAs covered some common intervention such as construction of classroom, a meeting place, putting a hand pump for drinking water, etc to benefit the community. However, such EPAs did not serve the purpose of building the rapport with the communities and no quality participation was achieved. ICRISAT consortium team identified the drivers of collective action (Sreedevi et al. 2004) and developed knowledge-based EPA to enhance community participation. The main objective was to use knowledge as capacity building measure to benefit the large number of farmers to get tangible economic benefits during the first season. (Dixit et al, 2007). Analysis of soil samples, introduction of seeds of stress-tolerant and high yielding cultivar in the watershed, which can benefit large number of farmers, were selected as the EPAs. ICRISAT-led consortium has assessed 11000 soil samples from the farmers' fields in different states of India (Andhra Pradesh, Karnataka, Kerala, Rajsthan, Madhya Pradesh, Gujarat and Tamil Nadu) and observed widespread deficiencies of sulphur (S), zinc (Zn) and boron (B) along with total nitrogen (N) and phosphorus (P) (Table 2a, Table 2b) (Sahrawat *et al.*, 2007). For rapport building, knowledge-based EPA for example, the results of the soil analysis were presented in the *gram sabhas* and the importance of soil analysis and nutrient deficiencies in crop production were discussed. A large number of farmers were convinced about the importance of balanced nutrition in crop production and came forward as volunteers to evaluate the INM options.

Convergence and Collective Action

Convergence of actors and their actions at watershed level is needed to harness the synergies and to maximize the benefits through efficient and sustainable use of natural resources to benefit small and marginal farmers through increased productivity per unit of resource. We have missed out large benefits of watershed programmes due to compartmental approach and there is an urgent need to bring in convergence, as the benefits are manifold and its win-win for all the stakeholders including line departments involved in improving rural livelihoods.

Table 2a. Percentage of farmers' fields deficient in soil nutrients in different states of India[(a)].

State	No. of farmers' fields	OC (%)	AvP (ppm)	K (ppm)	S (ppm)	B (ppm)	Zn (ppm)
Andhra Pradesh	1927	84	39	12	87	88	81
Karnataka	1260	58	49	18	85	76	72
Madhya Pradesh	73	9	86	1	96	65	93
Rajasthan	179	22	40	9	64	43	24
Gujarat	82	12	60	10	46	100	82
Tamil Nadu	119	57	51	24	71	89	61
Kerala	28	11	21	7	96	100	18

[(a)] OC = Organic Carbon; AvP = Available phosphorus

Table 2b. Percentage of farmers' fields deficient in soil nutrients in different states of Karnataka, India[(a)].

State	No. of farmers' fields	OC (%)	AvP (ppm)	K (ppm)	S (ppm)	B (ppm)	Zn (ppm)
Dharwad district	1129	31	53	1	79	39	44
Haveri district	1532	55	42	5	85	46	60
Chitradurga Dist	1489	76	54	15	86	64	80
Madhgiri Dist	987	81	67	30	93	91	51
Tumkur Dist	2054	75	64	35	92	92	50
Kolar Dist	2161	81	31	34	85	87	32
Chickballapur Dist	2257	78	37	34	80	80	52

[(a)] OC = Organic Carbon; AvP = Available phosphorus

New institutional mechanisms are also needed at district, state, and national level to converge various watershed programmes implemented by several ministries and development agencies to enhance the impact and efficiency by overcoming duplicity and confusion. In 2005, the National Commission on Farmers recommended a holistic integrated watershed management approach, with focus on rainwater harvesting and improving soil health for sustainable development of drought-prone rainfed areas (Government of India, 2005). Recently, Government of India has established National Rain-fed Areas Authority (NRAA) with the mandate to converge various programmes for integrated development of rainfed agriculture in the country and have released Common Watershed Guidelines (Government of India, 2008). Recently, Department of Land Resources, Ministry of Rural Development has merged all it's watershed programs in to Integrated Watershed Development Program (IWDP). Similarly, national rural employment guarantee act (NREGA) programs are trying to converge watershed activities. These are welcome developments, however, it is just a beginning and lot more still needs to be done to provide institutional and policy support for development of rainfed areas. Thus, it has become increasingly clear that water management for rainfed agriculture requires a landscape perspective, and involves cross-scale interactions from farm household scale to watershed/catchment scale.

Enhancing partnerships and institutional innovations through the consortium approach was the major impetus for harnessing community watershed's potential to reduce households' poverty. The underlying element of the consortium approach adapted in ICRISAT-led community watersheds is engaging a range of actors with the locales as the primary implementing unit. This created the venue for receiving technical support and building the capacity of members like women for the management of conservation and livelihood development activities. Incorporating knowledge-based entry point in the approach led to the facilitation of rapport and at the same time enabled the community to take rational decisions for their own development. As demonstrated by ICRISAT, the strongest merit of consortium approach is in the area of capacity building where farm households are not the sole beneficiaries and researchers, development workers and students of various disciplines are also trained, and policymakers from the NARSs sensitized on the entire gamut of community watershed activities. Private-public partnership has provided the means for increased investments not only for enhancing productivity but also for building institutions as engines for people-led NRM. From another aspect, the consortium approach has contributed to scaling through the nucleus-satellite scheme and building productive alliances for further research and technical backstopping. A balanced R&D programme in community watersheds has encouraged scientific debate and at the same time promoted development through tangible economic benefits.

Capacity Building

ICRISAT-led consortium's comprehensive assessment of watershed programs in India identified the poor capacity building as the weakest link for scaling-up the program and enhancing the impacts as watershed development is knowledge intensive and inherently slow It has recommended strengthening of capacity building strategies at different levels from community level to national level. Capacity building of different stakeholders from farmers up to policy makers in various aspects of holistic watershed management is needed and it should be through a consortium of quality service providing training institutions. As a forward looking step it has also suggested quality management systems and certification system for the service providers. Establishment of Model watersheds as sites of learning in each district for hands on training for the stakeholders and also for monitoring detailed impacts are recommended (Wani et ai, 2008a). Empowerment of different stakeholders through capacity building in participatory integrated watershed management could be facilitated for scaling-up the benefits from the nucleus and satellite watersheds in the target regions (Figure 5).

ICT-enabled Farmer-centred Learning Systems for Knowledge Exchange

It is increasingly realized that facilitation of knowledge flows is a key in fostering new rural livelihood opportunities using modern information and communication technologies (ICTs). The concept adapted is one of intelligent intermediation for facilitation of flows of information and knowledge. The community centre managed by the PIAs functions as a Rural Information Hub connecting participating villages (or groups of villages, as the case may be) and also with other Internet connected websites. It is operated or managed by a rural group (women or youth SHGs) identified by the village watershed council through a consultative process. The activities on this module are planned to adopt a hub-and-spokes model for information dissemination among the participants and stakeholders. The electronic network across select nuclear watersheds enables sharing of experience and best practices.

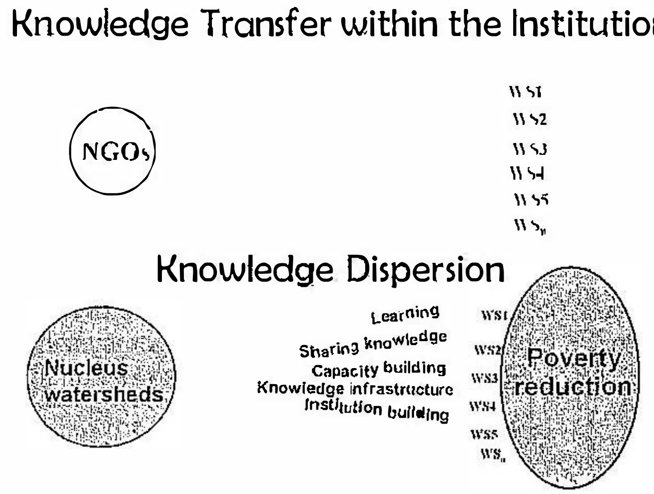


Figure 5. Knowledge transfer within the institution and the region (WS = Watershed).

Forward Looking Approach to Manage High Risk and Impacts of Climate Change

Rainfed agriculture is a risky business due to high spatial and temporal variability of rainfall. Rainfall is concentrated in short rainy seasons (approximately 3 to 5 months), with few intensive rainfall events, which are unreliable in temporal distribution, manifested by high deviations from the mean rainfall (coefficients of variation of rainfall as high as 40% in semiarid regions) (Wani *et al.*, 2004). In fact, even if water is not always the key-limiting factor for yield increase, rainfall is the only truly random production factor in the agricultural system. This is manifested through high rainfall variability causing recurrent flooding, droughts and dry spells.

Established but incomplete evidence suggests that the high risk for water related yield loss makes farmers avert risk, which in turn determines farmers' perceptions on investments in other production factors (such as labour, improved seed and fertilizers) (Wani et al. 2006a & b). Temporal and spatial variability of climate, especially rainfall, is a major constraint to yield improvements, competitiveness and commercialization of rainfed crop, tree crops and livestock systems in most of the tropics. Management options should therefore start by focussing on reducing rainfall induced risks.

Evidence is emerging that climate change is making the variability more intense with increased frequency of extreme events such as drought, floods and hurricanes (IPCC, 2001). A recent study assessing rainfed cereal potential under different climate change scenarios, with varying total rainfall amounts concluded that it is difficult to estimate the degree of regional impact. But most scenarios resulted in losses of rainfed production potential in the most vulnerable developing countries. In these countries, the loss of production area was estimated at 10-20%, with an approximate potential of 1-3 billion people affected in 2080 (IIASA, 2002). In particular, sub-Sahara Africa is estimated to lose 12% of the cultivation potential mostly projected in the Sudan-Sahelian zone which is already subject to high climatic variability and adverse crop conditions. Because of the risk associated with climate variability, small-holder farmers are generally and rationally keen to start by reducing risk of crop failure due to dry spells and drought before they consider investments in soil fertility, improved crop varieties, and other yield enhancing inputs (Hilhost and Muchena, 2000).

Conjunctive Use of Water: Discard Artificial Divide between Irrigated and Rainfed Agriculture

Adopt integrated water resource management approach in the watersheds by discarding the artificial divide between rainfed and irrigated agriculture. There is an urgent need to have sustainable water (rain-, ground- and surface-water) use policies to ensure sustainable development. In the absence of suitable policies and mechanisms for sustainable use of groundwater resources benefits of watershed programmes can easily be undone in short period with overexploitation of the augmented water resources (Sreedevi et al. 2006). Cultivation of water inefficient crops like rice and sugarcane need to be controlled using groundwater in watersheds through suitable incentive mechanisms for rainfed irrigated crops and policy to stop cultivation of high water requiring crops (Wani et al. 2008a).

Business Model

Watersheds should be developed as business model through public-private partnership using principles of market-led diversification using high-value crops, value chain approach and livelihood approach rather than only soil and water conservation approach. Strengths of rainfed areas using available water resources efficiently through involvement of private entrepreneurs and value addition can be harnessed by linking small and marginal farmers to markets through public-private partnership business model for watershed management.

Multiple Benefits and Impacts of the Community Watershed Development

Through the use of new science tools [i.e. remote sensing, geographical information systems (GIS) and simulation modelling) along with an understanding of the entire food production-utilization system (i.e. food quality and market) and genuine involvement of stakeholders, ICRISAT-led watersheds effected remarkable impacts on SAT resource-poor farm households.

Reducing rural poverty in the watershed communities is evident in the transformation of their economies. The ICRISAT model ensured improved productivity with the adoption of cost-efficient water harvesting structures (WHS) as an entry point for improving livelihoods. Crop intensification and diversification with high-value crops is one leading example that allowed households to achieve production of basic staples and surplus for modest incomes. The model has provision for improving the capacity of farm households through training and networking and for alleviating livelihood and enhanced participation especially of the most vulnerable groups like women and the landless.

Building on social capital made the huge difference in addressing rural poverty of watershed communities. This is evident in the case of Kothapally watershed in Andhra Pradesh, India. Today, it is a prosperous village on the path of long-term sustainability and has become a beacon for science-led rural development. In 2001, the average village income from agriculture, livestock and non-farming sources was US$ 945 compared with the neighbouring non-watershed village income of US$ 613 (Figure 4). The villagers proudly professed: "*We did not face any difficulty for water even during the drought year of 2002. When surrounding villages had no drinking water, our wells had sufficient water.*"

Crop Livestock integration is another facet harnessed for poverty reduction. The Lucheba watershed, Guizhou province of southern China has transformed its economy through modest injection of capital-allied contributions of labour and finance, to create basic infrastructures like access to roads and drinking water supply. With technical support from the consortium, the farming system was intensified from rice and rape seed to tending livestock (pig raising) and growing horticultural crops (fruit trees like *Ziziphus*; vegetables like beans, peas and sweetpotato) and groundnuts. In forage production, wild buckwheat was specifically important as an alley crop as it was a good forage grass for pigs. This cropping technology was also effective in controlling erosion and increasing farm income in sloping lands. This holds true in many watersheds of India where the improvement in fodder production has intensified livestock activities like breed improvement (artificial insemination and natural means) and livestock centre/health camp establishment (Wani *et al.*, 2006b). In Tad Fa and Wang Chai watersheds in Thailand, there was a 45% increase in farm income within three years. Farmers earned an average net income of US$ 1195 per cropping season. A complete turnaround in livelihood system of farm households was inevitable in ICRISAT-led watersheds (Wani et al. 2008b).

Increasing crop productivity is a common objective in all the watershed programmes; and the enhanced crop productivity is achieved after the implementation of soil and water conservation practices along with appropriate crop and nutrient management. For example, the implementation of improved crop management technology in the benchmark watersheds of Andhra Pradesh increased the maize yield by 2.5 times (Table 3) and sorghum yield by threefold (Wani *et al.*, 2006b & 2008b). Overall, in the 65 community watersheds (each measuring approximately 500 ha), implementing best-bet practices resulted in significant yield advantages in sorghum (35-270%), maize (30-174%), pearl millet (72-242%), groundnut (28-179%), sole pigeonpea (97-204%) and intercropped pigeonpea (40-110%). In Thanh Ha watershed of Vietnam, yields of soybean, groundnut and mung bean increased by threefold to fourfold (2.8–3.5 t/ha) as compared with baseline yields (0.5 to 1.0 t/ha), reducing the yield gap between potential farmers' yields. A reduction in nitrogen fertilizer (90–120 kg urea per ha) by 38% increased maize yield by 18%. In Tad Fa watershed of northeastern Thailand, maize yield increased by 27-34% with improved crop management.

Table 3. Crop yields in Adarsha watershed Kothapally during 1999-2007.

Crop	1998	Yield (kg/ha)									
	base-line yield	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	Ave-rage yields	SE±
Sole maize	1500	3250	3750	3300	3480	3920	3420	3920	3635	3640	283.3
Improved intercropped maize	-	2700	2790	2800	3083	3129	2950	3360	3180	3030	263.0
Traditional intercropped maize	-	700	1600	1600	1800	1950	2025	2275	2150	1785	115.6
Improved intercropped pigeonpea		640	940	800	720	950	680	925	970	860	120.3
Traditional intercropped pigeonpea	190	200	180	-	-	-	-	-	-	190	-
Improved Sole sorghum	-	3050	3170	2600	2425	2290	2325	2250	2085	2530	164.0
Traditional sole sorghum	1070	1070	1010	940	910	952	1025	1083	995	1000	120.7
Intercropped sorghum	-	1770	1940	2200	-	2110	1980	1960	1850	1970	206.0

Improving water availability in the watersheds was attributed to efficient management of rainwater and *in-situ* conservation, establishment of WHS and improved groundwater levels. Findings in most of the watershed sites reveal that open wells located near WHS have significantly higher water levels compared to those away from the WHS. Even after the rainy season, the water level in wells nearer to WHS sustained good groundwater yield. In the various watersheds of India like Lalatora (in Madhya Prdesh), treated area registered a groundwater level rise by 7.3 m. At Bundi, Rajasthan, the average rise was 5.7 m and the irrigated area increased from 207 ha to 343 ha. In Kothapally watershed in Andhra Pradesh, the groundwater level rise was 4.2 m in open wells. With such improvement in groundwater availability, the supply of clean drinking water was guaranteed. In Lucheba watershed in China, a drinking water project, which constitutes a water storage tank and pipelines to farm households, was a joint effort of the community and the watershed project. This solved the drinking water problem for 62 households and more than 300 livestock. Earlier every farmer's household used to spend 2-3 hours per day fetching drinking water. This was the main motivation for the excellent farmers' participation in the project. On the other hand, collective pumping out of well water established efficient water distribution system and enabled farmers' group to earn more income by growing watermelon with reduced drudgery as women had to carry water on the head from a long distance. Pumping of water from the river as a means to irrigate watermelon has provided maximum income for households in Thanh Ha watershed (in Vietnam) (Wani *et al.*, 2006b).

Supplemental irrigation can play a very important role in reducing the risk of crop failures and in optimizing the productivity in the SAT. In these regions, there is good potential for delivering excess rainwater to storage structures or groundwater because even under improved systems, there is loss of 12-30% of the rainfall as runoff. Striking results were recorded from supplemental irrigation on crop yields in ICRISAT benchmark watersheds in Madhya Pradesh. On-farm studies made during 2000-03 postrainy seasons, showed that chickpea yield (1.25 t/ha) increased by 127% over the control yield (0.55 t/ha); and groundnut pod yield (1.3 t/ha) increased by 59% over the control yield (0.82 t/ha) by application of two supplemental irrigations of 40 mm (Pathak *et al.*, 2009).

Sustaining development and protecting the environment are the two-pronged achievements of the watersheds. The effectiveness of improved watershed technologies was evident in reducing runoff volume, peak runoff rate and soil loss and improving groundwater recharge. This is particularly significant in Tad Fa watershed where interventions such as contour cultivation at mid-slopes, vegetative bunds planted with *Vetiver*, fruit trees grown on steep slopes and relay cropping with rice bean reduced seasonal runoff to less than half (194 mm) and soil loss less than $1/7^{th}$ (4.21 t/ha) as compared to the conventional system (473 mm runoff and soil loss 31.2 t/ha). This holds true with peak runoff rate where the reduction is approximately one-third (Table 4).

Large number of fields (80-100%) in the SAT were found severely deficient in zinc, boron and sulphur as well as nitrogen and phosphorus. Amendment of soils with the deficient micro- and secondary nutrients increased crop yields by 30 to 70%, resulting in overall increase in water and nutrient use efficiency. Introduction of integrated pest management (IPM) and improved cropping systems decreased the use of pesticides worth US$ 44 to 66 per ha. Crop rotation using legumes in Wang Chai watershed (Thailand) substantially reduced nitrogen requirement for rainfed sugarcane. The IPM practices, which brought into use local knowledge using insect traps of molasses, light traps and tobacco waste, led to extensive vegetable production in Xiaoxingcun (China) and Wang Chai (Thailand) watersheds.

Table 4. Seasonal rainfall, runoff and soil loss from different benchmark watersheds in India and Thailand.

Watershed	Seasonal rainfall (mm)	Runoff (mm)		Soil loss (t/ha)	
		Treated	Untreated	Treated	Untreated
Tad Fa (Khon Kaen, NE Thailand)	1284	169	364	4.21	31.2
Kothapally (Andhra Pradesh, India)	743	44	67	0.82	1.9
Ringnodia (Madhya Pradesh, India)	764	21	66	0.75	2.2
Lalatora (Madhya Pradesh, India)	1046	70	273	0.63	3.2

Improved land and water management practices along with integrated nutrient management comprising application of inorganic fertilizers and organic amendments (such as crop residues, vermicompost, farm manures and *Gliricidia* loppings) as well as crop diversification with legumes not only enhanced productivity but also improved soil quality. Increased carbon sequestration of 7.4 t/ha in 24 years was observed with improved management options in a long-term watershed experiment at ICRISAT (Wani et al. 2003a). Normalized difference vegetation index (NDVI) estimation from the satellite images showed that within four years, vegetation cover could increase by 35% in Kothapally. The IGNRM options in the watersheds reduced loss of NO_3-N in runoff water (8 vs 14 kg nitrogen per ha). Reduced runoff and erosion reduced risk of downstream flooding and siltation of water bodies that directly improved environmental quality in the watersheds (Pathak *et al.*, 2005; Sahrawat *et al.*, 2005; Wani *et al.*, 2005).

Conserving biodiversity in the watersheds was engendered through participatory NRM. The index of surface percentage of crops (ISPC), crop agro-biodiversity factor (CAF), and surface variability of main crops changed as a result of integrated watershed management interventions. Pronounced agro-biodiversity impacts were observed in Kothapally watershed where farmers now grow 22 crops in a season with a remarkable shift in cropping pattern from cotton (200 ha in 1998 to 100 ha in 2002) to a maize/pigeonpea intercrop system (40 ha in 1998 to 180 ha in 2002), thereby changing the CAF from 0.41 in 1998 to 0.73 in 2002. In Thanh Ha, Vietnam the CAF changed from 0.25 in 1998 to 0.6 in 2002 with the introduction of legumes. Similarly, rehabilitation of the common property resource land in Bundi watershed through the collective action of the community ensured the availability of fodder for all the households and income of US$ 1670 per yr for the SHG through sale of grass to the surrounding villages. Aboveground diversity of plants (54 plant species belonging to 35 families) as well as belowground diversity of microorganisms (21 bacterial isolates, 31 fungal species and 1.6 times higher biomass C) was evident in rehabilitated CPR as compared to the degraded CPR land (9 plant species, 18 bacterial isolates and 20 fungal isolates of which 75% belong to *Aspergillus* genus) (Wani *et al.*, 2005)

Conclusions

Sustainable rural development through conservation of land and water resources gives plausible solution for alleviating rural poverty and improving the livelihoods of rural poor through watershed approach. In an effective convergence mode for improving the rural livelihoods in the target districts, with watersheds as the operational units, a holistic integrated systems approach by drawing attention on the past experiences, existing opportunities and skills, and supported partnerships can enable change and improve the livelihoods of rural poor. The rationale behind convergence through watersheds has been that these watersheds help in "cross learning" and drawing wide range of experiences from different sectors. A significant conclusion is that there should be a balance between attending to needs and priorities of rural livelihoods and enhancing positive directions of change by building effective and sustainable partnerships along with the capacity building of the stakeholders. Based on the experience and performance of the existing integrated community watersheds in different socioeconomic environments, appropriate exit strategies, which include proper sequencing of interventions, building up of financial, technical and organizational capacity of local communities to internalize and sustain interventions, and the requirement for any minimal external technical and organizational support need to be identified.

Acknowledgements

We acknowledge the help of number of community based organizations in different watersheds who undertook PR&D. Financial support provided by the Government of India, Asian Development Bank (ADB), Manila, The Phillippines, DFID, through APRLP (Andhra Pradesh Rural Livelihood Project), Sir Dorabji Tata Trust, Mumbai and World Bank supported Sujala Watershed Program of Government of Karnataka.

References

Derpsch, R. (1998) Historical review of no-tillage cultivation of crops. In: *Conservation Tillage for Sustainable Agriculture- from an International Workshop,* Harare, 22 to 27 June, 1997. Part II (Annexes) (Benites, J., Chuma, E., Fowler, R., Kienzle, J., Molapong, K., Manu, J., Nyagumbo, I., Steiner, K. and van Veenhuizen R, Eds.), pp 205-218. Proceedings Deutsche Gesellschaft, GTZ, Eschborn, Germany.

Derpsch, R. 2005. The extent of conservation agriculture adoption worldwide: Implications and impact. Keynote paper at the 3rd World Congress on Conservation Agriculture, Oct 3 to 7, 2005, Nairobi, Kenya organized by RELMA/ICRAF, Nairobi, Kenya.

Dixit, Sreenath., Wani, S.P., Rego, T.J. and Pardhasaradhi, G. 2007. Knowledge-based Entry Point and Innovative Up-scaling Strategy for Watershed Development Projects. Indian Journal of Dryland Agriculture and Development. **22 (1):**22-31.

Duivenbooden, van N., Pala, M., Studer, C., Bielders, C.L. and Beukes, D.J. 2000. Cropping systems and crop complementarity in dryland agriculture to increase soil water use efficiency: a review. *Netherland Journal of Agricultural Science* **48,** 213-236.

Falkenmark, M. 1986. Fresh water - Time for a modified approach. *Ambio,* **15(4),**192-200.

Falkenmark, M. and Rockström, J. (2004). Balancing water for humans and nature: the new approach in ecohydrology. Earthscan, London, UK. pp 322.

Government of India. 2005. Serving Farmers and Saving Farming–2006: Year of Agricultural Renewal. Third Report. December 2005. National Commission on Farmers, Ministry of Agriculture, Government of India, New Delhi, India. pp 305.

Government of India. 2008. Common guidelines for watershed development projects. National Rain-fed Area Authority (NRAA), Ministry of Land Resources, Government of Andhra Pradesh, India. pp 57.

Harris, H.C., Cooper, P.J.M. and Pala, M. (1991) *Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas. Proceedings of an International Workshop sponsored by MAFRA/ICARDA/CIMMYT, 1519 May 1989 Ankara, Turkey.* International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria, 352 pp.

Hilhost, T. and Muchena, F. 2000. *Nutrients on the Move: Soil Fertility Dynamics in African Farming Systems.* International Institute for Environment and Development, London, UK. pp 146.

Hobbs, P.R. and Gupta, R.K. (2002). Rice-wheat cropping systems in the Indo-Gangetic plains: Issues of water productivity in relation to new resource conserving technologies. In: *Water Productivity in agriculture: Limits and opportunities for improvement,* (Kijne, J.W, Ed.), pp 239-253. CAB International, Wallingford, UK.

IIASA 2002. Climate change and agricultural vulnerability. Special report for the UN World Summit on sustainable Development, Johhanesburg, 2002 pp 160. (http://www.iiasa.ac.at/Research/LUC/JB-Report.pdf).

IPCC. 2001. Intergovernmental Panel on Climate Change, *Third Assessment Report.* Cambridge University Press, Cambridge, UK. www.ipcc.ch

Irz, X. and Roe, T. 2000. Can the world feed itself? Some insights from growth theory, Agrekon, **39(3)**, 513-528.

Joshi, P.K., Jha, A.K., Wani, S.P., Laxmi Joshi and Shiyani, R.L. 2005. Meta-analysis to assess impact of watershed program and people's participation. *Comprehensive Assessment Research Report 8.* Comprehensive Assessment Secretariat (IWMI), Colombo, Sri Lanka. pp.1-18.

Kerr, J., Pangare, G. and Pangare, V. 2002. Watershed development project in India: An evaluation. Research Report no. 127. Environment and Policy Production Technology Division, International Food Policy Research Institute, Washington, DC, USA. pp 102.

Landers, J.N., Mattana Saturnio, H., de Freitas, P.L. and Trecenti, R. (2001) Experiences with farmer clubs in dissemination of zero tillage in tropical Brazil. In: *Conservation Agriculture, a Worldwide Challenge,* (García-Torres, L., Benites, J. and Martínez-Vilela,A, Eds.), pp.71-76. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Molden, D., Karen Frenken, Randolph Barker, Charlotte de Fraiture, bancy Mati, mark Svendsen, Claudia Sadoff, and Max Finlayson, C. (2007) Trends in water and agricultural development In: *Water for Food: Water for Life- A Comprehensive Assessment of Water Management in Agriculture* (Moden D, Ed.), pp. 57-89. 'International Water Management Institute (IWMI), Colombo, Srilanka.

Oweis, T. and Taimeh, A. 1996. Evaluation of small basin water harvesting systems in the arid region of Jordan. *Water Resources Management* **10,** 21-34.

Pathak, P., Sahrawat, K.L., Rego, T.J. and Wani, S.P. 2005. Measurable biophysical indicators for impact assessment: changes in soil quality. In: *Natural Resource Management in Agriculture: Methods for assessing Economic and Environmental Impacts.* (Shiferaw, B., Freeman, H.A. and Swinton, S.M. Eds), pp 53-74. CAB International, Wallingford, UK, Pathak, P., Sahrawat, K.L., Wani, S.P., Sachan, R.C. and Sudi, R. (2009). Opportunities for water harvesting and supplemental irrigation for improving rainfed agriculture in semi-arid areas. In: Rain-fed agriculture: Unlocking the Potential. (Wani, S.P., John Rockstrom and Theib Oweis Eds.). Comprehensive Assessment of Water Management in Agriculture Series, CABI Publication, In Print.

Rockström, J. and Falkenmark, M. 2000. Semiarid crop production from a hydrological perspective: Gap between potential and actual yields. *Critical Reviews in Plant Science* 19(4), 319-346.

Rockström, J., Nuhu Hatibu, Theib Oweis. and Wani, S.P. (2007). Managing water in rain-fed agriculture. In: *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture* (Molden, D. Ed.), pp. 315-348. Earthscan, London, UK and International Water Management Institute (IWMI), Colombo, Srilanka.

Rosegrant, M., Ximing, C., Cline, S., Nakagawa, N. 2002. The role of rain-fed agriculture in the future of global food production. *EPTD Discussion Paper No. 90*, Environment and Production Technology Division, IFPRI, Washington DC, USA, pp 105. (htlp://www.ifpri.org/divs/eptd/dp/papers/eptdp90.pdf)

Ryan, J.G. and Spencer, D.C. 2001. *Challenges and Opportunities Shaping the Future of the Semi-Arid Tropics and their Implications.* International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India, pp 83.

Sahrawat, K.L., Bhattacharyya, T., Wani, S.P., Ray, S.K., Pal, D.K. and Padmaja, K.V. 2005. Long-term lowland rice and arable cropping effects on carbon and nitrogen status of some semi-arid tropical soils. *Current Science* 89(12), 2159-2163.

Sahrawat, K.L., Wani, S.P., Rego, T.J., Pardhasaradhi, G. and Murthy, K.V.S. 2007. Widespread deficiencies of sulphur, boron and zinc in dryland soils of the Indian semiarid tropics. In: *Current Science*, 93 (10), 1-6.

Seckler, D. and Amarasinghe, U. (2004). Major problems in the global water-food nexus. In: *Perspectives in World Food and Agriculture 2004* (Scanes, C. and Miranowski, J. Eds), pp 227-251. Iowa State Press/World Food Prize, Ames, Iowa, USA.

SEI (Stockholm Environment Institute). 2005. *Sustainable pathways to attain the millennium development goals - assessing the role of water, energy and sanitation.* Document prepared *for the UN World Summit, Sept 14, 2005, New York, USA* SEI, *Stockholm, Swedan.* (http://www.sei.se/mdg.htm).

Singh, P., Aggarwal, P.K., Bhatia, V.S., Murthy, M.V.R., Pala, M., Oweis, T., Benli, B., Rao, K.P.C., and Wani, S.P. (2009). Yield Gap Analysis: Modelling of Achievable Yields at Farm Level. In: Rain-fed agriculture: Unlocking the Potential. (Wani, S.P., John Rockström and Theib Oweis Eds.).Comprehensive Assessment of Water Management in Agriculture Series, CABI Publication, In Print.

Somme, G., Oweis, T., Abdulal, Q., Bruggeman, A., Ali, A. 2004. Micro-catchment water harvesting for improved vegetative cover in the Syrian badia. *On-farm Water Husbandry Research Reports Series No3*. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria, pp 33.

Sreedevi, T.K., Shiferaw, B. and Wani, S.P. 2004. *Adarsha Watershed, Kothapally: Understanding the Drivers of Higher Impact.* International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India. pp 22.

Sreedevi, T.K., Wani, S.P., Sudi, R., Patel, M.S., Jayesh, T., Singh, S.N. and Tushar Shah. 2006. On-site and off-site impact of watershed development: A case study of Rajasamadhiyala, Gujarat, India. *Global Theme on Agroecosystems Report No. 20.* International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India, pp 48.

Sreedevi, T.K. and Wani, S.P. (2009). Integrated farm management practices and up-scaling the impact for increased productivity of rainfed systems. In: Rain-fed agriculture: Unlocking the Potential. (Wani, S.P., John Rockstrom and Theib Oweis Eds.). Comprehensive Assessment of Water Management in Agriculture Series, CABI Publication, In Print.

Thirtle, C., Beyers, L., Lin, L., Mckenzie-Hill, V., Irz, X., Wiggins, S. and Piesse, J. 2002 The impacts of changes in agricultural productivity on the incidence of poverty in developing countries. *DFID Report No 7946.* Department for International Development (DFID), London, UK.

Twomlow, S., Shiferaw, B., Cooper, Peter. and Keatinge, J.D.H. 2006. *Integrating Genetics and Natural Resource Management for Technology Targeting and Greater Impact of Agricultural Research in the Semi-Arid Tropics,* International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India, pp 28.

UNEP (United Nations Environment Programme). 1997. *World Atlas of Desertification, Second Edition.*

UNStat 2005. www.unstat.com. Last accessed in 2005.

Wani, S.P., Pathak, P., Tam, H.M., Ramakrishna, A., Singh, P. and Sreedevi, T.K. (2002) Integrated watershed management for minimizing land degradation and sustaining productivity in Asia. In: *Integrated Land Management in the Dry Areas.* (Zafar Adeel Ed.), pp 207-230. *Proceedings of a Joint UNU-CAS International Workshop, 8-13 September 2001, Beijing, China,* United Nations University, Tokyo, Japan.

Wani, S.P., Pathak, P., Jangawad, L.S., Eswaran, H., Singh, P. 2003a. Improved management of Vertisols in the semi-arid tropics for increased productivity and soil carbon sequestration. *Soil Use and Management*, 19, 217-222.

Wani, S.P., Pathak, P, Sreedevi, T.K., Singh, H.P. and Singh, P. (2003b).Efficient management of rainwater for increased crop productivity and groundwater recharge in Asia. In: *Water Productivity in Agriculture: Limits and Opportunities for Improvement.* (Kijne, J.W., Barker, R. and Molden, D. Eds,), pp. 199-215. CAB International, Wallingford, UK; International Water Management Institute (IWMI), Colombo, Sri Lanka.

Wani, S.P., Balloli, S.S., Kesava Rao, A.V.R. and Sreedevi, T.K. 2004. Combating drought through integrated watershed management for sustainable dryland agriculture. In: *Regional Workshop on Agricultural Drought Monitoring and Assessment Using Space Technology*, 4 May 2004, National Remote Sensing Agency (NRSA), Hyderabad, India, pp. 39-48.

Wani, S.P., Meera Reddy, Sreedevi, T.K. and Damle Raju (eds). 2006a. *Corporate Science and Technology Institutions– Partnerships for Inclusive and Sustainable Development and Economic Growth*: Proceedings of the CII-ICRISAT Workshop, 27 February 2006, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India. pp 38.

Wani, S.P., Ramakrishna, Y.S., Sreedevi, T.K., Long, T.D., Thawilkal Wangkahart, Shiferaw, B., Pathak, P. and Kesava Rao, A.V.R. 2006b. Issues, concepts, approaches and practices in integrated watershed management: Experience and lessons from Asia. In: *Integrated Management of Watersheds for Agricultural Diversification and Sustainable Livelihoods in Eastern and Central Africa; Lessons and Experiences from Semi-Arid South Asia.* Proceedings of the International Workshop held at ICRISAT, Nairobi, 6–7 December 2004. International Crops Research Institute for the Semi-Arid Tropics, (ICRISAT)Patancheru 502 324, Andhra Pradesh, India, pp. 17-36.

Wani, S.P., Joshi, P.K., Raju, K.V., Sreedevi, T.K., Wilson, J.M., Shah Amita, Diwakar, P.G., Palanisami, K., Marimuthu, S., Jha, A.K., Ramakrishna, Y.S., Meenakshi Sundaram, S.S. and D'Souza, Marcella. 2008a. Community Watershed as a Growth Engine for Development of Dryland Areas. A Comprehensive Assessment of Watershed Programs in India. Global Theme on Agroecosystems Report no. 47, Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. pp 145.

Wani, S.P., Joshi, P.K., Ramakrishna, Y.S., Sreedevi, T.K., Piara Singh and Pathak, P. (2008b). A new paradigm in watershed management: A must for development of rain-fed areas for inclusive growth. In: *Conservation Farming: Enhancing Productivity and Profitability of Rain-fed Areas* (Anand Swarup, Suraj Bhan and Bali, J.S Eds), pp 163-178. *Soil Conservation Society of India*, New Delhi, India.

Wani, S.P., Sreedevi, T.K. and Marimuthu, S. 2008c. *A Comprehensive Assessment of Watershed Programmes in India.* Proceedings of the Review Meeting and Component Workshops, 23-27 July, 2007. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India. pp 332.

Wani, S.P., Sreedevi, T.K., Rockström Johan. and Ramakrishna, Y.S. (2009).Raifned Agriculture – Past trends and future prospects. In: Rain-fed agriculture: Unlocking the Potential. (Wani, S.P., John Rockström and Theib Oweis Eds.).Comprehensive Assessment of Water Management in Agriculture Series, CABI Publication, In Print.

WHO (World Health Organization). 2000. Gender, health and poverty. *Factsheet No. 25*, (http://www.who.int/mediacenter/factsheets/fs251/en/).

World Bank. 2005. *Agricultural Growth for the Poor: An Agenda for Development.* The International Bank for Reconstruction and Development. The World Bank, Washington, DC, USA. pp19.