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The 12th Dr. B.V. Mehta Memorial Lecture*

Taking Soil Science to Farmers' Doorsteps through Community Watershed Management**

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This lecture is dedicated to great soil scientist Dr. B.V. Mehta and the research is based on the work of a large number of research and development workers from different institutions, including policy makers and resource poor farmers. Soil Science is the backbone of sustainable management and development of natural resources and thus has to play an important role in meeting the emerging challenges. Scientists and policy makers in the tropical developing world have a major challenge on land as this region is hotspot of poverty, malnutrition, water scarcity, land degradation and desertification and most likely to bear the brunt of consequences of climate change due to global warming. However, ground reality reveals that despite availability of modern science, tools and scientific knowledge in the research institutes, the poor farmers are struggling to meet their daily needs and are suffering from poverty. Due to lack of opportunities for the Soil Scientists, the students in Soil Science are shying away from the discipline; and as a result the new strategic research in the areas of analytical technique development, application of research findings at the field level as well as policy formulation are suffering very badly. Soil Scientists need to take on the challenge and translate the present challenge into opportunities and contribute significantly to achieve the millennium development goals of sustainable development, reducing poverty, improving access and availability of drinking water and building global partnerships. To achieve this goal, community watersheds framework provide opportunities as well as necessary impetus to bring back the soil science at the center stage to help the humankind.

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The world food production outstripped the population growth during the last 50 years. However, there are regions of food insecurity and poverty where more than 1.2 billion poor people live below US$ 1.25 per day. About 60% of them live in South Asia and sub-Saharan Africa. Food demand is estimated to double in the next 50 years.

Management of natural resources in dryland areas is very important not only because livelihoods of millions of rural poor (>500 million) are directly connected to these areas but also due to the fact that these areas will continue to play a crucial role in determining food security for growing population and reducing poverty in the coming decades (Rockström *et al.* 2007). In the past 40 years, 30% of the overall grain production growth is due to 20-25% expansion of agricultural land during the period (FAO 2002; Ramankutty *et al.* 2002). The remaining yield outputs originated from intensification through yield increases per unit land area. In developing countries rain-fed grain yields are on average 1.5 t ha^{-1}, compared to 3.1 t ha^{-1} for irrigated yields (Rosegrant *et al.* 2002) and increase in production from rain-fed agriculture has mainly originated from land expansion.

Agriculture will continue to be the backbone of economies in Africa and South Asia in the foreseeable future. A look into a rain-fed region 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; Rockstrom *et al.* 2007).

Failure of Out-scaling Innovation – Indigenous and External

Upgrading rain-fed agriculture requires that technologies (indigenous or improved) which are strongly adapted to local biophysical and socio-cultural conditions accompanied with institutional and behavioral changes (Harris *et al.* 1991; van Duivenbooden *et al.* 2000). Well-established evidence points to the important role of social and ecological crises for adoption of new thinking and system transformation. Adoption of conservation agriculture in several parts of the world was driven by crises, *e.g.* in the USA, as a response to the Dust Bowl in the 1930s, increased emphasis on watershed management in India is largely to cope with droughts in drought-prone areas, *i.e.* drylands in India following the occurrence of severe droughts in the early 1980s.

Moreover, investments in rain-fed agriculture pose serious challenges, as the large numbers of households are small, with marginal farmers and poor infrastructure facilities. The knowledge-intensive extension effort needed in the rain-fed areas suffers from limited information on the options available, social and economic constraints to adoption, lack of enabling environments and backup services, poor market linkages, weak infrastructure and low means to pay. This is the context in which one has to really look how the Soil Science can be taken to the doorsteps of the farmers for making an impact through scaling-up. Integrated watershed management approaches have shown the potential for scaling-out benefits ensuring community participation largely due to tangible benefits as well as capacity development through knowledge sharing (Wani *et al.* 2000; 2003d).

Rain-fed Agriculture – A Large Untapped Potential

In tropical regions, agricultural yields in commercial rain-fed agriculture exceeds 5-6 t ha^{-1} (Rockström and Falkenmark 2000; Wani *et al.* 2003a, 2003c). 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^{-1}, with an average of 1 t ha^{-1} in sub-Saharan Africa and 1-1.5 t ha^{-1} in South Asia, Central Asia and West Asia and North Africa (CWANA) for rain-fed agriculture (Rockström and Falkenmark 2000; Wani *et al.* 2003a, 2003c).

Yield gap analyses carried out by Comprehensive Assessment (CA), for major rain-fed crops in semiarid regions in Asia and Africa and rain-fed wheat in WANA, reveal large yield gaps with farmers' yields being lower by a factor 2 to 4 times than the achievable yields for major rain-fed crops. Figure 1 illustrates typical example of observed yield gaps in various countries in Africa, Asia and the Middle East. In

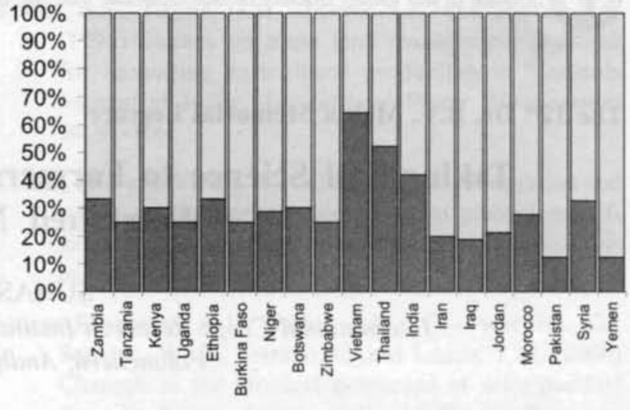

Fig. 1. Examples of observed yield gap (for major grains) between farmers' yields and achievable yields (100% denotes achievable yield level and columns actual observed yield levels). (Source: Derived from Rockstrom *et al.* 2007).

countries in Eastern and Southern Africa, the yield gap is very large. Similarly, in many countries in West Asia, farmers' yields are less than 30% of achievable yields, while in some Asian countries the figure is closer to 50%.

Watersheds as Growth Engine for Development of Rain-fed Areas

Integrated watershed management (IWM) has been promoted as a suitable strategy for improving productivity and sustainable intensification of agriculture in rain-fed drought-prone regions. India has one of the largest micro-watershed development programmes in the world and is continuously evolving through new guidelines, policies, institutions and expanding the scope of the watershed programmes (Wani *et al.* 2008a, 2008b; Government of India 2008). Current watershed programmes are addressing the issues of not only soil and water conservation but also focus on a holistic strategy encompassing equity, gender, productivity enhancement, employment generation, income enhancement and most importantly to build the resilience of the community and the natural resources to meet the challenges of future including due to climate change. Community-based IWM interventions create synergies between targeted technologies, policies and institutions that improve productivity, resource use sustainability and market access for the resource users (Wani *et al.* 2003d).

Up to 10th Five Year Plan (until 2006), about US $ six billions have been invested by Government of India and other donor agencies for treating 38 Mha in the country. Appreciating this fact, the new generation of watershed development programmes are implemented with a larger aim to address issues of food security, equity, poverty, severe land degradation and water scarcity in dry land areas.

Although, watershed development approach is embraced as a policy for development of drought prone regions in the country, a number of evaluations showed that all has not gone well with the watershed programmes (Kerr *et al.* 2002; Farrington and Lobo 1997; Joshi *et al.* 2005; Wani *et al.* 2002, 2003b). Recently, ICRISAT-led consortium undertook comprehensive assessment of watershed programs in India. The meta analysis of 636 watershed case studies revalidated the results of earlier meta analysis study (Joshi *et al.* 2005) and showed that less than one per cent of watershed projects were not economically remunerative with B:C ratio (<1). However, the assessment recommended up-gradation of the programme for enhancing the performance of 68% of the projects which were performing below average B:C ratio (1:2), internal rate of return (27.4%) and other indicators of sustainability like run off, soil loss and equity (employment generation) (Wani *et al.* 2008a). The comprehensive assessment of watershed programmes has recommended watershed development approach as growth engine of sustainable development in dryland areas by developing watersheds as business model through public-private partnership mode and convergence of actors and programmes with full community participation

New Paradigm in Community Watershed Management in Rain-fed Areas

Evidences collected during the CA of water for food and water for life revealed that business as usual in global agriculture would not be able to meet the goal of food security and reducing the poverty. If situation continued it will lead to crises in many parts of the world (Molden *et al.* 2007). However, the world's available land and water resources can satisfy the future demands by taking the following steps:

- Upgrading rain-fed agriculture by investing more in rain-fed agriculture to enhance agricultural productivity (rain-fed scenario).
- Discarding the artificial divide between rain-fed and irrigated agriculture and adopt integrated water resource management approach.
- Investing in irrigation for expanding irrigation where scope exists and improving efficiency of the existing irrigation systems (irrigation scenario).
- Conducting agricultural trade within and between countries (trade scenario).
- Reducing gross food demand by influencing diets and reducing post-harvest losses, including industrial and household waste.

To upgrade the rain-fed agriculture in the developing countries, the community participatory and integrated approach for developing small watershed is recommended and has been found to be effective through a number of islands of success in Asia and Africa (Wani *et al.* 2002, 2008a; Rockstrom *et al.* 2007).

Watershed as an Entry Point

A hydrological watershed is a delineated area from which the runoff drains through interconnecting up-stream and downstream areas creating interdependence between resources and resource users over time and space. Since soil and vegetation can also be conveniently and efficiently managed in this unit, the watershed is considered the ideal unit for managing the vital resources of soil, water and vegetation. 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 people and livestock in a sustainable manner (Wani *et al.* 2002, 2003b, 2005).

Integrated Watershed Management Approach

The conventional watershed approach is compartmental structure-driven and lacks the strategy for efficient resource use. Though watershed serves as an entry point, a paradigm shift is needed from these traditional structure-driven watershed programmes to a holistic system's approach to alleviate poverty through increased agricultural productivity by environment-friendly resource management practices (Wani *et al.* 2003d, 2008b). Watershed, as an entry point should lead to exploring multiple livelihood interventions/options (Wani *et al.* 2006, 2007, 2008b) and the new community watershed management model fits into the framework as a tool to assist in sustainable rural livelihoods.

ICRISAT's consortium model for community watershed management espouses the principles of collective action, convergence, cooperation and capacity building (4Cs) with technical backstopping by a consortium of institutions to address the issues of equity, efficiency, economics and environment (4Es). The new integrated community watershed model provides technological options for management of runoff water harvesting, waterway systems, *in-situ* conservation of rainwater for groundwater recharging and supplemental irrigation, appropriate nutrient and soil management practices, crop production technology and appropriate farming systems with income-generating micro-enterprises for improving livelihoods while protecting the environment (Wani *et al.* 2002, 2006; Sreedevi *et al.* 2004).

Soil Health: An Important Driver for Enhancing Water Use Efficiency in Rain-Fed Areas

Soil health is severely affected by 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 micronutrients like zinc, boron and secondary nutrients such as sulphur (Table 1). In addition, soil organic matter an important driving force for supporting biological activity in soil, is low particularly in tropical areas. Management practices that augment soil organic matter and maintain at a threshold level are needed. Farm bunds could be productively used for growing nitrogen-fixing shrubs and trees to generate nitrogen-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. Also, 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 carbon up to 150 cm depth in Vertisols at Patancheru, India under rain-fed conditions (Wani *et al.* 2003a). Under National Agricultural Technology Project (NATP), ICRISAT, National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Central Research Institute for Dryland Agriculture (CRIDA) and Indian Institute of Soil Science (IISS) have identified carbon sequestering systems for Alfisols and Vertisols in India (ICRISAT 2005).

Often, soil fertility is the limiting factor to increased yields in rain-fed agriculture (Stoorvogel and Smaling 1990; Sahrawat *et al.* 2007). Soil degradation, through nutrient depletion and loss of organic matter, causes serious yield decline closely related to water determinants, as it affects water availability for crops, due to poor rainfall infiltration and plant water uptake, due to weak roots. It is estimated that approximately 85% of African farmland in 2002-04 experienced a loss of more than 30 kg ha^{-1} yr^{-1} of nutrients (IFDC 2006).

A substantial increase in crop yields was experienced after micronutrient amendments in farmers participatory trials (in more than 300 villages) and a further increase by 70 to 120% when both micronutrients and adequate nitrogen and phosphorus were applied, for a number of rain-fed crops (maize, sorghum, mung bean, pigeonpea, chickpea, castor and groundnut) in farmers' fields. Rainwater productivity (*i.e.* total amount of grains produced per unit of rainfall) was significantly increased in example above as a result of micronutrient amendment. The rainwater productivity for grain, production has increased by 70-100% for maize, groundnut, mungbean, castor and sorghum by adding boron, zinc and sulphur. In terms of net economic returns, rainwater productivity was substantially higher by 1.50 to 1.75 times. Similarly, rainwater productivity increased significantly when

Table 1. Percentage of farmers' fields deficient in soil nutrients in different states of India[(a)]

State	No. of farmers' fields	OC	AvP	K	S	B	Zn
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
Karnataka* (47 villages)	11609						
Chickballapur	2257	78	37	34	80	80	52
Kolar	2161	81	31	34	85	87	32
Tumkur	2054	75	64	35	92	92	50
Madhgiri	987	81	67	30	93	91	51
Chitradurga	1489	76	54	15	86	64	80
Haveri	1532	55	42	5	85	46	60
Dharwad	1129	31	53	1	79	39	44

(a) OC = Organic carbon; AvP = Available phosphorus
*Extensive soil sampling undertaken to interpolate analysis at district level using GIS.

adopting integrated land and water management options as well as use of improved cultivars in semiarid regions of India (Wani *et al.* 2003d).

Multiple Benefits and Impacts through Integrated Watershed Management

Through the use of new tools [*i.e.* remote sensing, geographic 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 from 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 for improving livelihood through enhanced participation especially of the most vulnerable groups like women and the landless.

Building on social capital made a large difference in addressing rural poverty of watershed communities. This is evident in the case of Adarsha Watershed, Kothapally 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 (Fig. 2). 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.*" To date, the village prides itself with households owning five tractors, seven lorries and 30 auto-rickshaws. People from surrounding villages come to Kothapally for on-farm employment. Similarly, 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.

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 capi-

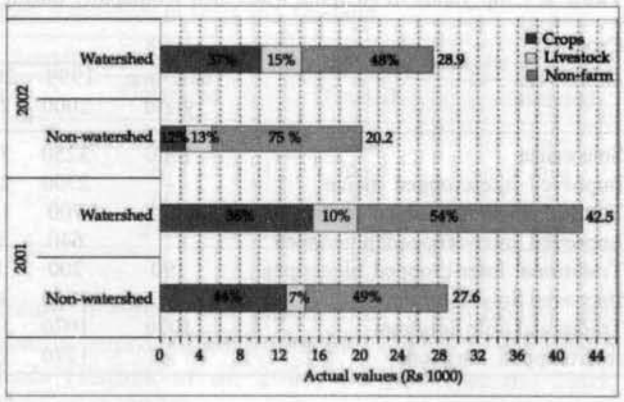

Fig. 2. Effect of integrated watershed management on flow of household net income (*Source*: ICRISAT Data - Adarsha Watershed, Andhra Pradesh, India)

tal-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 sweet potato) 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.* 2006).

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 2) and sorghum yield by threefold. 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%) (Table 3). In Thanh Ha watershed of Vietnam, yields of soybean, groundnut and mung bean increased by threefold to fourfold (2.8–3.5 t ha^{-1}) as compared with baseline yields (0.5 to 1.0 t ha^{-1}), reducing the

Table 2. Crop yields in Adarsha watershed Kothapally during 1999-2007

Crop	1998 base-line yield	Yield (kg ha^{-1}) 1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	Average 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 inter-cropped maize	-	700	1600	1600	1800	1950	2025	2275	2150	1785	115.6
Improved inter-cropped pigeonpea		640	940	800	720	950	680	925	970	860	120.3
Traditional inter-cropped 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

Table 3. Mean yield and uptake of nutrients by crops grown in APRLP watersheds, Andhra Pradesh, India in 2002

Crop	Stover yield (t ha^{-1})		Grain yield (t ha^{-1})		Total nutrients removed (g ha^{-1})					
					Control			Treated		
	Control	Treated	Control	Treated	S	B	Zn	S	B	Zn
Mung bean	0.73	1.00	0.77	1.11	2325	20	46	4009	30	68
Maize	3.46	4.29	2.73	4.56	4536	16	112	7014	19	192
Groundnut	1.99	2.49	0.70	0.94	4355	40	50	6418	52	81
Pigeonpea	1.31	2.10	0.54	0.87	1619	22	27	2649	36	45
Castor	0.82	1.19	0.59	0.89	2216	18	40	3550	26	62

Source: Rego *et al.* (2005)

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 (Sreedevi and Wani 2009).

Improving water availability in the watersheds was attributed to an efficient management of rainwater and *in-situ* conservation, establishment of WHS and improved groundwater levels. In the various watersheds of India like Lalatora (in Madhya Pradesh), 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. 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 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 in fetching drinking water. This was the main motivation behind the excellent farmers' participation in the project. On the other hand, in Thanh Ha watershed in Vietnam, 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 (Wani *et al.* 2006).

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^{-1}) increased by 127% over the control yield (0.55 t ha^{-1}); and groundnut pod yield (1.3 t ha^{-1}) increased by 59% over the control yield (0.82 t ha^{-1}) by application of two supplemental irrigations of 40 mm. Similar yield responses in mungbean and chickpea crops were obtained from supplemental irrigation at the ICRISAT center in Patancheru (Pathak *et al.* 2009).

Sustaining development and protecting the environment are the two-pronged achievements of the

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^{-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	1.9
Ringnodia (Madhya Pradesh, India)	764	21	66	0.75	2.2
Lalatora (Madhya Pradesh, India)	1046	70	273	0.63	3.2

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 to less than $1/7^{th}$ (4.21 t ha^{-1}) as compared to the conventional system (473 mm runoff and soil loss 31.2 t ha^{-1}). This holds true with peak runoff rate where the reduction is approximately one-third (Table 4).

Introduction of IPM in cotton and pigeonpea substantially reduced the number of chemical insecticidal sprays in Kothapally, India during the season and thus reduced the pollution of water bodies with harmful chemicals. 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 rain-fed 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.

Increased carbon sequestration of 7.4 t ha^{-1} in 24 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 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 agrobiodiversity factor (CAF) and surface variability of main crops changed as a result of integrated watershed management interventions. Pronounced agrobiodiversity 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 (Wani *et al.* 2005).

What it Calls for Taking Soil Science from Labs to the Farmers' Doorsteps

Based on the well established evidence from the above example of community watershed development through consortium approach, it is demonstrated that Soil Science can be taken to the doorsteps of the farmers for scaling-out the benefits through science-led development. However, to achieve the desired impact of reaching to the unreached, it calls for concerted and dedicated efforts from the Soil Scientists.

Knowledge-Based Entry Point Activity

In the new consortium approach increased community participation in the watershed management was achieved by ensuring tangible economic benefits through knowledge-based entry point activity (Wani *et al.* 2003a). Detailed soil analysis as a baseline characterization of farmers' fields in the watershed was very effectively used as the knowledge-based entry point activity (Sreedevi *et al.* 2004; Dixit *et al.* 2007). The process behind this success of using Soil Science to benefit large number of farmers as an innovation process which demystified the soil sampling for the farmers and challenged the scientists to come up with economically viable and widely applicable soil sampling process (Sahrawat *et al.* 2008) and effective communication technology to take the results of soil analysis at the door steps of the farmers.

Work in a Multidisciplinary Team and Multi-Institutional Consortium

Tangible economic benefits for the farmers through introduction of improved interventions cannot be achieved by working in disciplinary mode that is compartmental. The era of ultra-specialization and compartmental approach has bypassed and scientists need to work in multidisciplinary teams to address the complex issues faced on the farmers' fields. It is known that only application of nitrogen and phosphorus cannot guarantee the crop responses if the soils are deficient in zinc and other micro- or secondary-nutrients. Similarly, improved nutrient management options alone cannot give the best results in the absence of suitable pest management options as well as suitable cultivars along with soil and water management interventions and market support.

To achieve the impact at a higher level through holistic system approach and working in a multidisciplinary team is not just enough and we need to work in a consortium approach to address the multifarious demands that cannot be met through the expertise of a single institution. To achieve the economic efficiency and higher impact, working in a consortium is much needed. Working in a multidisciplinary team or a consortium itself needs a determination and will to change our work style and working environment. It calls for change in the mind set and willingness to accommodate others views in the team. Trust building in the team and in the consortium is very important; and it cannot be achieved overnight as it is not available on shelf in the market. It needs action and time as well as enabling environment in the institutions. Good leadership to lead multidisciplinary team and consortium is crucial; and sufficient resources need to be allocated to encourage such initiatives. The evaluation systems for the research scientists and the university teachers need change to reward multidisciplinary teams as well as the individuals for achieving the desired impact.

Convert Challenges into Opportunities

In the community watershed consortium, Soil Scientists had a tough task of convincing the other disciplinary scientists the importance of soil analysis. They were always challenged as to how soil testing will achieve the impact and also have quality publications by working on the farmers' fields in the community watersheds? The first challenge was how to undertake soil sampling for a micro watershed comprising 200 and above households by adopting cost-effective and efficient soil analysis, which is representative and scientifically sound? This challenge was converted in to an opportunity by undertaking a well-planned experiment in a watershed that resulted into a statistically proven stratified soil sampling method to cover 500-1000 ha watershed (Sahrawat *et al.* 2008). With the help of statistical technique from the samples collected from all the farmers' fields in the Appayapally watershed of Mahaboobnagar district in Andhra Pradesh thousands of combinations from the field samples were generated and analysed to identify the best representative sampling percentage of farmers' fields. This provided the necessary technology to undertake technically-sound and representative soil sampling in a watershed in rain-fed area. The skeptics of on-farm research were silenced through a publication in an international reputed journal.

Participatory Research and Development (PR&D)

Adopt the principle of "Seeing is believing" and undertake participatory research along with the farmers. We adopted the approach of using lead farmers as trainers and opinion builders in the community watersheds. Farmers as well as non-governmental organization staff and departmental staff were trained in the villages to undertake strafied soil sampling. By adopting this approach in two weeks' time we could sample five districts in Karnataka covering 11609 farmers' fields in 562 villages. Once the soil samples were analysed scientists went to the villages and explained the results through charts and discussions with the farmers in a village meeting and indicated the possible remedial measures. In these meetings voluntary farmers were identified for undertaking PR&D trials with balanced nutrient treatments along with the farmers' practice. For the benefit of the villagers details of the soil sample analysis along with the recommendations were disseminated through wall writings in local language. Once the crops were grown in the PR&D trials through field days the lead farmers explained the whole process from soil sampling to conduct of trials and evaluation of results by them to other farmers. This method of peer-to-peer communication was very effective and farmers were very happy that they are benefited from the soil analysis results, which not only increased their productivity by 30-70% with micronutrient applications but also reduced the cost on unwanted nutrient inputs such as potassium in many villages.

Work With the Policy Makers and Use New Science Tools

For achieving the possible impact scientists need to work with and influence the policy makers and convince them about the problems faced by farmers and their possible solutions. To achieve this, sufficient research data needs to be generated to establish the widespread nature of the problem and by providing an exemplar to demonstrate a tangible solution of the main problems. In the case of soil sampling in the community watersheds, once we established that this technique works and has a potential to benefit the farmers, the Commissioner of Watersheds in Karnataka wanted to map the soil nutrient status in the selected districts of the state. This provided other challenges to develop a suitable method for selection of representative villages and the interpolation or extrapolation of the soil test results using geographic information system (GIS) technique. With this problem at hand, we first developed GIS interpolation technique and prepared simple colour coded maps that are easy to grasp on the severity of the deficiencies in soils, for the policy makers. This step resulted in the conduct of more than 3000 farmers participatory research trials with micronutrients on one hectare each with a number of crops in five districts. Farmers have harvested 35 to 65% increased crop yields of maize, sorghum, soybean, finger millet, sunflower and groundnut as well as vegetables using the treatments of their choice as they had to pay the costs of the nutrients. This example provides a complete journey of taking the soil sample analysis technique from laboratory to the farmers' door steps and converting the skeptics of about the value of soil testing; and now it's power to unlock the potential of rain-fed agriculture where the soils are not only thirsty but hungry also.

Ladies and gentlemen this is what I wanted to share with you and demonstrate that you have the potential and opportunity to help the millions of poor farmers in the country to pull them out of poverty. Let me thank the Indian Society of Soil Science, Dharwad chapter for giving me the honour to deliver Dr. B.V. Mehta Memorial Lecture at University of Agriculture, Dharwad, Karnataka. Thank you.

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An Introduction to Dr. B.V. Mehta Memorial Lecture

This series of lecture dedicated to the memory of Dr. B.V. Mehta is organized annually by the Indian Society of Soil Science through one of the Chapters of the Society. A sum of Rs. 50,000/- raised by the Anand Chapter of ISSS was passed on to the Society as the corpus. Out of the income accruing from the corpus this series of lecture is organized every year. A short biographical sketch of Dr. B.V. Mehta was published in the *Journal of the Indian Society of Soil Science* (1997) Vol. 45, pp 691-692. The first lecture was organised by the Calcutta Chapter of the Society during the 62nd Annual Convention of the Society in 1997 at Science City, Calcatta and Dr. D.L. Deb was the speaker on this occasion. The subsequent lectures in this series were delivered by Dr. M.S. Patel (1998), Dr. V.K. Nayyar (1999), Dr. K.M. Ramanathan (2000), Dr. Pratap Narain (2001), Dr. C.L. Acharya (2002), Dr. K.L. Sahrawat (2003), Dr. P.K. Chhonkar (2004), Dr. D. Panda (2005), Dr. G. Narayanasamy (2006), Dr. R.P. Dhir (2007) and Dr. Suhas P. Wani (2008).