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Efficient Rainwater Management for Enhanced Productivity in Arid and Semi-Arid Drylands

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ABSTRACT

Rainfed areas are the hot spots of poverty, water scarcity, land degradation, and low social and physical capital development. However, vast potential of rainfed agriculture remains untapped as current rainfed crop yields range between 1-1.5 t ha^{-1}, which can be easily more than doubled with improved management. Main constraints for increasing crop yields are not only limited water but also by inappropriate management of water and soil resources. Current rainwater use efficiency of 35-45%, can be substantially increased by adopting integrated water resources management approach along with improved soil health and crop management options. There is an urgent need to have a new paradigm to mange water and land resources in the micro-catchments (watersheds) by converging all the necessary production functions as well as socioeconomic, institutional, and market factors to harness the vast untapped potential of rainfed agriculture for achieving inclusive and sustainable growth in the developing countries. Higher investments are needed in the rainfed areas to harness the potential and new innovative methods and partnerships are needed for knowledge management and sharing with the stakeholders. Concerted and converged approach are needed for development of rainfed areas and artificial divide between rainfed agriculture and irrigated agriculture need to be discarded; and convergence of various programmes in rainfed areas in watersheds are needed.

Key words : Rain water, Acid, Semi-arid, watershed

Rainfed agriculture has very important role in the global food security, as eighty per cent of the world's agricultural land area is rainfed and generates 58% of the world's staple foods (SIWI, 2001). In sub-Saharan Africa (SSA), more than 95% of the farmed land is rainfed, while the corresponding figure for Latin America is almost 90%, for South Asia about 60%, for East Asia 65% and for Near East and North Africa 75%. Farming systems in sub-Saharan Africa and Latin America are almost exclusively rainfed, while a predominant blue water dependence in irrigation is concentrated in the West Asian (> 80 % dependence) and North African regions (> 60 % dependence) (Rockström, 2003). In South and East Asia the picture is mixed, with countries depending in varying degrees on both rainfed and irrigated agriculture (e.g., India where 60% of water use in agriculture are estimated to originate from directly infiltrated rainfall, while 40% originates from extraction of river and groundwater for irrigation).

Most of 852 million hungry and malnourished people in the world are in Asia, which is also a hot spot of land degradation, particularly in India (221 million) and in China (142 million). In Asia, 75% of the poor are in rural areas and they depend on agriculture for their livelihood. About half of the hungry live in smallholder farming households, while two-tenths are landless. About 10% are pastoralists, fishfolk and forest users (Sanchez *et al.*, 2005). If the current production practices are continued, the Asian countries will face a serious food shortage in the very near future. In the arid, semi-arid regions of Asia and Africa, the economy remains strongly dependent on agriculture. Rainfed agriculture that constitutes the livelihood base for the vast majority of rural inhabitants (about 75 per cent of the poor in

South Asia, and about 80 per cent of the population in east Africa) in the developing countries, is a source of food security, employment and cash income (Rockstrom *et al.*, 2003).

Constraints in Rainfed Agriculture Areas

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 measures, poor infrastructure and inappropriate policies (Wani *et al.*, 2003a&c, Rockstrom *et al.*, 2007). Drought and land degradation are interlinked in a cause and effect relationship; and the two combined are the main causes of poverty in the farm households. This unholy nexus between drought, poverty and land degradation has to be broken to meet the MDG of halving the number of food insecure poor by 2015. Water scarcity is a significant problem for farmers in Africa, Asia, and the near East where 80 - 90 per cent of water withdrawals are used for agriculture (FAO 2000, Rosegrant *et al.*, 2002). Water a finite resource, the very basis of life and the single most important feature of our planet, is the most threatened natural resource at the present time. Water is the most important driver for four of the millennium development goals (MDGs), as shown in the **Fig. 1**. In the context of four MDGs contribution of water resources management through direct interventions are suggested to achieve the milestones by 2015. However, in many SAT situations water quantity *per se* is not the limiting factor for increased productivity but its management and efficient use are the main yield determinants. These rainfed areas are also prone to severe land degradation. Reduction in the producing capacity of land due to wind and water erosion of soil, loss of soil humus, depletion of soil nutrients, secondary salinization, diminution and deterioration of vegetation cover as well as loss of biodiversity is referred as land degradation. A global assessment of the extent and form of land degradation showed that 57% of the total area of drylands occurring in two major Asian countries namely China (178.9 m ha) and India (108.6 m ha) are degraded (UNEP, 1997). Accelerated erosion resulting in loss of nutrient rich top fertile soil however, occurs nearly everywhere

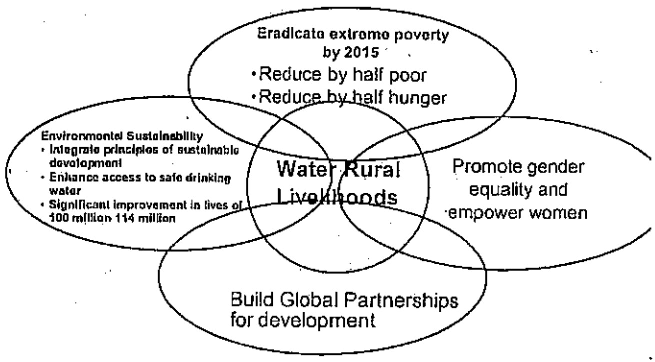


Fig. 1. Water an important driver for achieving the millennium development goals

where agriculture is practiced and is irreversible. The torrential character of the seasonal rainfall creates high risk for the cultivated lands. In India, alone some 150 million ha are affected by water erosion and 18 m ha by wind erosion. Thus, erosion leaves behind an impoverished soil on one hand, and siltation of reservoirs and tanks on the other. In addition imbalanced use of nutrients in agriculture by the farmers results in mining of soil nutrients. Recent studies in India revealed that 80 to 100% of the farmers' fields were found critically deficient in zinc, boron, and sulphur in addition to nitrogen and organic carbon (Rego *et al.*, 2005, Wani *et al.*, 2006a). If the current production practices are continued, developing countries in Asia and Africa will face a serious food shortage in the very near future.

Potential of Rainfed Agriculture

As indicated earlier water quantity *per se* is not the main limitation as is evident from the water balance studies made for a few SAT locations. Weekly water balances of selected watersheds in India, China, Thailand and Vietnam were completed based on long-term agrometeorological data and soil type. The water balance components included potential evapotranspiration (PET), actual evapotranspiration (AET), water surplus (WS) and water deficit (WD). PET varied from about 890 mm at Lucheba in China to 1890 mm at Tirunelveli in South India **(Table 1)**. AET values are relatively lower at the watersheds in China and India compared to those in Thailand and Vietnam. Varying levels of water surplus and water deficit occur at the watersheds. Among all the locations, Tirunelveli in India has the largest water deficit (1347 mm) and no water surplus. Chine in

Table 1. Annual water balance characters (all values in mm).

Country	Location	Rainfall	PET	AET	WS	WD
China	Xiaoxingcun	641	1464	641	Nil	815
	Lucheba	1284	891	831	384	60
Thailand	Wang Chai	1171	1315	1031	138	284
	Tad Fa	1220	1511	1081	147	430
Vietnam	Chine	2028	1246	1124	907	122
	Vinh Phuc	1585	1138	1076	508	62
India	Bundi	755	1641	570	186	1071
	Guna	1091	1643	681	396	962
	Junagadh	868	1764	524	354	1240
	Nemmikal	816	1740	735	89	1001
	Tirunelveli	568	1890	542	Nil	1347

Vietnam has the largest water surplus of 907 mm. These analyses defined the dependability for moisture availability for crop production and opportunities for water harvesting and groundwater recharge.

In several regions of the world, rainfed agriculture generates among the world's highest yields. These are predominantly temperate regions, with relatively reliable rainfall and inherently productive soils. Even in tropical regions, particularly in the sub-humid and humid zones, agricultural yields in commercial rainfed agriculture exceed 5-6 t ha^{-1} (Falkenmark and Rockström, 2000; Wani *et al.*, 2003a&b). Evidence from long-term experiments at ICRISAT, Patancheru, India since 1976, demonstrated the virtuous 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^{-1} per yr) compared to 1.1 t ha^{-1} per yr, average yield of sole sorghum in the traditional (farmers') post-rainy system where crops are grown on stored soil moisture (**Fig. 2**). The annual gain in grain yield in the improved system was 82 kg ha^{-1} per yr compared with 23 kg ha^{-1} per 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^{-1} and potential yield of 7 t ha^{-1} 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 300 kg C ha^{-1} per year (Wani *et al.*, 2003b).Yield gap analyses, undertaken by the Comprehensive Assessment, for major rainfed crops in semi-arid regions in Asia (**Fig. 3**) and Africa and rainfed wheat in West Asia and North Africa (WANA), reveal large yield gaps, with farmers' yields being a factor of 2–4 lower than achievable yields for major rainfed crops grown in Asia and Africa (Rockstrom *et al.*, 2007). At the same time, the dry sub-humid and semi-arid regions experience the lowest yields and the lowest productivity improvements. Here, yields oscillate in the region of 0.5–2 t ha^{-1}, with an average of 1 t ha^{-1}, in sub-Saharan Africa, and 1-1.5 t ha^{-1}, in the SAT Asia and Central and West Asia and North Africa (CWANA) for rainfed agriculture (Rockström, and Falkenmark, 2000; Wani *et al.*, 2003a&b, Rockstrom *et al.*, 2007).

Farmers' yields continue to be very low compared to the experimental yields (attainable yields) as well as simulated crop yields (potential yields), resulting in a very significant yield gap between actual and attainable rainfed yields. The difference is largely explained by inappropriate soil, water, and crop management options used at the farm level, combined with persistent land degradation.

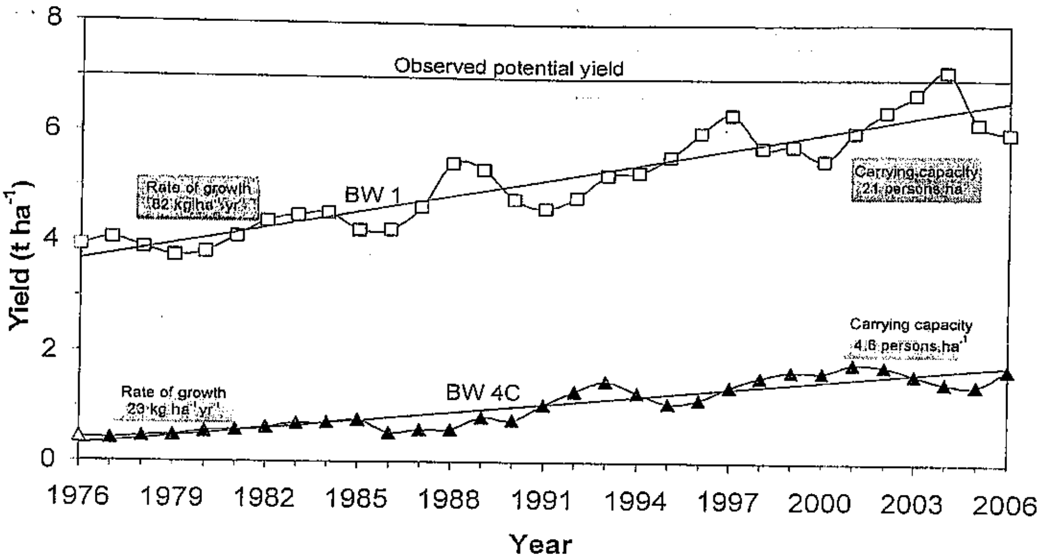


Fig. 2. Three-year moving average of sorghum and pigeon pea grain yield under improved and tradtional management in a deep Vertisol catchment at Patancheru, India.

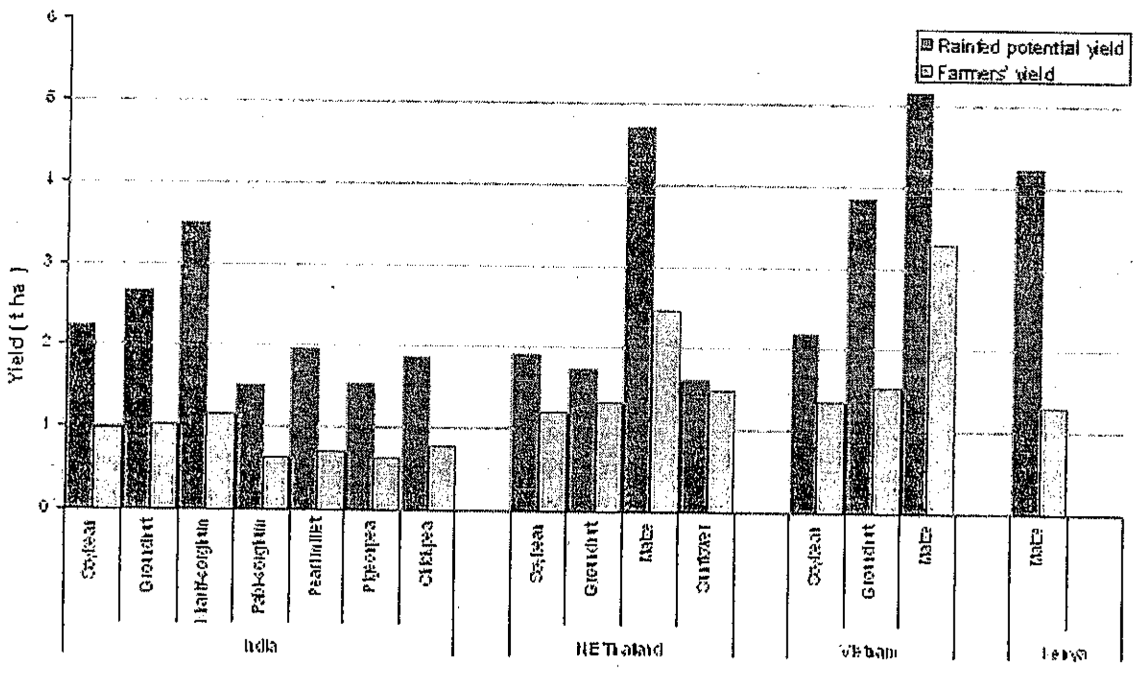


Fig. 3. Yield gap of important rainfed crops in different countries

The vast potential of the rainfed agriculture need to be unlocked through knowledge-based management of natural resources for increasing the productivity and incomes to achieve food secured developing world. Soil and water management play very critical role in increasing agricultural productivity in rainfed areas in the fragile SAT systems.

Need for a New Paradigm for Soil and Water Management in Rainfed Agriculture

For rainfed agriculture business as usual scenario cannot sustain the growth and needed food security. There is an urgent need to develop a new paradigm for soil and water management. We need to have holistic approach based on converging all the necessary aspects of natural resource conservation, their efficient use, production functions, income enhancement avenues through value chain and enabling policies and much needed investments in rainfed areas.

Soil Health an Important Driver for Enhancing Water Use Efficiency

Soil health is severely affected due to land degradation and is in need of urgent attention. ICRISAT's on-farm diagnostic work in different community watersheds in different states of India as well as in China, Vietnam and Thailand showed severe mining of soils for essential plant nutrients. Exhaustive analysis showed that 80-100% farmers' fields are deficient not only in total nitrogen but also micro-nutrients like zinc, boron and secondary nutrients such as sulphur **(Table 2)**. In addition, soil organic matter an important driving force for supporting biological activity in soil is very much in short supply particularly in tropical countries. Management practices that augment soil organic matter and maintain at a threshold level are needed. Farm bunds could be productively used for growing N_2 fixing shrubs and trees to generate N-rich loppings. For example, growing *Gliricidia sepium* at close spacing of 75 cm on farm bunds could provide 28-30 kg. N ha^{-1} in addition to valuable organic matter. In addition, large quantities of farm residues and other organic wastes could be converted into valuable source of plant nutrients and organic matter through vermicomposting (Wani *et al.*, 2005). Strategic long-term catchment research at ICRISAT has shown that legume-based systems particularly with pigeonpea could sequester 330 kg C upto 150 cm depth in Vertisols at Patancheru under rainfed conditions (Wani *et al.*, 2003). Under National Agricultural Technology Project (NATP), ICRISAT-NBSS&LUP-CRIDA and IISS have identified C sequestering systems for Alfisols and Vertisols in India (ICRISAT, 2005; Bhattacharyya *et al.*, 2006). Integrated nutrient management strategies go a long way in improving soil health for enhancing water use efficiency and increasing farmers' incomes.

Need for Integrated Water Resources Management in Watersheds

For enhancing rainwater use efficiency in rainfed agriculture, the management of water alone cannot result in enhanced water productivity as the crop yields in these areas are limited by additional factors than water limitation. ICRISAT's experience in rainfed areas has clearly demonstrated that more than water quantity per se management of water resources is the limitation in the SAT regions (Wani *et al.*, 2006a).

Based on the Policy on water resource management for agriculture remains focused on irrigation, and the framework for integrated water resource management (IWRM) at catchment and basin scales are primarily concentrated on allocation and management of blue water in rivers, groundwater and lakes. The evidence from the comprehensive assessment of water for food and poverty reduction indicated that the use of water for agriculture is larger

Table 2. Percentage of farmers' fields deficient in soil nutrients in different states of India

State	No. of farmers' fields	Org. C %	Av. P 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
Tamilnadu	119	57	51	24	71	89	61
Kerala	28	11	21	7	96	100	18

than irrigation, and there is an urgent need for a widening of the policy scope to include explicit strategies for water management in rainfed agriculture including grazing and forest systems. However, what is needed is effective integration so as to have a focus on the investments options on water management across the continuum from rainfed to irrigated agriculture. The time is opportune to abandon the obsolete sectoral divide between irrigated and rainfed agriculture, which would place water resource management and planning more centrally in the policy domain of agriculture at large, and not as today, as a part of water resource policy.

Furthermore, the current focus on water resource planning at the river basin scale is not appropriate for water management in rainfed agriculture, which overwhelmingly occurs on farms of < 5 ha at the scale of small catchments, below the river basin scale. Therefore, focus should be to manage water at the catchment scale (or small tributary scale of a river basin), opening for much needed investments in water resource management also in rainfed agriculture (Rockström *et al.*, 2007).

In several countries, central and state governments have emphasized management of rainfed agriculture under various programmes. Important efforts for example have been made under the watershed development programmes in India. Originally, these programmes were implemented by different ministries such as the Ministry of Agriculture, the Ministry of Rural Development and the Ministry of Forestry, causing difficulties for integrated water management. Recently, steps were taken to unify the programme according to the "Hariyali Guidelines" (Wani *et al.*, 2006a). Detailed meta analysis of 311 watershed case studies in India revealed that watershed programs are silently revolutionalizing rainfed areas with positive impacts (B:C ratio of 1:2.14, IRR of 22%, increased cropping intensity by 63%, increased irrigated areas by 34%, reduced run off by 13% and increased employment by 181 person days per year per ha). However, 65% of the watersheds were performing below average performance as they lacked community participation, programs were supply driven, equity and sustainability issues were eluding and compartmental approach was adopted (Joshi *et al.*, 2004).

Based on detailed studies and synthesis of the results, impacts, shortcomings, learnings from large number of watershed programs and on-farm experiences gained, ICRISAT-led consortium developed an innovative farmers' participatory consortium model for integrated watershed management (Wani *et al.*, 2002, 2003a,c). ICRISAT-led watershed espouses the Integrated Genetic Natural Resources Management (IGNRM) approach where activities are implemented at landscape level. Research and development (R&D) interventions at landscape level were conducted at benchmark sites representing the different SAT agroecoregions. The entire process revolves around the four E's (empowerment, equity, efficiency and environment), which are addressed by adopting specific strategies prescribed by the four C's (consortium, convergence, cooperation and capacity building). The consortium strategy brings together institutions from the scientific, non-government, government, and farmers group for knowledge management. Convergence allows integration and negotiation of ideas among actors. Cooperation enjoins all stakeholders to harness the power of collective actions. Capacity building engages in empowerment for sustainability (Wani *et al.*, 2003b).

The important components of the new model, which are distinct from the earlier ones are:

- Collective action by farmers and participation from beginning through cooperative and collegiate mode in place of contractual mode.
- Integrated water resource management (IWRM) and holistic system approach through convergence for improving livelihoods as against traditional compartmental approach.
- A consortium of institutions for technical backstopping.
- Knowledge-based entry point to build rapport with community and enhanced participation of farmers and landless people through empowerment.
- Tangible economic benefits to individuals through on-farm interventions enhancing efficiency of conserved soil and water resources.
- Low-cost and environment-friendly soil and water conservation measures through out the

toposequence for more equitable benefits to larger number of farmers.

- Income-generating activities for landless and women through allied sector activities and rehabilitation of waste lands for improved livelihoods and protecting the environment.

Integrated watershed management deals with conservation and efficient use of rainwater, groundwater, land and other natural resources for increasing agricultural productivity and improving livelihoods. Water management is used as an entry point to increase cropping intensity and also to rehabilitate degraded lands in the catchments with the aim of increasing productivity, enhancing biodiversity, increasing incomes and improved livelihoods. Such an approach demands integrated and holistic solutions from seed to final produce with involvement of various institutions and actors with divergent expertise varying from technical, social, financial, market, human resource development, and so on. The program outputs are tuned to reduce poverty, minimize land degradation, increase productivity and production, building communities' resilience to shocks due to natural calamities such as drought and flooding as well as the climate variability due to global warming.

In 2005, the National Commission on Farmers adopted 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 Rainfed Area Authority with the mandate to converge various programmes for integrated development of rainfed agriculture in the country.. These are welcome developments where policy makers have realised the need to develop rainfed areas for reducing poverty and increasing agricultural production. However, it is just a beginning and a lot more still need 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 and upstream-down stream linkages.

Shifting Non-Productive Evaporation to Productive Transpiration

Rainwater use efficiency in arid and SAT agricultural systems is 35 to 50% and up to 50 % of the rainwater falling on crop or pasture fields is lost as non-productive evaporation. This is a key window for improvement of green water productivity, as it entails shifting non-productive evaporation to productive transpiration, with no downstream water trade-off. This *vapour shift* (or transfer), where management of soil physical conditions, soil fertility, crop varieties and agronomy are combined to shift the evaporative loss into useful transpiration by plants, is a particular opportunity in arid, semi-arid and dry-subhumid regions (Rockström *et al.*, 2007).

Field measurements of rainfed grain yields and actual green water flows indicate that doubling yields from 1 to 2 t^{-1}/ha in semi-arid tropical agro-ecosystems, green water productivity may improve from approximately 3500 m^3/t^{-1} to less than 2000 m^3/t^{-1}. This is a result of the dynamic nature of water productivity improvements when moving from very low yields to higher yields. At low yields, crop water uptake is low and evaporative losses are high, as the leaf area coverage of the soil is low, which together results in high losses of rainwater as evaporation from soil. When yield levels increase, shading of soil improves, and when yields reach 4-5 t^{-1}/ha and above, the canopy density is so high that the opportunity to reduce evaporation in favour of increased transpiration reduces, lowering the relative improvement of water productivity. This indicates that large opportunities of improving water productivity are found in low-yielding farming systems (Rockström, 2003; Oweis *et al.*, 1998), i.e., particularly in rainfed agriculture as compared to irrigated agriculture where water productivity already is higher due to better yields.

Investments in Rainfed Areas Produce Multiple Benefits

Through the use of new science tools (i.e. remote sensing, GIS, and simulation modeling) twinned 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 to 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 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 enhanced participation most, especially of the most vulnerable groups like women and the landless. For example, the self-help groups (SHGs) common in the watershed villages of India and an improved initiative in China provide income and empowerment of women. The environmental clubs whose conceptualization is traced from Bundi watershed of Rajasthan, India, inculcated environmental protection, sanitation and hygiene among the children.

Building on social capital made the huge difference in addressing rural poverty of watershed communities. A case in point is Kothapally watershed. 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 neighboring non-watershed village with US$ 613 (**Fig. 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*".

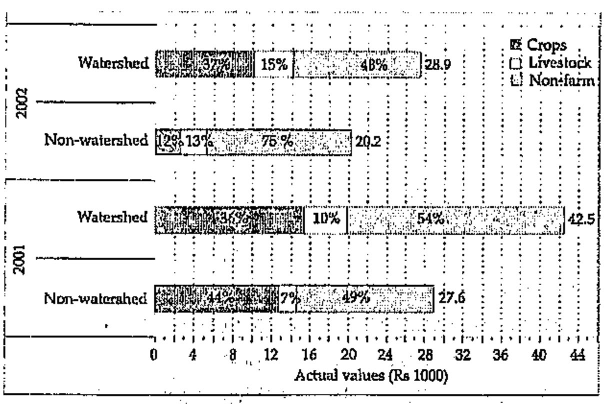


Fig. 4. Income stability and resilience effects during drought year (2002) in Adarsha watershed, Kothapally, AP, India

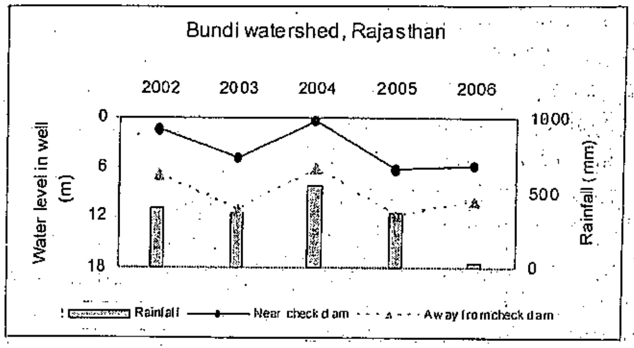
To date, the village prides itself with households owning 5 tractors, 7 lorries and 30 auto rickshaws. People from surrounding villages come to Kothapally for on-farm employment. There were evidences to suggest that with more training on livelihood and enterprise development, migration is bound to cease. Between 2000 and 2003, investments in new livelihood enterprises such as seed oil mill, tree nursery, and worm composting increased average income by 77% in Powerguda, a tribal village in Andhra Pradesh.

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 labor and finance, to create basic infrastructures like access road 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 *Zizipus*; vegetables like beans, peas, sweetpotato) and groundnuts. Forage production specifically wild buckwheat as an alley crop 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 have intensified livestock activities like breed improvement (artificial insemination and natural means) and livestock center/health camp establishment (Wani *et al.*, 2006b).

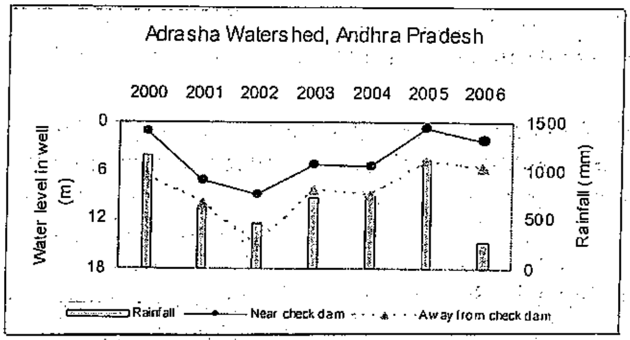
In Tad Fa and Wang Chai watersheds in Thailand, there was a 45% increase in farm income within three years. Farmers earned an average net income of US$1195 per cropping season. A complete turnaround in livelihood system of farm households was inevitable in ICRISAT-led watersheds.

Increasing crop productivity is common objective in all the watershed programs; 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 and sorghum yield by 3 times (Wani *et al.*, 2006a). Over-all, 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 mungbean increased by three to four folds (2.8–3.5 t ha^{-1}) as compared with baseline yields (0.5 to 1.0 t ha^{-1}), reducing the yield gap between potential farmers' yields. A reduction in N fertilizer (90–120 kg urea ha^{-1}) by 38% increased maize yield by18%. In Tad Fa watershed of northeastern Thailand, maize yield increased by 27–34% with improved crop management.

Improving water availability in the watersheds was attributed to efficient management of rainwater and *in-situ* conservation, establishing water harvesting structures (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, treated area registered a groundwater level rise by 7.3 m. At Bundi, the average rise was at 5.7 m and the irrigated area increased from 207 ha to, 343 ha. In Kothapally watershed, the groundwater level rise was at 4.2 m in open wells (**Fig. 5**). The various WHS resulted in an additional groundwater recharge per year of approximately 4,28,000 m^3 on the average. With this improvement in groundwater availability, the supply of clean drinking water was guaranteed. In Lucheba watershed, 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



Estimated additional groundwater recharge due to watershed interventions = 6,75,000 m^3 per year.



Estimated additional groundwater recharge due to watershed interventions = 4,27,800 m^3 per year

Fig. 5. The impact of watershed interventions on groundwater levels at two benchmark sites in India.

the project. On the other hand, collective pumping of well water out establishing efficient water distribution system enabled farmers group to earn more income by growing watermelon with reduced drudgery for women who had to carry on 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 (Wani *et al.*, 2006b).

Supplemental irrigation can play a very important in reducing the risk of crop failures and in optimizing the productivity on SAT soils. In the SAT 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 2000-2003 post-rainy seasons, showed that the chickpea yield (1.25 t/ha) increased by 127% over the control yield (0.55 t/ha); and the groundnut pod yield (1.3 t/ha) increased by 59% over the control yield (0.82 t/ha) by application of two supplemental irrigation of 40 mm. Similar yield responses in mungbean and chickpea crops were obtained from supplemental irrigation at the ICRISAT center in Patancheru. Our results showed that crops on light-textured soils such as Alfisols respond better from supplemental irrigation. Clearly, there is potential to enhance productivity and reduce the risks of crop failures through application of harvested water through supplemental irrigation at critical stage of the crop.

Sustaining development and protecting the environment are the two-pronged achievements of the watersheds. The effectiveness of improved watershed technologies was evident in reducing run-off volume, peak run-off 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 run-off to less than half (194 mm) and soil loss less than 1/7th (4.21 t ha^{-1}) as compared to the conventional system (473 mm run-off and soil loss 31.2 t ha^{-1}). This holds true with peak run-off rate where the reduction is approximately 1/3rd **(Table 3)**.

Large number of fields (80-100%) in the SAT were found severely deficient in Zn, B, and S along with N and P. 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$ 44–66 ha^{-1}. Crop rotation using legumes in Wang Chai watershed substantially reduced N 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.

Improved land and water management practices along with integrated nutrient management (INM) comprising of applications of inorganic fertilizers and organic amendments such as crop residues, vermicompost, farm manures, *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^{-1} in 24

Table 3 Cropyields in Adarsha watershed Kothapally during 1999-2006

Crop	1998 baseline yield	Yield (kg ha^{-1})								Average yields	SE±
		1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007		
Sole maize	1500	3250	3750	3300	3480	3921	3420	3918	3635	3644	283.3
Inter crop	-	2700	2790	2800	3083	3129	2950	3362	3180	3029	263.0
Maize	-	700	1600	1600	1800	1950	2025	2275	2150	1785	115.6
Traditional Inter crop	190	640	940	800	720	949	680	925	970	861	120.3
Pigeonpea		200	180	-	-	-	-	-	-	190	-
Traditional Sole	-	3050	3170	2600	2425	2288	2325	2250	2085	2530	164.0
Sorghum	1070	1070	1011	938	952	1025	1083	995	996	120.7	
Traditional Inter crop Sorghum	-	1770	1940	2200	-	109	1980	1958	1850	1971	206.0

years was observed with improved management options in a long-term watershed experiment at ICRISAT. By adopting fuel-switch for carbon, women SHGs in Powerguda (a remote village of Andhra Pradesh, India) have pioneered the sale of carbon units (147 t CO_2 C) to the World Bank from their 4,500 *Pongamia* trees. Seeds of which are collected for producing saplings for distribution/promotion of biodiesel plantation. 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 run off water (8 vs 14 kg N ha^{-1}). Introduction of IPM in cotton and pigeonpea substantially reduced the number of chemical insecticidal sprays during the season and use of pesticides reduced the pollution of water bodies with harmful chemicals. 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 (IWM) 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 to 180 ha), 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 y^{-1} 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)

Promoting natural resource management (NRM) at landscape level is the scale of work done by the ICRISAT consortium. Benefiting from data obtained from using new science tools like remote sensing, a comprehensive understanding of the effects of the changes (i.e. vegetation cover on degraded lands) in the watersheds is made. This in turn provided the indicators to assess agricultural productivity. Promoting NRM at the landscape level by using tools that provide the needed database is anticipated to have better impact because of the possible integration of all the factors (natural resources with the ancillary information).

While there were some interventions at plot to farm level, the impact factors of NRM such as sustainability of production, soil and water quality, and other environment resources have been looked at from a landscape perspective. This accounts for some successes in addressing concerns on equity issue like benefits for the poorest people such as the

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

Watreshed	Seasonal rainfall (mm)	Runoff (mm)		Soil loss (t ha^{-1})	
		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	1.90
Ringnodia, Madhya Pradesh, India	764	21	66	0.75	2.2
Lalatora, Madhya Pradesh, India	1046	70	273	0.63	3.2

landless who are unable to take advantage of improved soil/water conditions and expansion of water intensive crops triggering renewed water stress. These remain as legitimate challenges of a holistic thinking, which can be better unraveled from a landscape scale. To date, the articulation of this recognition is to be seen in policy recommendations for serious attention to capacity building and not just for planning activities.

Equal importance was given to on-site and off-site impacts. The effects of water conservation at the upper ridge to downstream communities was factored in. Water harvesting structures specifically the rehabilitation of the *nala* (drain) bund at the upper portion in Bundi watershed allowed irrigation of 6.6 ha at the downstream part. Another case is the Aniyala watershed located at the lower topo-sequence of Rajasamadhiyala watershed. Excess water flows of the 21 water harvesting structures in Rajasamadhiyala cascades into Aniyala. This increased groundwater recharge by 25% and improved the groundwater source by 50% in a normal rainfall year. Because of this, there was an increase in crop production by 25-30% (Sreedevi *et al.*, 2006). The quality and number of livestock in the village improved because of water and fodder availability. Off-site effects of watershed specifically equity issues is one area that needs to be strengthened for enhanced impact.

Enhancing partnerships and institutional innovations through the consortium approach was the major impetus for harnessing watershed's potential to reduce households' poverty. The underlying element of the consortium approach adapted in ICRISAT-led watersheds is engaging a range of actors with the locales as the primary implementing unit. Complex issues were effectively addressed by the joint efforts of ICRISAT and in collaboration with key partners namely-the national agricultural research systems (NARSs), non-government organizations (NGOs), government organizations (GOs), agricultural universities community-based organization and other private interest groups with farm households as the key decision-makers. In SHGs, like village seedbanks, these were established not just to provide timely and quality seeds. 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. 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 (PPP) has provided the means for increased investments not only for enhancing productivity but also for building institutions as engines for people-led natural resource management.

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. With cooperation, a balanced R4D was implemented rather than a 'purist model' of participation or blind adherence to government guidelines. A balanced R4D in community watersheds has encouraged scientific debate and at the same time promoted development through tangible economic benefits

The contributions of other international agricultural research centers (IARCs) like the International Water Management Institute (IWMI), International Livestock Research Institute (ILRI) and World Wildlife Fund (WWF) have become allies because of common denominators like goal (poverty reduction) and subject (water resources). It must be reckoned that while centers have their own mandates, these will have to be addressed from a holistic perspective seeking the assistance and contributions of other centers; their technical expertise and findings. This not only maximized the use of resources but the problem situation in watersheds allowed for an integrated approach requiring the alliance of institutions and stakeholders. Similarly, the various networks like the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) and Cereals and Legumes Asia Network (CLAN) have provided an added venue for exchange and collaboration. This led to a strong south-south partnership.

CONCLUSIONS

Rainfed areas, which constitute about 80% of cultivated areas worldwide, are also home to 65 million poor people who reside in the SAT regions. Along with water scarcity, land degradation, poverty, malnutrition and demographic pressure are important constraints, which need urgent attention. In dry sub-humid and SAT areas, the yields of rainfed crops oscillate between 1 to 1.5 t ha^{-1} as against the potential of 5 t ha^{-1} in the SAT. There is a need to have a new paradigm for soil and water resource management in rainfed areas where at the catchment scale water need to be managed in integrated manner in a continuum from rainfed to supplemented irrigation using harvested run-off water or recharged groundwater. Evidence clearly demonstrate that water alone cannot do the job of increasing productivity and other limiting factors such as nutrients, pests, low quality seeds infrastructure and lack of knowledge hold back the potential. Investments in rainfed areas produce multiple benefits such as reducing poverty, developing social capital, community-empowerment, building institutions, protecting environment, reducing land degradation, conserving biodiversity, sequestering carbon and provide environmental services. Soil fertility is an important driver for enhancing agricultural productivity through increased water use efficiency. In a new paradigm— it is not only conservation and efficient use of natural resources but also harnessing social, institutional and policy options along with market forces are of critical importance to improve the rural livelihoods.

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