8 Scaling-up of Science-led Development – Sir Dorabji Tata Trust Initiative

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Abstract

Soil health mapping in Sir Dorabji Tata Trust-supported initiative across 16 districts of Madhya Pradesh and Rajasthan, India showed widespread deficiencies of sulfur, boron, zinc and phosphorus. Soil test-based balanced nutrient management recorded yield benefit of 10–40%, while the integrated nutrient approach recorded still higher yield up to 20–50% along with 25–50% saving in chemical fertilizers through promotion of on-farm vermicomposting. Maximum yield advantage (90–200%) was realized with improved varieties and nutrient management. Other advantages included food/fodder nutrition, rainwater use efficiency, more food per kg of nitrogen or phosphorus, and residual benefits of micro/secondary nutrients and vermicompost. Promoting land-form management enabled farmers to cultivate rainy season fallows and harvest 1270–1700 kg/ha soybean. *In-situ* and *ex-situ* rainwater management interventions improved surface and groundwater availability and irrigated area with marked reduction in crop failures in the catchment areas. Women mainstreaming was targeted through livelihood options like nutri-kitchen gardens, fodder promotion for livestock, seed banks, composting and dal-processing. The initiative built capacities of about 30,000 farmers through direct interventions and of around 4–5 times more farmers through information dissemination.

8.1 Project Background

8.1.1 Why the project?

The actual yields from rainfed agriculture have remained quite low as compared to yields achievable because of the fact that rainfed regions have been bypassed since green revolution era (Wani *et al*., 2016). Studies focused in Rajasthan, Madhya Pradesh and other semi-arid regions of India show that there are large yield gaps of 850 to 1320 kg/ha in soybean, 1180 to 2010 kg/ha in groundnut, 610 to 1150 kg/ha in chickpea, 680 to 1040 kg/ha in pearl millet, 460 kg/ha in mustard and 70 kg/ha in wheat (Bhatia *et al*., 2006; Murty *et al*., 2007; Aggarwal *et al*., 2008). A long-term experiment (since 1976) at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), based at Patancheru, India has demonstrated a virtuous cycle of persistent yield increases up to 5 times through improved land, water and nutrient management in rainfed agriculture (Wani *et al*., 2003, 2011a, 2015a).

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In this context, Sir Dorabji Tata Trust (SDTT) supported ICRISAT to undertake farmer participatory action research for improving rural livelihoods and minimizing land degradation in dryland areas of assured rainfall ecoregion of Madhya Pradesh and Rajasthan. The specific objectives were as follows.

(i) To enhance productivity and reduce land degradation in target districts.
(ii) To use these sites as centres of learning for scaling-out the benefits.
(iii) Capacity building of lead farmers, development workers and consortium partners in the target region.

The initiative of the Tata-ICRISAT-ICAR (Indian Council of Agricultural Research) project during 2000 to 2013 demonstrated the power of science-led development model for improving agricultural productivity and income of the rural poor in India (see Chapter 2 in this volume). The initiative of the Tata-ICRISAT-ICAR project during 2000–2007 showed the proof of concept and piloted the power of science-led development model for improving agricultural productivity and income of the rural poor in three districts, namely Bundi in Rajasthan, and Guna and Vidisha in Madhya Pradesh. During the second phase, in addition to scaling-up in three districts, the programme was extended to nine districts in Madhya Pradesh and seven districts in Rajasthan for developing the sites of learning and capacity building of stakeholders.

8.1.2 Pilot site details in Rajasthan and Madhya Pradesh

The target ecoregions for this project were the dryland areas of Madhya Pradesh and eastern Rajasthan with assured rainfall, with medium water-holding-capacity soils. Specifically, the seven target districts in Rajasthan were Alwar (Rajgarh block), Banswara (Kushalgarh block), Bhilwara (Jahajpur block), Bundi (Hindoli block), Jhalawar (Jhalarpatal block), Sawai Madhopur (Khandar block) and Tonk (Deoli and Newai blocks). The nine districts in Madhya Pradesh were Barwani (Barwani block), Guna (Madusudangarh block), Indore (Samer block), Raisen (Silwani), Rajgarh (Rajagarh block), Sagar (JC Nagar block), Sehore (Sehore block), Shajapur (Agar block) and Vidisha (Vidisha, Lateri blocks) (Fig. 8.1).

Agriculture is the predominant occupation of its inhabitants and the dismal state of affairs in agriculture is mainly responsible for poor farm-based livelihoods. Depletion of the resource base diminishes the capabilities of poor farmers to earn more and making them vulnerable to drought and other climate-related disasters. As there is evidence that every 1% increase in

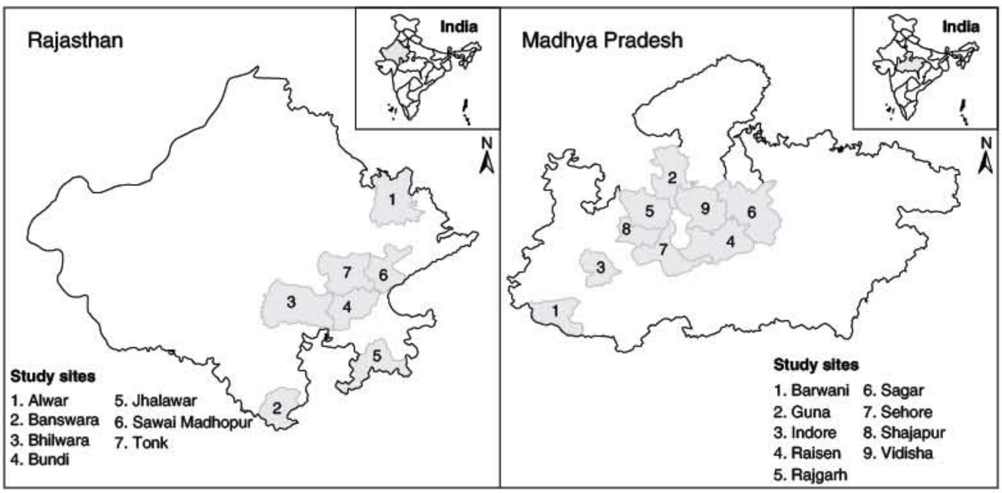

Fig. 8.1. Study sites in Rajasthan and Madhya Pradesh states of India.

agricultural yields translates to a 0.6% to 1.2% decrease in the percentage of absolute poor (Thirtle *et al.*, 2002), addressing the issue of agricultural development in these neglected regions is much more important today than ever before as agriculture in such regions has a key role to play in economic development and poverty reduction (Irz and Roe, 2000).

The rainfall in Madhya Pradesh varies from 770 to 1690 mm per year and soils are predominantly black soils (Vertisols and Vertic Inceptisols) and loamy soils (Alfisols) varying in soil depth. Major crops grown in the region are soybean, sorghum, maize, rice, pigeonpea, wheat and chickpea. The length of growing period (LGP) varies from 90 to 180 days and in some cases extends up to 210 days. This ecoregion has the potential to grow two crops (200% cropping intensity) with supplemental irrigation during the post-rainy season. However, irrespective of this, only 120–130% cropping intensity is observed in Madhya Pradesh. The groundwater table is depleting every year and at the same time causing severe land degradation. In Madhya Pradesh, due to perceived fear of waterlogging and risk of reduced yields of post-rainy season crops, farmers leave 2 million ha land fallow during the rainy season. In eastern Rajasthan, the soils are mostly red and black with the rainfall varying from 660 to 1025 mm per annum. The LGP in eastern Rajasthan varies from 90 to 150 days and the main crops grown are pearl millet, sorghum, maize, wheat, chickpea, mustard and sesame.

8.1.3 Cropping systems and production scenario in Rajasthan

In the cropping pattern of Rajasthan, pearl millet, maize, soybean and groundnut are important rainy season crops. In terms of pearl millet area (6.98 million ha) and production (8.06 million t) in India during 2015–16, Rajasthan stands on the top among all states by covering about 57.9% of total acreage and 43.8% of production at national level (Government of India, 2016). In spite of the highest acreage (4.04 million ha) and production (3.53 million t) of pearl millet in Rajasthan, low productivity is an issue of concern. Maize is grown in 0.88 million ha with a production of 1.21 million t and contributes 10.1% in acreage and 5.55% in production to all India level, with lowest productivity compared to national level. For the country as such, soybean and groundnut together contribute about 60% of total oilseed production (Government of India, 2016). Rajasthan contributes 10.3% (1.20 million ha) in acreage and 11.6% (1 million t) in production of soybean at country level; and 11.4% (0.52 million ha) in acreage and 15.6% (1.06 million t) in production of groundnut in the country. Being the cheapest source of high quality protein (40%), soybean has potential to play an important role in mitigating the large-scale problem of protein malnutrition, particularly in children and women in the rural areas of the state. Its oil content (18%) is second only to groundnut among food legumes. Similarly, groundnut seeds contain high quality edible oil (50%), easily digestible protein (25%) and carbohydrates (20%). Moreover, both soybean and groundnut are legume crops which help in improving soil health, and hence have an important role in fitting in the cropping system mainly during the rainy season and sustaining soil fertility in the drylands of Rajasthan.

Among post-rainy season crops, wheat, rapeseed/mustard and chickpea are the most important crops of Rajasthan covering 3.11, 2.55 and 0.94 million ha respectively (Government of India, 2016). Mustard/rapeseed in India (5.76 million ha, 6.82 million t) is grown mainly in northern and eastern India. Only one-third of the total mustard area in India is rainfed. Rajasthan ranks highest covering about 44.3% area and 47.9% production at national level, which indicates the importance of the crop in the state. The leguminous crop chickpea has been a preferred crop in low-input traditional production systems because of its minimal dependence on monetary inputs of nitrogen (N) and phosphorus (P) fertilizers, irrigation and agrochemicals in general. It is a valuable source of protein for the poor population and a source of livelihood for the small and marginal farmers in India and other developing countries. Also, chickpea is a suitable legume crop for the cropping system during the post-rainy season and thus contributes to soil health improvement and sustains soil fertility, particularly in drylands.

8.1.4 Cropping systems and production scenario in Madhya Pradesh

In the cropping pattern of Madhya Pradesh, soybean, groundnut and mustard are the major oilseed crops (Wani *et al.*, 2016). Madhya Pradesh contributes the largest acreage (56%) and production (51%) of soybean at national level (Wani *et al.*, 2016). Low soybean productivity in the state in comparison to national level in spite of suitable agroclimatic conditions is a matter of concern. Groundnut is another important oilseed crop in India (5.31 million ha area, 6.93 million tons production) and Madhya Pradesh contributes significantly, about 4% of national acreage and about 5% of national production (Wani *et al.*, 2016). Among pulse crops, chickpea is one of the most important crops of India contributing about 44% of total pulse production, and Madhya Pradesh state contributes the highest (37%) to national chickpea acreage and 43% to national chickpea production (Wani *et al.*, 2016).

Among cereals, wheat, maize, rice and nutri (coarse) cereals fit in the cropping system in Madhya Pradesh, and their lower productivity mainly due to poor management is an issue of concern. Wheat is cultivated during the post-rainy season and Madhya Pradesh ranks after Uttar Pradesh in acreage and Uttar Pradesh, Punjab and Haryana in production; and contributes to about 16% of national acreage and 11% of national production (Wani *et al.*, 2016). Wheat yields in different states vary tremendously due to different technologies adopted by the farmers and the agroclimatic characteristics of the region. Maize and rice are other important cereal crops grown widely in the state during the rainy season.

8.2 Institutional Arrangements and Modalities of Scaling-up

This project adopted collective working with lead non-governmental organizations (NGOs) in the region to reach out to the large number of farmers. The NGOs, ICRISAT entered into partnership in Madhya Pradesh included, BAIF Development Research Foundation, BYPASS and CARD. Similarly, in Rajasthan, ICRISAT entered into partnership with BAIF Development Research Foundation and DEEP Development Research Foundation Institute. In Rajasthan and Madhya Pradesh enhancing water-use efficiency of rainy season and post-rainy season crop trials for the project supported by Ministry of Water Resources, Government of India were also converged with the on-going programme in the selected districts.

Other collaborative partners included universities like Maharana Pratap University of Agriculture and Technology, Udaipur; Rajasthan Agricultural University, Bikaner; Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur; and Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior. National research institutes as partners included Indian Institute of Soil Science, Bhopal; National Research Centre for Soybean, Indore; Central Institute of Agricultural Engineering, Bhopal; Central Arid Zone Research Institute, Jodhpur; Central Research Institute for Dryland Agriculture, Hyderabad; and National Research Centre for Agroforestry, Jhansi. Jain Irrigation Ltd was among the key private-sector partners.

A state level coordination committee of partners led by ICRISAT monitored implementation of the initiative. Annual reviews and planning meetings of all partners were put in place to review the previous year's progress and make plans for the incoming year based on the learnings and opportunities available. During the year, progress was monitored through half-yearly and annual reports. Responsible ICRISAT scientists from headquarters and on-ground staff coordinated among the partners on a day-to-day basis, and for orientation/capacity building and progress updates on monthly basis.

8.3 Major Interventions

8.3.1 Mapping soil fertility degradation and management

Soil health mapping

To diagnose soil fertility-related constraints, soil samples were collected from farmers' fields in Madhya Pradesh and Rajasthan by adopting participatory stratified soil sampling method (see Chapter 3 in this volume) and analysed for diagnosing soil fertility-related constraints in a state-of-the-art laboratory in ICRISAT headquarter at Patancheru.

A soil health assessment of crop fields across districts in Madhya Pradesh showed 47–100% fields having adequate levels of soil organic carbon (C) (Table 8.1; Wani *et al.*, 2016). Except for the Sehore district, most (>50%) fields in general were sufficient in soil organic C and available N also. Similarly, most fields (55–75%) in Indore and Shajapur had adequate P levels; while the rest of the districts of Barwani, Guna Raisen, Rajgarh, Sagar, Sehore and Vidisha had only 8–40% fields sufficient in available P, indicating thus, deficiency in most of the fields. Available potassium (K) was sufficient in 95–100% fields and so not really a limiting nutrient to productivity enhancement. Across the districts, relatively few fields in general had adequate levels of sulfur (S) and micronutrients boron (B) and zinc (Zn), or, in other words, deficiency in most fields, which farmers are not aware of and that is not part of their fertilizer management practices, and so apparently holding back the realization of higher yields. Specifically, S was in adequate amounts in most fields in Indore (91% fields) and Shajapur (75% fields), but in the rest of the districts only 4–47% fields had adequate S. Similarly, B was in adequate amounts in most fields in Indore (83% fields), while rest of the districts had only 5–50% fields with adequate B levels. Micronutrient Zn was in adequate amounts in most fields (60–78%) in Indore, Rajgarh, Sagar and Shajapur; while few fields (3–48%) had adequate Zn in Barwani, Guna, Raisen, Sehore and Vidisha.

In contrast to Madhya Pradesh, Rajasthan soils were relatively poor in soil organic C, particularly in Alwar, Sawai Madhopur and Tonk districts, where only few fields (16–33%) were adequate in soil organic C, and thus indicating deficiency in most fields and also low levels of available N (Table 8.1). The other districts of Banswara, Bhilwara, Bundi and Jhalawar had most fields (57–93%) with sufficient levels of soil C. Soils were critical in available P in Bundi, Sawai Madhopur and Tonk where only 27 to 47% fields tested with adequate amounts of P. Most fields (50–90%) in Alwar, Banswara, Bhilwara and Jhalawar were however, having adequate levels of P. Similar to Madhya Pradesh, the soil fertility-related degradation due to S, B and Zn was widespread in the districts in Rajasthan. Leaving aside Bhilwara district, only

Table 8.1. Soil health status of farmers' fields indicating sufficiency/adequacy of essential nutrients in Madhya Pradesh and Rajasthan states of India. From: Chander *et al.* (2013a,b); Wani *et al.* (2016).

District	No. of farmers	% of fields with adequate C	% of fields with adequate available nutrients				
			P	K	S	B	Zn
Madhya Pradesh							
Barwani	20	55	30	100	45	20	25
Guna	38	79	21	100	13	50	5
Indore	23	91	61	100	91	83	78
Raisen	20	70	10	100	10	10	10
Rajgarh	30	87	40	100	47	27	73
Sagar	32	91	22	100	37	9	66
Sehore	19	47	16	95	26	5	5
Shajapur	20	90	75	100	75	20	60
Vidisha	72	68	8	100	4	7	3
Rajasthan							
Alwar	30	33	90	100	37	13	17
Banswara	30	57	50	83	30	0	20
Bhilwara	30	83	60	83	57	53	63
Bundi	36	61	47	50	28	28	33
Jhalawar	30	93	70	100	13	23	40
Sawai Madhopur	44	16	27	93	14	48	59
Tonk	78	28	45	68	21	36	6

13–37% fields tested adequate in S, and 0–48% fields in B. Similarly with exception of Bhilwara and Sawai Madhopur, only 6–40% fields tested adequate in available Zn. In Bhilwara district, however, majority fields tested with adequate levels of S (57% fields), B (53% fields) and Zn (63% fields); while in Sawai Madhopur most fields (59%) tested had adequate levels of Zn.

In other parts of semi-arid tropics (SAT) also, soil fertility-related degradation (Sahrawat *et al.*, 2010; Wani *et al.*, 2011b; Chander *et al.*, 2012; Wani *et al.*, 2015a,b, 2016), in addition to water scarcity, has been identified as the main cause for low crop yields and inefficient utilization of production resources. This corrective fertilizer management strategy to address soil fertility-related degradation apparently is the building stone to realize achievable yields. Lack of awareness about soil health status leads farmers into fertilizer use which rarely matches soil needs and hence an uneconomic and inefficient practice from a sustainability point of view as well.

Soil health management for enhanced crop and water productivity

Based on soil analysis results and variable soil fertility across the region, fertilizer recommendations were developed and promoted in the target regions. In this initiative, soil test-based fertilizer recommendations were designed at block level by considering practical aspects such as available infrastructure, human power and economics in research for impact for smallholders in the Indian SAT. The deficient secondary and micronutrient inputs were arranged on 50% incentives for the participatory trials/demonstrations with the farmers, which were applied by following either of two options, i.e. full dose once in two years or half dose every year. For soil C building, recycling of on-farm wastes through composting was promoted and also to bring in 25–50% saving in chemical fertilizers by the farmers. Around 1000–1500 trials/demonstrations were conducted in target regions during the project period during each of the rainy and post-rainy seasons and random crop cuttings were done along with data collection from farmers to evaluate the benefits.

The first phase during 2002–7 showed proof-of-concept and pilot testing of benefits of soil test-based balanced nutrition (BN) in crops, while during the second phase (2008–12), it was scaled-up to develop sites of learning in adjoining districts. In Madhya Pradesh, soybean productivity significantly increased with BN over farmers' practice (12–25%) (Table 8.2; Chander *et al.*, 2013a). However, the substitution of 50% of chemical fertilizers with vermicompost as integrated nutrient management (INM) further increased yields over BN with nutrients applied solely through chemical fertilizers. Soybean productivity increased by 17% to 50%, as compared

Table 8.2. Effect of nutrient management on soybean grain yield, benefit–cost ratio and rainwater use efficiency under rainfed conditions in Madhya Pradesh during 2010 and 2011.[a] From: Chander *et al.* (2013a).

	Grain yield (kg/ha)				Benefit–cost ratio		Rainwater use efficiency (kg/mm/ha)		
District	FP	BN	INM	LSD (5%)	BN	INM	FP	BN	INM
2010									
Guna	1270	1440	1580	34	1.31	4.58	1.76	1.99	2.19
Raisen	1360	1600	1600	115	1.85	3.55	1.76	2.07	2.07
Shajapur	1900	2120	2410	69	2.99	10.2	3.45	3.85	4.38
Vidisha	1130	1410	1700	640	2.16	8.43	1.48	1.84	2.22
2011									
Guna	1370	1560	1600	169	1.47	3.4	0.83	0.95	0.97
Shajapur	1220	1400	1510	44	2.45	5.8	1.12	1.28	1.38
Vidisha	1190	1380	1460	91	1.47	3.99	0.88	1.02	1.08

[a]Note: FP = Farmers' practice (application of N, P and K only); BN = Balanced nutrition (FP inputs plus S + B + Zn); and INM = Integrated nutrient management (50% BN inputs + vermicompost).

with farmers' standard practice. A cost–benefit analysis showed BN as an economically remunerative option and INM as a still better option. Rainwater use efficiency (RWUE) which indicates quantity (kg) of food produced per unit (mm) of rainfall per unit area (ha) also enhanced under improved management. The INM practice recorded 0.97 to 4.38 kg/mm/ha followed by BN at 0.95 to 3.85 kg/mm/ha as compared with farmers' practice with lowest RWUE of 0.83 to 3.45 kg/mm/ha. Similar benefits were recorded with other crops in the region. Water is a scarce resource and chief determinant of poverty and hunger in rural dryland areas. So improving RWUE is important for achieving food security and better livelihoods. Lack of good rainwater and other management practices in the target region is one of the factors for low RWUE. Soil fertility degradation is also one of the major limitations to effectively use available rainwater and other resources in crop production leading to low rainwater and other resource use efficiency. The results from the present on-farm study thus proved very clearly that soil fertility management, with a purpose to increase proportion of water balance as productive transpiration, is one of the most important rainwater management strategies to improve yields and water productivity (Rockström *et al.*, 2010).

Similarly, in Rajasthan, BN showed significant yield advantage of 15–40% in maize, 10–20% in pearl millet, 14–17% in groundnut and 6–22% in soybean (Table 8.3; Chander *et al.*, 2013a). The INM option either maintained the yields at par with balanced nutrition solely through chemical fertilizers or increased over it. An economic analysis showed the benefit-cost ratio of BN in the range of 1.59–4.28 for

Table 8.3. Effect of nutrient management on crop yield, benefit–cost ratio and rainwater use efficiency under rainfed conditions in Rajasthan.[a] From: Chander *et al.* (2013a).

	Grain yield (kg/ha)			LSD	Benefit–cost ratio		Rainwater use efficiency (kg/mm/ha)		
District	FP	BN	INM	(5%)	BN	INM	FP	BN	INM
2010									
Maize									
Banswara	2850	3390	3620	780	2.45	5.8	4.85	5.77	6.16
Sawai Madhopur	1560	2180	2530	268	4.28	8.24	2.31	3.23	3.75
Tonk	2840	3350	3560	280	2.32	5.08	4.21	4.96	5.27
Pearl millet									
Sawai Madhopur	1410	1590	1700	234	1.12	2.42	2.09	2.36	2.52
Tonk	2210	2560	2800	325	1.43	3.66	3.27	3.79	4.15
Groundnut									
Tonk	820	960	1060	107	1.78	5.84	1.21	1.42	1.57
Soybean									
Jhalawar	1700	1810	2020	82	0.85	3.96	3.04	3.23	3.61
2011									
Maize									
Banswara	2410	3290	3140	1456	4	5.5	2.44	3.33	3.18
Sawai Madhopur	2330	2700	3000	324	2.55	5.69	3.12	3.61	4.02
Tonk	2410	2760	3060	378	1.59	4.59	3.07	3.51	3.89
Pearl millet									
Sawai Madhopur	1340	1470	1610	73	0.81	2.26	1.79	1.97	2.16
Tonk	1720	2060	2280	365	1.39	3.47	2.19	2.62	2.9
Groundnut									
Tonk	1340	1530	1660	142	2.42	7.79	1.7	1.95	2.11
Soybean									
Jhalawar	1940	2370	2620	307	3.32	8.42	1.85	2.26	2.5

[a]Note: FP = Farmers' practice (application of N, P and K only); BN = Balanced nutrition (FP inputs plus S + B + Zn); and INM = Integrated nutrient management (50% BN inputs + vermicompost).

maize, 0.81–1.43 for pearl millet, 1.78–2.42 for groundnut and 0.85–3.32 for soybean, while the benefit:cost ratio of INM option was far better than BN, viz. 4.59–8.24 for maize, 2.26–3.66 for pearl millet, 5.84–7.79 for groundnut and 3.96–8.42 for soybean. The INM practice also resulted in the most efficient use of scarce water resources by crops like maize, pearl millet, groundnut and soybean with RWUE of 1.57–6.16 kg/mm/ha. Balanced nutrition solely through chemical fertilizers was the next best option from RWUE point of view at 1.42–5.77 kg/mm/ha, while farmers' practice showed the lowest RWUE of 1.21–4.85 kg/mm/ha.

In participatory trials, soil test-based nutrient management showed resilience building of production system as evident from residual benefits of secondary and micronutrients. As an example, in Madhya Pradesh districts, the plots with applied S, B, Zn and vermicompost as BN and INM during the rainy season of 2010 showed significant residual benefits during the succeeding post-rainy season 2010–11 and rainy season 2011; the benefits were, however, more under INM. During post-rainy season 2010–11, wheat yields were higher by 12–26% and chickpea by 14–39% in the plots with INM (Chander *et al.*, 2013a). Similarly, in the rainy season 2011, soybean yields were higher by 9–33% under INM-treated plots. In target districts in Rajasthan, the residual benefits of rainy season 2010, applied S, B, Zn and vermicompost as BN and INM were studied in succeeding post-rainy season wheat and chickpea. As such, yield increase of 7–97% was recorded in INM-applied plots and 11–54% under BN-applied plots (Chander *et al.*, 2013a). The results clearly showed that the adoption of improved management of INM and BN options not only are economically remunerative during the season of application but also lead to production system resilience building resulting in benefits in the succeeding seasons.

In this initiative, linkages with soil health and plant quality and soil health management served as an effective strategy to address micronutrient malnutrition through agronomic fortification of crops. Balanced nutrition and INM interventions in general tended to increase soybean grain nutrient contents over farmers' practice; the differences however, were insignificant except for S and Zn contents under the INM option (Chander *et al.*, 2013a).

8.3.2 Integrated rainwater management

Integrated rainwater management is one of the critical components for increasing and sustaining productivity in the project areas of Rajasthan and Madhya Pradesh. Currently only 40–60% of the rainfall is effectively used for crop production. Therefore, large numbers of *in-situ* (broad-bed and furrow (BBF), conservation furrow and contour cultivation) and *ex-situ* soil and water management interventions were implemented and evaluated in several districts of Madhya Pradesh (Raisen, Sagar, Vidisha, Bhopal, Indore and Guna) and Rajasthan (Bundi, Alwar and Sawai Madhopur). On-farm trials on *in-situ* water management of Vertisols of Central India revealed that BBF system resulted in a 35% yield increase in soybean during rainy season and yield advantage of 21% in chickpea during post-rainy season when compared with farmers' practice. Similar yield advantages were recorded in maize and wheat rotation under BBF system (Table 8.4). Yield advantage in rainfall use efficiency was also reflected in cropping systems involving soybean–chickpea, maize–chickpea and soybean/maize–chickpea under improved

Table 8.4. Effect of land configuration on productivity of soybean and maize-based system in the watersheds of Madhya Pradesh, 2001–2005.

Watershed location	Crop	Grain yield (t/ha) Farmers' practice	Grain yield (t/ha) BBF system[a]	Increase in yield (%)
Vidisha and Guna	Soybean	1.27	1.72	35
	Chickpea	0.80	1.01	21
Bhopal	Maize	2.81	3.65	30
	Wheat	3.30	3.25	16

[a]BBF = Broad-bed and furrow.

land management systems. The rainfall use efficiency ranged from 10.9 to 11.6 kg/ha/mm under BBF system across various cropping systems compared with 8.2 to 8.9 kg/ha/mm with flat-on-grade system of cultivation on Vertisols (Table 8.5). Based on these findings about 675 improved farm implements and 32 training programmes at different locations were provided to farmers for scaling-up *in-situ* water management interventions on large areas of Madhya Pradesh.

Several *ex-situ* water management interventions (check-dams, percolation tanks, gully plugs, farm ponds, gabion structures, earthen check-dam, bore well and open well recharge pits, etc.) were implemented and evaluated in different watersheds of Madhya Pradesh and Rajasthan. These interventions have significantly improved both surface and groundwater availability in different cropping seasons (Fig. 8.2). It has resulted in significant increase in the irrigated area particularly during the post-rainy and summer seasons. There is a threefold increase in the mean pumping duration and substantial improvement in recovery or recharge period and the total area irrigated by wells during post-watershed interventions period (Table 8.6).

The integrated watershed management intervention at the Gokulpura-Goverdhanpura watershed in Bundi made significant impact on land use pattern (Table 8.7). It is evident that the area under irrigation had increased by 66% due to the increased water availability in the wells after the implementation of *in-situ* and *ex-situ* water management interventions. Area with supplemental irrigation increased drastically. This resulted in a marked reduction in crop failures in the watershed area and gave greater confidence to farmers to use improved agricultural inputs. In addition to this, about 35 ha land was brought under high-value horticulture with irrigation facility.

Table 8.5. Rainfall use efficiency (kg/ha/mm) of different cropping systems under improved land management practices in Bhopal, Madhya Pradesh.

Cropping system[a]	Flat-on-grade	Broad-bed and furrow
Soybean–chickpea	8.2	11.6
Maize–chickpea	8.9	11.6
Soybean/ maize–chickpea	8.9	10.9

[a]– = Sequential system; / = Intercropping system.

8.3.3 Improved crops, varieties and cropping systems

Promoting farmer-preferred crop varieties

Prevalence of low-yielding crop cultivars is one of the major reasons for low crop yields in target regions, and varietal replacement is a big opportunity for enhancing productivity and income levels of farmers. Under the initial phase of the

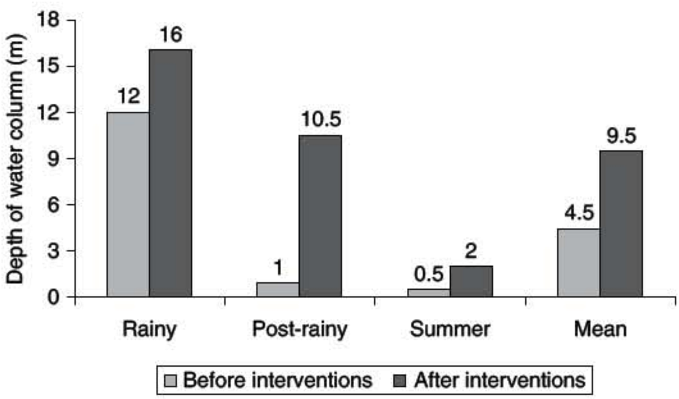

Fig. 8.2. Effect of various *ex-situ* water interventions on depth of water column in open wells during different cropping seasons in Gokulpura-Goverdhanpura watershed, Bundi, Rajasthan.

Table 8.6. Effect of watershed interventions on the performance of open wells in Gokulpura-Goverdhanpura watershed Bundi, Rajasthan.[a]

	Pumping duration (h)		Recharge/recovery period in well (h)		Area irrigated by one well (ha)	
Season	BWI	AWI	BWI	AWI	BWI	AWI
Rainy	4	11	13.5	10	1	2.5
Post-rainy	1.5	6.5	21	16	0.5	1.5
Summer	0	1	30	21	0	0.2
Mean	1.83	6.2	21.5	15.7	0.5	1.4

[a]BWI = Before watershed interventions; AWI = After watershed interventions.

Table 8.7. Land use pattern in Gokulpura-Goverdhanpura watershed, Bundi, Rajasthan.[a]

Land use system	Before watershed interventions (ha)	After watershed interventions (ha)
Irrigated	207 (15)	343 (25)
Rainfed	327 (24)	209 (15)
Pasture	167 (12)	114 (8)
Horticulture	0	35 (3)
Forest	360 (27)	360 (27)
Dwelling and river	294 (22)	294 (22)
Total	1355	1355

[a]Figures in parentheses are the percentage values of total area.

project, the benefits of improved cultivars were recorded in farmers' fields. Therefore, improved crop cultivars along with good management practices were promoted under the project initiative to bridge yield gaps in the target regions.

Participatory trials in Rajasthan showed that with maize crop across the districts, maize grain yield with farmers' standard practice (local cultivar and application of only NPK fertilizers) was 1150–2990 kg/ha (Table 8.8; Chander *et al.*, 2013b). Replacement of local cultivar with improved cultivar increased maize grain yield by 22–68%. But the practice of adopting the improved cultivar along with BN recorded the highest increase in grain yield, which varied from 92% to 204% over farmer's practice. It is thus evident that impoverished soils in the drylands need to be rejuvenated to harness the yield potential of improved cultivars. The benefit–cost ratio of the best technology in maize crop varied from 3.33 to 8.03, indicating economic viability for adoption at farm level. The additional profit in adopting the best practice varied from ₹9910 to ₹29,890 per ha. The RWUE of existing farmers' cultivars with applied N and P in maize varied from 3.36 to 7.39 mg/kg/ha. The introduction of improved cultivar in on-farm trials in target districts increased RWUE from 5.43 to 10.8 mg/kg/ha, and thereby proved the ability of improved cultivar to best utilize the limiting water resources. The integrated approach involving soil test-based addition of secondary and micronutrients to improved cultivar, however, recorded the maximum RWUE (8.20 to 16.2 mg/kg/ha). The best practice also recorded increased stover yield of 58–165% over farmers' practice (Chander *et al.*, 2013b). Stover is used as cattle fodder, and thereby increased fodder availability translated into beneficial impacts on cattle-based livelihoods. Improvement in stover productivity in monetary terms ranged from ₹3500 (US$77.3) to ₹8100 (US$179) with an average of ₹6300 (US$139) per ha (Chander *et al.*, 2013b).

Similarly, the replacement of local pearl millet cultivar with improved cultivar increased grain yield by 46% in Tonk district and 54% in Sawai Madhopur district (Table 8.8; Chander *et al.*, 2013b). The adoption of best practice, however, enhanced pearl millet yield by 166% in Tonk and 115% in Sawai Madhopur. Similar yield improvement (150%) was also recorded with best practice in groundnut as compared with farmers' practice in Tonk district. Considering the net additional returns and benefit–cost ratio, pearl millet seems to be the best crop compared to groundnut for Tonk and Sawai Madhopur region because of low rainfall. The net additional returns with best practice varied from ₹6110 to ₹7620 for pearl millet and ₹1350 for groundnut cultivation. As in maize crop, the RWUE in pearl millet also increased from 2.72 to

Table 8.8. Effects of improved crop varieties and nutrient management practices on crop yield, benefit-cost (BC) ratio and rainwater use efficiency (RWUE) under rainfed conditions in Rajasthan, India.[a] From: Chander *et al*. (2013b).

	Yield (kg/ha)					RWUE (kg/mm/ha)			
District	FP	IC	IC+BN	LSD (5%)	BC ratio	FP	IC	IC+BN	LSD (5%)
Maize									
Tonk	1150	1930	3160	280	4.26	3.4	5.52	9.13	0.73
Sawai Madhopur	1430	2030	3000	420	3.33	4.1	5.77	8.59	0.95
Bundi	1380	2180	4240	714	6.05	3.6	5.68	10.93	1.68
Bhilwara	2990	4340	6510	860	7.45	7.4	10.8	16.15	1.69
Jhalawar	2550	3520	4960	316	5.11	4.2	5.82	8.2	0.52
Udaipur	2530	3090	6320	509	8.03	4.5	5.43	11.11	0.89
Pearl millet									
Tonk	810	1180	2160	212	3.4	2.7	3.93	7.2	0.59
Groundnut									
Tonk	300	550	750	140	1.15	0.9	1.69	2.28	0.38
Pearl millet									
Sawai Madhopur	1010	1560	2170	225	2.92	2.9	4.49	6.27	0.51

[a]Note: FP = Local cultivar + farmers' practice of application of N, P and K; IC = Improved cultivar + farmers' practice of application of N, P and K; and BN = Balanced nutrition (FP inputs plus S + B + Zn).

2.90 kg/mm/ha with farmers' practice to 6.27–7.20 kg/mm/ha under best management. In groundnut, RWUE increased from 0.92 kg/mm/ha under farmers' practice to 2.28 kg/mm/ha with best practice. A relative analysis of RWUE by crop plants in Rajasthan revealed that C4 crop plants (maize and pearl millet) are more efficient in contrast to counterpart C3 plants (groundnut) for better water productivity.

Intensification of rainy season fallows

There are regions in Madhya Pradesh where no crop is grown during rainy season primarily due to waterlogging (Wani *et al.*, 2002, 2016). Traditionally farmers grow a secured post-rainy season crop on stored soil moisture and keep the fields fallow during rainy season. Three fundamental barriers to cropping in black soil region are: (i) threat of flooding of the rainy season crop due to heavy rains; (ii) difficulty of soil preparation prior to the monsoon for timely sowing of a rainy season crop; and (iii) reduction in available soil moisture for the post-rainy season crop. Soil degradation is also an important issue to be considered to take two good crops in a year. It is estimated that 2.02 million ha, accounting for 6.57% of the total area of the state, remains under rainy season fallows (Sreedevi *et al.*, 2009). Madhya Pradesh in Central India is endowed with Vertisols and associated soils along with assured rainfall (700–1200 mm). The Vertisols contain high (40–60%) montmorillonite clay and exhibit typical swelling and shrinking characteristics under moist and dry conditions. Vertisols have poor hydraulic conductivity, and consequently are frequently poorly drained. Madhya Pradesh is endowed with well-distributed rains. Vertisols with good moisture-holding capacity can be used to grow short-duration soybean by adopting sound land management practices. This will help increase income to farmers besides preventing land degradation due to runoff erosion.

In rainy season fallow regions, the project interventions of landform management coupled with soil test-based balanced fertilization enabled farmers to grow and harvest good soybean yields during the rainy season (Table 8.9; Wani *et al.*, 2016). The BBF landform management tended to prove superior over contour furrow. In the same plots, after taking rainy season crop with recommended technology, post-rainy season wheat and chickpea crops were also grown.

Table 8.9. Effects of landform management and balanced nutrition on soybean yield in rainy season fallow regions in Madhya Pradesh, rainy season 2010.[a] From: Wani *et al*. (2016).

		Grain yield (kg/ha)			Straw yield (kg/ha)		
District	No. of trials	CF + BN	BBF + BN	LSD (5%)	CF + BN	BBF + BN	LSD (5%)
Guna	21	1350	1450	210	2110	2310	226
Raisen	26	1270	1360	59	1930	2300	70
Indore	5	1600	1700	231	1730	1810	158
Vidisha	5	1340	1520	511	1440	1830	748

[a]Note: CF = Conservation furrow at 4–5 m distance; BBF = Broad-bed and furrow (1 m raised bed followed by 0.5 m furrow); and BN = Balanced nutrition (N, P, K plus S, B, Zn).

Results showed increased wheat and chickpea grain yields in rainy season fallow plots as compared to farmers' practice of growing only one crop (wheat or chickpea) in post-rainy season. These results are expected due to improved soil health as a result of soil test-based balanced nutrition during rainy season and more moisture storage due to appropriate landform management.

8.3.4 Forage production for promoting livestock-based livelihoods

On-farm fodder promotion

Rearing livestock is a common practice by farmers in target regions. However, fodder shortage is a major drawback for low productivity. Therefore under this project, seeds of forage crops such as fodder sorghum, lucern and berseem were distributed for forage cultivation. This helped to provide good quality fodder to animals. A large number of farm demonstrations (~25–75 each year) were arranged under this activity wherein farmers learnt to grow good quality fodder for their cattle and increase milk production which is especially in the domain of women and thus, contribute to increasing their incomes.

Wasteland management

Under the Tata–ICRISAT–ICAR initiative funded by SDTT, efforts were undertaken to demonstrate combating land degradation in Bundi district during the year 2000. The soils in selected pilot site in Thana, Govardhanpura and Gokulpura cluster of villages in Bundi district, eastern Rajasthan, India are degraded due to overgrazing. The total geographical area of this cluster is 1356 ha, of which common grazing land is 95 ha. BAIF Institute of Rural Development, an NGO partner, initially recognized the problem and engaged the community to demonstrate wasteland development interventions in half (45 ha) of the common grazing land. Villagers contributed labour to erect stone fencing in around 45 ha and construct soil and water conservation structures like gully plugs, percolation pits, contour and staggered trenches. With a rainwater-harvesting structure in place, useful grasses and saplings were planted, resulting in the establishment of good plantation despite consecutive droughts between 2000 to 2003.

A participatory assessment later showed that this management has led to abundance of grasses/fodder in the area and such conservation initiative has benefited all sections of society (Dixit *et al*., 2005). In addition, biodiversity in the conserved plot increased tremendously. Rehabilitated grazing land got richer in floristic diversity as it contained 56 plant species (20 woody taxa, 36 herbacious species), while there were only 9 species in open degraded land. In addition, below ground microbial biodiversity assessed through collecting surface (0 to 0.15 m) soil samples recorded 32% higher microbial biomass carbon (460 vs 288 μg C g^{-1} soil) in rehabilitated land as compared to the degraded land. Biomass nitrogen was 37% higher (37.8 vs 25.4 μg N g^{-1} soil) in rehabilitated land. Similarly, the population of bacteria (10×10^4 vs 8.8×10^4 cfu g^{-1} soil), fungi (37×10^3 vs 15×10^2 cfu g^{-1} soil), actinomycetes (57×10^3 vs 35×10^3 cfu g^{-1} soil) were found significantly higher in rehabilitated grazing lands than in degraded grazing lands. Further higher diversity in microbial population was found in samples from rehabilitated land compared to the degraded land.

8.3.5 Other income-generating activities

Along with strengthening natural soil and water resources, efforts were placed to strengthen livelihoods of farmers and especially mainstreaming of women through certain targeted activities. Women farmers were trained in kitchen gardens, recycling agricultural wastes through vermicomposting, raising nurseries for biological N fixing-trees, producing improved seed and establishing a village seed bank, dal processing, etc. All these activities were promoted through women collectively as self-help groups (SHGs) and thrift saving activities. Major livelihood activities promoted in project sites to show these as learning sites were kitchen gardening, vermicomposting and biomass generation, and seed bank.

Kitchen gardening

Under this activity, especially the women farmers were guided and supported to grow vegetables in a small area or as kitchen garden (10–100 m^2) to improve family nutrition and capture the market-led opportunities. The demand-driven seeds of vegetables such as brinjal, tomato, okra, cabbage, cauliflower, etc. were provided during the initiative by ICRISAT along with required capacity building and other inputs like soil test-based nutrients. Demonstrations of vegetables along with needs-based micro/secondary nutrients were done with 200 new women farmers every year to strengthen their skills which resulted in high yields and benefits in income and family nutrition.

Vermicomposting and biomass generation

Vermicompost pits (~100 functioning) were constructed at project locations as sites of learning and farmers were encouraged to apply the produced vermicompost in their fields to maintain soil health. The benefits were documented as increased crop yields and savings in chemical fertilizers.

Under the SDTT project, biomass generation was promoted in villages which had less population of cattle and thereby having less dung and compost. Seeds of *Gliricidia* were provided to farmers each year to grow seedlings to cover 10–50 ha as learning sites. Leaves of *Gliricidia* contain N (2.4%), P (0.1%), K (1.8%), calcium and magnesium and they add various plant nutrients and organic matter to the soil, and increase crop productivity of unproductive soils.

Seed bank

In an effort to counter the timely availability of sufficient quantities of improved seed, seed bank activities were initiated in Madhya Pradesh (Sehore) and Rajasthan (Tonk) districts. Farmers were trained in seed production of crops like groundnut, chickpea, soybean and wheat, and seed grading and storage. This intervention has not only ensured availability of quality seed to farmers but also made available village-wise livelihood option for them.

Strengthening livestock-based livelihoods

The partner NGO BAIF has expertise in maintaining cattle health and breed improvement. And thereby large number of animal health camps were organized for deworming and breed improvement of livestock (~2000–3000 every year) in the project regions. Also the farmers were organized through SHGs and supported to purchase and expand livestock.

8.4 Capacity Building

To ensure sustainability of science-led development, due focus was on capacity building of stakeholders.

8.4.1 Capacity building under the initiative

Without appropriate training and knowledge sharing, no technology can percolate down to grassroots level for adoption. Thus farmers were oriented to better crop production technology and their capacity was built by organizing various types of training on new technology and better farming practices. Some of the major interventions were technical training conducted in villages, planning exercises, training of SHGs for management of seed banks, exposure visits and farmers' days. Capacity building of various stakeholders and farmers has been an important component of the SDTT project. Various capacity-building activities were taken up for the effective implementation of productivity enhancement through sustainable management of natural resources in Madhya Pradesh and Rajasthan. During the project period, annual workshops, training during crop seasons and field days were targeted activities. During the project period, capacity of about 20,000–30,000 farmers was improved directly through hands-on training and demonstrations and 4–5 times through field days.

In this initiative, ICRISAT also conducted capacity-building courses for the senior policy makers from Rajasthan and Madhya Pradesh in integrated watershed management programme implemented by the Department of Land Resources, Ministry of Rural Development. To further boost the efforts to sensitize the senior policy makers in the country, a National Symposium for Enhancing the Impact of the Integrated Watershed Management Program was held in New Delhi during 2010.

Capacity building of ultimate stakeholders, the farming community, is a core feature of any development project and SDTT is no exception. Sharing of knowledge in a village community is an essential means of spreading new technology. This was done by interactive group discussions, field visits, demonstrations and farmers' days where farmers could interact with scientists in exchanging ideas, views and experience. Hands-on training was a major benefit to the farmers. Soil health management, micronutrients, seed treatment and pest management were some of the hands-on training programmes regularly imparted to farmers in the project locations. Other major points of group discussions were water-use efficiency and enhancing productivity through various interventions. Thus the project created a common platform for information sharing to access information and resource and also disseminated information in the neighbourhood cluster of villages.

8.4.2 Important principles of capacity building followed

Quality of training, developing training material, content development and delivery of a programme are some aspects which affect any capacity-building programme. Seldom is there any quality check, especially where an assessment is to be done as to whether the training objectives were met. All capacity-building programmes need to address these basic issues to make the training an effective tool for transferring new technologies, so that it really benefits the ultimate stakeholder. Any capacity-building programme has primarily two objectives: transfer of technology and knowledge and skill development.

As the training flows from top-level functionaries of a state department/organization to the farm level, training becomes more skills-based for applications rather than principles and concept. Accordingly, training methodologies change, become more participatory and results-oriented. Awareness of this among the planners and policy makers is important so that the training pedagogy is relevant to the audience/participants.

Training is not a one-time event but should be sustainable in the long term. Development objectives are not a single intervention, but rather a continuous effort towards a long-term perspective and goal. Any training programme needs to be highly interactive, participatory and results-oriented. This needs the training to take a systems approach for better impact and technology transfer. There is no common prescription for all the training programmes in a project. It needs constant innovation in delivery mechanisms, wide consultations with the stakeholders and proactive steps in planning process. In other words, training has to be dynamic and systems-oriented if there is to be a change in the lives of millions of farmers to give them a better quality of life. Training has to be an agent for change – a change for the better. This has been a guiding principle in capacity-building efforts in the project.

8.5 Summary and Key Findings

The pilot initiative supported by SDTT has demonstrated widespread deficiencies of S, B and Zn in the semi-arid regions in Madhya Pradesh and Rajasthan states of India, which farmers should consider and include in their fertilizer management strategies. The on-farm evaluation results in pilot sites suggest the need to promote the use of vermicompost in food production for higher productivity and net returns. Vermicompost use for food production may be economical and practical only if it is produced on-farm from available wastes. Varietal replacement, rainy season fallow cultivation, wasteland management and developing livelihood opportunities like village seed banks, fodder promotion for livestock productivity and nutri-kitchen gardens are other big opportunities to improve incomes and productivity. *In-situ* and *ex-situ* rainwater management is critical in water augmentation and enhancing water-use efficiency, leading to higher production, incomes and reduced instances of crop failures. The smallholders in the rainfed SAT in India are unaware of such issues and available technologies and are not in a position to implement the science-led strategy on their own. So, there is a strong need for desired policy orientation by the respective governments to promote capacity strengthening and soil test-based INM and BN strategies through appropriate incentives for poor smallholders in the SAT in India.

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References

Aggarwal, P.K., Hebbar, K.B., Venugopalan, M.V., Rani, S., Bala, A. *et al*. (2008) *Quantification of Yield Gaps in Rain-fed Rice, Wheat, Cotton and Mustard in India*. Global Theme on Agroecosystems Report No. 43. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.

Bhatia, V.S., Singh, P., Wani, S.P., Kesava Rao, A.V.R. and Srinivas, K. (2006) *Yield Gap Analysis of Soybean, Groundnut, Pigeonpea and Chickpea in India Using Simulation Modeling*. Global Theme on Agroecosystems Report No. 31. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.

Chander, G., Wani, S.P., Sahrawat, K.L. and Jangawad, L.S. (2012) Balanced plant nutrition enhances rainfed crop yields and water productivity in Jharkhand and Madhya Pradesh states in India. *Journal of Tropical Agriculture* 50(1–2), 24–29.

Chander, G., Wani, S.P., Sahrawat, K.L., Kamdi, P.J., Pal, C.K. *et al*. (2013a) Balanced and integrated nutrient management for enhanced and economic food production: case study from rainfed semi-arid tropics in India. *Archives of Agronomy and Soil Science* 59(12), 1643–1658.

Chander, G., Wani, S.P., Sahrawat, K.L., Pal, C.K. and Mathur, T.P. (2013b) Integrated plant genetic and balanced nutrient management enhances crop and water productivity of rainfed production systems in Rajasthan, India. *Communications in Soil Science and Plant Analysis* 44, 3456–3464.

Dixit, S., Tewari, J.C., Wani, S.P., Vineela, C., Chaurasia, A.K. and Panchal, H.B. (2005) *Participatory Biodiversity Assessment: Enabling Rural Poor for Better Natural Resource Management*. Global Theme on Agroecosystems Report No. 18. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.

Government of India (2016) *Agricultural Statistics at a Glance 2016*. New Delhi: Directorate of Economics and Statistics, Ministry of Agriculture. Available at: http://eands.dacnet.nic.in/latest_2006.htm (accessed 19 April 2018).

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

Murty, M.V.R., Singh, P., Wani, S.P., Khairwal, I.S. and Srinivas, K. (2007) *Yield Gap Analysis of Sorghum and Pearl Millet in India Using Simulation Modeling*. Global Theme on Agroecosystems Report No. 37. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.

Rockström, J., Karlberg, L., Wani, S.P., Barron, J., Hatibu, N. *et al*. (2010) Managing water in rainfed agriculture – the need for a paradigm shift. *Agricultural Water Management* 97, 543–550.

Sahrawat, K.L., Wani, S.P., Pardhasaradhi, G. and Murthy, K.V.S. (2010) Diagnosis of secondary and micronutrient deficiencies and their management in rainfed agroecosystems: case study from Indian semi-arid tropics. *Communications in Soil Science and Plant Analysis* 41, 346–360.

Sreedevi, T.K., Wani, S.P., Rao, A.V.R.K., Singh, P. and Ahmed, I. (2009) New science tools for managing community watersheds for enhancing impact. *Journal of SAT Agricultural Research* 7, 1–19.

Thirtle, C., Beyers, L., Lin, L., McKenzie-Hill, V., Irz, X. *et al*. (2002) *The Impacts of Changes in Agricultural Productivity on the Incidence of Poverty in Developing Countries*. DFID Report No. 7946. Department for International Development, London.

Wani, S.P., Dwivedi, R.S., Ramana, K.V., Vadivelu, A., Navalgund, R.R. and Pande, A.B. (2002) *Spatial Distribution of Rainy Season Fallows in Madhya Pradesh: Potential for Increasing Productivity and Minimizing Land Degradation*. Global Theme on Agroecosystems Report No. 3. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.

Wani, S.P., Pathak, P., Jangawad, L.S., Eswaran, H. and Singh, P. (2003) 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., Rockström, J., Venkateswarlu, B. and Singh, A.K. (2011a) New paradigm to unlock the potential of rainfed agriculture in the semi-arid tropics. In: Lal, R. and Steward, B.A. (eds) *World Soil Resources and Food Security*. CRC Press, Boca Raton, FL, pp. 419–470.

Wani, S.P., Sahrawat, K.L., Sarvesh, K.V., Mudbi, B. and Krishnappa, K. (2011b) *Soil Fertility Atlas for Karnataka*. Patancheru, India: International Crops Research Institute for the Semi-Arid Tropics.

Wani, S.P., Chander, G., Sahrawat, K.L. and Pardhasaradhi, G. (2015a) Soil test-based balanced nutrient management for sustainable intensification and food security: case from Indian semi-arid tropics. *Communications in Soil Science and Plant Analysis* 46(S1), 20–33.

Wani, S.P., Chander, G. and Uppal, R.K. (2015b) Enhancing nutrient use efficiencies in rainfed systems. In: Rakshit, A., Singh, H.B. and Sen, A. (eds) *Nutrient Use Efficiency: From Basics to Advances*. Springer, New Delhi, pp. 359–380. DOI: 10.1007/978-81-322-2169-2_23.

Wani, S.P., Chander, G., Sahrawat, K.L., Pal, D.K., Pathak, P. *et al*. (2016) Sustainable use of natural resources for crop intensification and better livelihoods in the rainfed semi-arid tropics of Central India. *NJAS – Wageningen Journal of Life Sciences* 78, 13–19.