19 Enhancing Resource Use Efficiency Through Soil Management for Improving Livelihoods

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Abstract

Sustainable intensification and improvement in farm-based livelihoods particularly in dryland tropics are the biggest challenges of the century. Widespread soil degradation, growing water scarcity, and looming threat of climate change further compound the problem of achieving food and nutritional security along with improved livelihoods. Large yield gaps in drylands provide a huge opportunity to increase the food production for future food security and mainstreaming of drylands. Soil management for correcting micro and secondary nutrient deficiencies has shown to increase crop productivity by 20–66% in Karnataka, India. During 2009–2013 in this state, more than 5 million farmers benefitted and net economic benefits through increased production were estimated to the tune of US$353 million (Rs. 1963 crores). Balanced nutrition led to increased nitrogen uptake efficiency, utilization efficiency, and use efficiency for grain yield and harvest index. Best practices like soil test-based fertilization including micronutrients and improved cultivars also contribute to increasing rainwater use efficiency in crops by channelizing unproductive evaporation loss into productive transpiration. In current rainy fallow regions, the landform management like broadbed and furrow along with balanced nutrition has shown that fallow lands in black soil regions in Madhya Pradesh can be successfully cultivated to grow soybean crop. Similarly soil fertility management along with other best practices provides opportunities for intensification through cultivating 11.4 million ha rice fallow in India by growing of early maturing chickpea. Thus, efficient rainy and post-rice fallow management is a way forward to enhance land

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use efficiency for higher productivity and incomes. Along with productivity and economic benefits, improved soil-nutrient-crop-water management is found to contribute to organic C building, enhancing microbial activity and resilience building of production systems. Efficient soil management thus serves as a foundation to enhance livelihoods through resource-efficient production and providing opportunities for scaling up.

Keywords
Agriculture • Incomes • Nutrient use efficiency • Soil degradation • Water use efficiency

19.1 Resource Crunch and Future Food Security: A Daunting Challenge

The biggest challenge of the 21st century is to ensure food security and reducing poverty with finite and scarce land and water resources for the ever growing global population expected to reach 9 billion+ by 2050 from 6.5 billion today (Wani et al. 2009b). Most of this increase in population is expected to occur in less-developed countries in Asia and Africa, where most of the poor live and where rainfed agriculture forms the dominant basis for livelihood security (Singh et al. 2009). Current global food production comes from 1.5 billion ha of cultivated land, representing 12% of the total land area (Schultz and de Wrachien 2002; Hanjra and Qureshi 2010). About 1.1 billion ha (80% of world's physical agricultural area) is rainfed and generates about 60% of the world's staple food (Hanjra and Qureshi 2010). Irrigated agriculture covers only 279 million ha or 19% of cropland (Thenkabail et al. 2010) (it becomes 400 million ha when multiple crops/cropping intensity is considered), but contributes 40% of agricultural output. In the last few decades the emerging evidence indicates that crop productivity growth in irrigated areas has slowed or stagnated due to multiple factors. Relying on irrigated agriculture is not possible as data on water supply and demand are startling: about 450 million people in 29 countries face severe water shortages (Serageldin 2001); as much as two-thirds of the world population could be water-stressed by 2025 (Seckler et al. 1999); aquifers, which supply one-third of the world's population, are being pumped out faster than nature can replenish them (Shah et al. 2006); half of the world's rivers and lakes are polluted; and major rivers, such as the Yellow, Ganges, and Colorado, do not flow to the sea for much of the year because of upstream withdrawals (Richter et al. 2003). In the current scenario, the potential of rainfed agriculture is well recognized, and therefore the increased food production has to come from land and water resources which are finite and in a degrading state (Wani et al. 2011a). The farm productivity and resource use efficiency in rainfed and irrigated agriculture are declining over the years due to inappropriate water and land management practices, water scarcity, and land degradation, and climate change is posing further challenges. The current water use efficiency in rainfed agriculture varies from 35 to 45%, and huge amount of fresh water harvesting, as soil moisture during monsoon period is lost through the nonproductive evaporation resulting in poor water use efficiency.

In India, population is expected to increase from the current 1.21 billion in 2011 (Directorate of Economics & Statistics, Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India 2014) to the expected 1.69 billion by 2050 (FAOSTAT 2013). Within existing land and water constraints, India must sustainably increase the productivity levels of the major rainfed crops to meet the ever-increasing demand of food to around 380 million tons in 2050 (Amarasinghe et al. 2007). Nearly 55% of the population in India is dependent on agriculture and allied sectors for their livelihoods, and agriculture contributes only around 14% to the nation's gross domestic production (GDP) (Directorate of Economics & Statistics, Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India 2014). The total cultivable land in India is 141 million ha with a cropping intensity of 135%. Indian agriculture is essentially small farm agriculture with majority of farmers' owning less than 1 ha of land, and 83% of farmers represent small farming households (Directorate of Economics & Statistics, Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India 2014). Groundwater and surface water sources in India irrigate about 44 and 21 million ha of agricultural lands, respectively, (nearly 46% of total cultivable land) and rest of the cultivable area (76 million ha) is rainfed. In India, per capita water availability has declined from 5177 m^3 in 1951 to 1545 m^3 in 2011 due to the rise in population from 361 million in 1951 to 1.21 billion in 2011 (Directorate of Economics & Statistics, Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India 2014). Water resources in most of the river basins have been allocated and/or utilized among various sectors (domestic, agriculture, industry, energy, ecosystems, etc.) and only limited scope exists to further harvest the fresh water. The irrigated regions are at or near to productivity plateau and there is little scope to increase the food production. Thus, rainfed regions which are bypassed for development in the past are at center stage for enhancing food production, while sustaining it in irrigated regions.

19.2 Fatigue in Food Production in Irrigated Regions and Rainfed Regions: Hope for Food Security

The farm productivity and resource use efficiency in both irrigated and rainfed systems are declining over the years due to inappropriate water and land management practices, water scarcity, land degradation, land fragmentation, lack of access to credit and markets, etc. Further, the climate change has led to the vulnerability of food production in tropical countries like India (Boomiraj et al. 2010; Rao et al. 2013). Despite huge investments (approx. 60 billion USD), the area under irrigation is not increasing and at the same time yields are stagnating (Shah 2011). Therefore, future food security largely depends on the rainfed systems, as current farmers' yields are lower by two to five folds than the achievable potential yields (Rockström et al. 2007; Wani et al. 2009b).

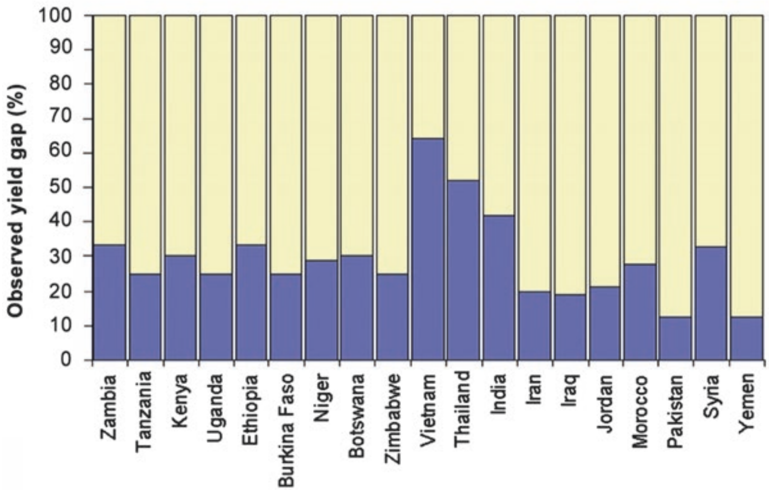

Fig. 19.1 Observed yield gaps (for major grains) between farmers' yields and achievable yields (100% denotes achievable yield level and columns actual observed yield levels). Source: Rockström et al. (2007)

19.3 Crop Yield Gaps and Opportunities

The actual yields from rainfed agriculture are quite low, as compared to achievable ones in semiarid tropical agro-ecosystems (Wani et al. 2012c). In countries in Eastern and Southern Africa the yield gap is very large. In many countries in West Asia, farmers' yields are less than 30% of achievable yields, while in some Asian countries the figure is close to 50%. Historic trends present a growing yield gap between farmers' practice and farming systems that benefit from management advances. The existing large yield gaps between the current and the potentially achievable crop yields particularly in the rainfed areas provide a huge opportunity to increase the country's food production substantially (Fig. 19.1).

Long-term studies at ICRISAT show that it is possible to achieve grain productivity of 5.1 tons per ha from rainfed agriculture compared to 1.1 tons per ha currently being achieved (Wani et al. 2003a, 2012c). Both management practices are sustainable in the long run, but have different carrying capacities, farmers' practice having a low carrying capacity of 5 persons ha^{-1}, while improved management 27 persons ha^{-1}, which is urgently needed for feeding the burgeoning population. The study validated the need for knowledge-based management in the drylands to bridge yield gap for future food security and improved farm incomes and livelihoods for smallholders in the SAT (Fig. 19.2).

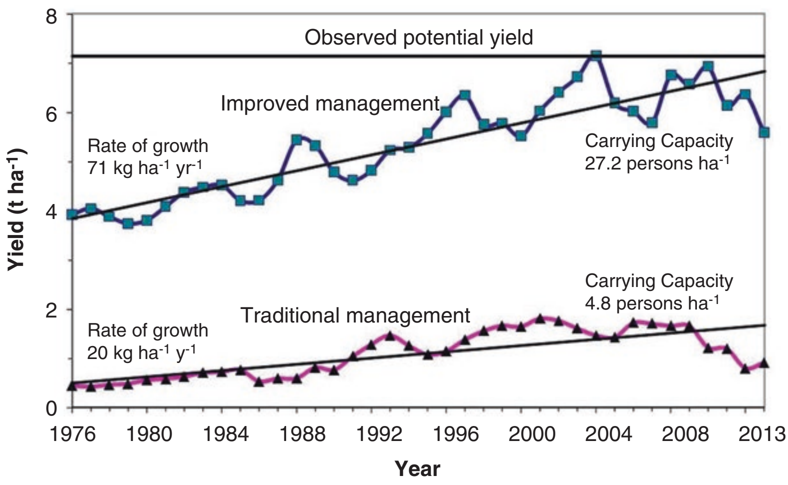

Fig. 19.2 Crop yields under improved and traditional management systems during 1976–2013 at ICRISAT, Patancheru, India

19.4 Issues with Regard to Soil Management

19.4.1 Poor Soil Health and Soil Degradation

Studies show that multi-nutrient deficiencies are constraining farmers from achieving the potential yields (Table 19.1). Soil analysis results from farmers' fields in different states like Andhra Pradesh, Gujarat, Karnataka, Kerala, Madhya Pradesh, Rajasthan, Tamil Nadu, Gujarat, and Jharkhand showed widespread deficiencies (18–100%) of secondary nutrients like sulfur and micronutrients like zinc, boron which have emerged as main constraints for sustaining agricultural productivity (Wani et al. 2012a, 2011b, 2013, 2015a, b; Sahrawat et al. 2010, 2007; Rego et al. 2005; Chennamaneni et al. 2014; Chander et al. 2012, 2013a, b, 2014b). The traditional practice of applying farm yard manure (FYM) has also declined as chemical fertilizers, like urea, are cheaper. Organic manure is used only for high-value crops. Soil organic carbon and nitrogen are primary indicators of soil health. Most of the arable land, across the country, shows low levels of soil organic carbon with deficiencies ranging from 11% to 76% (Wani et al. 2015a). Similarly, soils suffer from deficiencies of phosphorus 21–74% while potassium deficiencies (1–24%) are not really limiting factor. The secondary and micronutrient deficiencies across the states ranged between 46–96% for sulfur; 56–100% for boron; and 18–85% for zinc. The general practice by the farmers is to add fertilizers containing only macronutrients [nitrogen–phosphorus–potassium (NPK)] and are not aware of secondary and micronutrient deficiencies which are apparently acting as limiting factors for the food production.

Table 19.1 Percent of farm field soil samples found deficient in available nutrients and having low levels of soil organic C

State	% samples with low levels of soil organic C	% samples deficient in available nutrients				
		P	K	S	B	Zn
Andhra Pradesh	76	38	12	79	85	69
Gujarat	12	60	10	46	100	85
Karnataka	52	41	23	52	62	55
Kerala	11	21	7	96	100	18
Madhya Pradesh	22	74	1	74	79	66
Rajasthan	38	45	15	71	56	46
Tamil Nadu	57	51	24	71	89	61

Source: Wani et al. (2015a)

19.4.2 Imbalanced Use of Fertilizers

The past fertilizer application strategies have resulted in more application of nitrogen and phosphorous containing fertilizers, which is currently in the NPK ratio of 8:2.7:1 instead of desired 4:2:1 (Directorate of Economics & Statistics, Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India 2014). Imbalanced use of fertilizers arises due to (1) fertilizer subsidy of the government skews the fertilizer consumption pattern in the country, (2) inadequate availability of the required fertilizers at the stipulated time in rural areas, and (3) lack of knowledge among farmers as to what nutrients are required by the crops and what is missing from their lands. For inputs such as improved cultivars, seeds, and pesticides, private companies and their dealer networks provide the information to the farmers. However, there is a limited or, in some cases, no such practice existing for fertilizers. The public infrastructure for soil analysis is poorly developed. Farmers rarely get the information in time, and these laboratories often provide information on NPK fertilizers in a format that farmers fail to understand.

Fallout of the fertilizer subsidy is that chemical fertilizers are cheaper than organic fertilizers. Thus, farmers have moved away from using organic manure, which is very critical for preserving good soil health, as organic carbon is the key fuel for keeping the soil microbial activities in a good state. Good soil health is required to ensure the quality of food, and for food and nutritional security. To address malnutrition in India, it is more economical and efficient to address food quality issues through soil health and diet diversification rather than through biofortification and nutritional amendments externally.

Unbalanced use of fertilizers also leads to depletion of particular nutrients in the soils as well as causing environmental degradation. It increases the cost of cultivation and also lowers its efficiency.

19.4.3 Declining Efficiency of Fertilizer Use

Subsidies and increased awareness about fertilizers have led to a significant increase in fertilizer consumption (Table 19.2). More importantly, while fertilizer

Table 19.2 All India consumption of N, P, and K fertilizers and area and production of food grains

Year	Consumption (000 t)			Total NPK (000 t)	Area (million ha)	Production (million t)	Fertilizer use efficiency (kg food per kg NPK)
	N	P	K				
1950–1951	58.7	6.9		65.6	97.3	50.8	775
1955–1956	107.5	13.0	10.3	130.8	110.6	66.9	511
1960–1961	210.0	53.1	29.0	292.1	115.6	82.0	281
1965–1966	574.8	132.5	77.3	784.6	115.1	72.4	92.2
1970–1971	1487.0	462.0	228.0	2177.0	124.3	108.4	49.8
1975–1976	2148.6	466.8	278.3	2893.7	128.2	121.0	41.8
1980–1981	3678.1	1213.6	623.9	5515.6	126.7	129.6	23.5
1985–1986	5660.8	2005.2	808.1	8474.1	128.0	150.4	17.8
1986–1987	5716.0	2078.9	850.0	8644.9	127.2	143.2	16.6
1987–1988	5716.8	2187.0	880.5	8784.3	119.7	140.4	16.0
1988–1989	7251.0	2720.7	1068.3	11040.0	127.7	169.9	15.4
1989–1990	7386.0	3014.2	1168.0	11568.2	126.8	171.0	14.8
1990–1991	7997.2	3221.0	1328.0	12546.2	127.8	176.4	14.1
1991–1992	8046.3	3321.2	1360.5	12728.0	121.9	168.4	13.2
1992–1993	8426.8	2843.8	883.9	12154.5	123.2	179.5	14.8
1993–1994	8788.3	2669.3	908.4	12366.0	122.8	184.3	14.9
1994–1995	9507.1	2931.7	1124.7	13563.5	123.9	191.5	14.1
1995–1996	9822.8	2897.5	1155.8	13876.1	121.0	180.4	13.0
1996–1997	10301.8	2976.8	1029.6	14308.2	123.6	199.3	13.9
1997–1998	10901.8	3913.6	1372.5	16187.9	124.1	192.3	11.9
1998–1999	11353.8	4112.2	1331.5	16797.5	125.2	203.6	12.1
1999–1900	11592.7	4798.3	1678.7	18069.7	123.1	209.8	11.6
2000–2001	10920.2	4214.6	1567.5	16702.3	121.1	196.8	11.8
2001–2002	11310.2	4382.4	1667.1	17359.7	122.8	212.9	12.3
2002–2003	10474.1	4018.8	1601.2	16094.1	113.9	174.8	10.9
2003–2004	11077.0	4124.3	1597.9	16799.2	123.5	213.2	12.7
2004–2005	11713.9	4623.8	2060.6	18398.3	120.1	198.4	10.8
2005–2006	12723.3	5203.7	2413.5	20340.5	121.6	208.6	10.3
2006–2007	13772.9	5543.3	2334.8	21651.0	123.7	217.3	10.0
2007–2008	14419.1	5514.7	2636.3	22570.1	124.1	230.8	10.2
2008–2009	15090.5	6506.2	3312.6	24909.3	122.8	234.5	9.4
2009–2010	15580.0	7274.0	3632.4	26486.4	121.3	218.1	8.2
2010–2011	16558.2	8049.7	3514.3	28122.2	126.7	244.5	8.7
2011–2012	17300.3	7914.3	2575.4	27790.0	124.8	259.3	9.3
2012–2013	16820.9	6653.4	2061.8	25536.1	120.8	257.1	10.1
2013–2014	16750.1	5633.5	2098.9	24482.5	126.0	264.8	10.8

Source: Directorate of Economics & Statistics, Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India (2014) consumption continued to rise substantially, the elasticity of output with respect to fertilizer use has dropped sharply. During the period since 1970–1971 to 2010–2011, while food grain production grew by about 2.3 times (108.4–244.5 million ton), the increase in fertilizer (NPK) consumption (2177–28122.2 thousand ton) was about 13 times (Directorate of Economics & Statistics, Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India 2014). However, the trends now show positive signs with food production at 264.8 million ton with use of 24482.5 thousand ton NPK fertilizers during 2013–2014. The average crop response was about 50 kg of food grain per kg of NPK fertilizer during the 1970–1971, and fell to about 8.70 during 2010–2011 and about 10.8 during 2013–2014. The increase in fertilizer use has come at significant cost. The fiscal burden of fertilizer subsidy was Rs. 60 crore in 1976–1977, which shot up to over Rs. 70,000 crore in 2012–2013. There are other important costs in the form of long-term soil degradation, degradation of water resources (in both quantity and quality), and general stagnation of yields due to application of suboptimal nutrient ratios.

Thus, disproportionate NPK fertilizer application, multinutrient deficiencies, and lack of organic manure application have led to reduction in the carbon content of the soil and contributed to stagnating agricultural productivity.

19.5 Soil Management as an Entry Point Activity

Entry point activity (EPA) in any project involves building the rapport with the community, strengthening, and sustaining it throughout the project and beyond. Selection of the appropriate EPA for building rapport with the community is very critical and an ideal EPA must have the following elements (Wani et al. 2009a):

- EPA should be knowledge based and should not involve direct cash payment through the project in the village.
- An activity should have a high success probability (>80–90%) and be based on proven research results.
- The EPA should involve participatory research and development (PR&D) approach, and community members should preferably be involved in undertaking the activity in watersheds.
- An EPA should result in the measurable tangible economic benefits to the farming community with a relatively high benefit:cost (B:C) ratio.
- The EPA preferably should be simple and easy for the participating farmers to undertake its participatory evaluation.
- Most importantly, the EPA should benefit the majority of farmers in the watershed; and
- Should have a reliable and cost-effective approach to assess the constraints.

Knowledge-based entry point interventions like soil mapping targeted at providing simple solutions to widespread problems are the best options for quick benefits and rapport building with the majority of farmers to initiate a collective action for technological upgradation of dryland agriculture (Wani et al. 2009a; Dixit et al. 2007; Chander et al. 2016). The characterization of fertility status of farmers' fields particularly in India has indicated micro and secondary nutrient deficiencies of boron (B), zinc (Zn), and sulfur (S) in addition to nitrogen (N), phosphorus (P), and potassium (K) (Wani et al. 2002a, b, 2009a, 2011b, 2012a, 2013, 2015a, b; Sahrawat et al. 2007, 2010; Chander et al. 2012, 2013a,b, 2014a,b). Such nutrient depletion is the chief biophysical factor limiting production. Soil health is prerequisite to strengthen agri-based enterprises and therefore has proved to be a very effective entry point intervention to quickly harness the productivity benefits while bringing on board the majority farmers to initiate the process of upgradation of dryland agriculture.

19.6 Soil Management at Watershed Catchment Scale for Enhanced Productivity and Resource Use Efficiency

Development at watershed catchment scale is one of the most trusted and eco-friendly approaches to managing soil and water resources and is capable of addressing many natural, social, and environmental intricacies (Rockström et al. 2007; Samra 1998; Wani et al. 2002b, 2003a, b). Management of natural resources at the watershed scale produces multiple benefits in terms of increasing food production, improving livelihoods, protecting the environment, addressing gender, and equity issues along with biodiversity concerns (Ahluwalia 2005; Rockström et al. 2007; Wani et al. 2003a, b, 2009a), and is also recommended as the best option to upgrade rainfed agriculture to meet the growing food demand globally (Rockström et al. 2007; Wani et al. 2007).

Soil test-based balanced nutrient management (application of deficient SBZn along with NP) as an EPA in fields in watersheds recorded 70–119% (2100 kg ha^{-1} in maize, 660 kg ha^{-1} in groundnut, 640 kg ha^{-1} in mungbean, and 1070 kg ha^{-1} in sorghum) improvement in crop productivity along with additional returns varying from Rs. 16,050/- to 28,160/- ha^{-1} over the farmers' practice (only NP) (Wani et al. 2014, 2016). Improved nutrient management recorded favorable benefit-cost ratios (1.43–15.2) over the farmers' practice (Wani et al. 2016).

Improved watershed management by the way of constructing water harvesting structures, cultivation across the slope, planting of *Gliricidia* on the bunds, less-exposed soil due to increased cropping intensity, increased use of organic manures, and better crop growth due to adoption of balanced nutrition and other best practices results in restriction to free flow of water leading to more infiltration and thereby reduced runoff in comparison to the rainfall received (Wani et al. 2012c). The reduced runoff which infiltrates into the soil apparently strengthens the green water sources in rainfed agriculture, the consumption of which is almost threefold more than blue water consumed (5000 vs. 1800 km^{3} year^{-1}) for food production (Karlberg et al. 2009). The impact of soil management for conserving in situ and ex situ moisture in watershed interventions is recorded as improvement in the groundwater. As a result of watershed interventions, the water use efficiency by different crops increases with substantial productivity improvement (Wani et al. 2012c), resulting in higher profit margin. Increased water availability enables farmers to increase cropping intensity and diversify to more remunerative land use systems involving horticulture, forage production on sloping lands, etc. Forage promotion strengthens livestock-based livelihoods which provide an alternative source of income and livelihoods, in addition to improving resilience to shocks. Soil erosion, which is a major environmental problem particularly in South Asia (Barton et al. 2004) and other parts of the SAT, is decreased due to improved watershed measures which apparently restrict displacement of soil particles and loss with the reduced runoff water.

Landform management to alleviate waterlogging proved effective intervention to manage high clay Vertisols for higher soybean and groundnut productivity by 13–27% (340–350 kg ha^{-1} in soybean and 160–250 kg ha^{-1} in groundnut) over the farmers' practice (Wani et al. 2014). However, the integrated approach of balanced nutrition and landform management plus improved cultivar was the best option in increasing sunflower productivity by 182% (1600 kg ha^{-1} in sunflower) over farmers' management (control). Adoption of soil-water-crop interventions in target watersheds has shown to abridge yield gaps by 12–96% in groundnut (160–1280 kg ha^{-1}), 29–100% (240–1130 kg ha^{-1}) in pigeonpea, and 0–100% (0–1175 kg ha^{-1}) in chickpea.

The findings from the watershed site at Kothapally revealed that watershed interventions increased the resilience of the production systems and thereby ensured the income stability during adverse climatic conditions (Wani et al. 2012c, 2009b). During the drought year 2002, crop productivity and average incomes from the watershed area were far larger compared to the non-watershed area and farmers in treated watershed area could meet their livelihood in the village, whereas in untreated village a steep decline (44–12%) in the share of agricultural income in total income indicated that people relied on increased nonagricultural sources of income, i.e., through migration during the drought year.

19.7 Soil Health Management for Farm-Based Livelihoods: Case of Bhuchetana in Andhra Pradesh

Under the Bhuchetana initiatives in Andhra Pradesh, the soil health mapping was undertaken in pilots across districts of Andhra Pradesh state which showed widespread soil fertility degradation. New fertilizer management strategies were designed which also included deficient sulfur, boron, and zinc in addition to nitrogen, phosphorus, and potassium. Along with department of agriculture, the balanced fertilizer management was scaled out in farmers' fields. The crop cutting experiments with all major crops during 2011–2012 to 2013–2014 showed significant productivity benefits between 20 and 50% (Fig. 19.3; Table 19.3). In economic terms, one rupee spent on soil management resulted benefit of Rs. 3/- to 15/- through higher crop productivity.

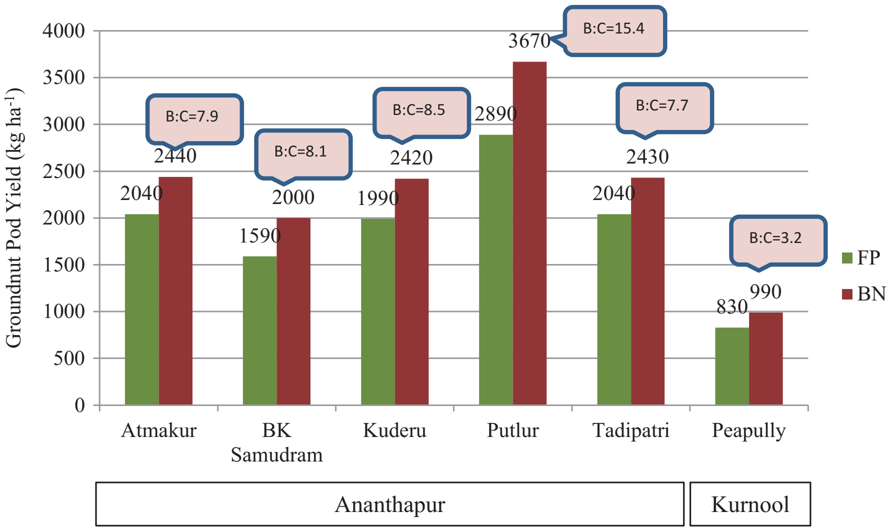

Fig. 19.3 Effects of balanced nutrition on groundnut pod yield in Anantapur and Kurnool districts, Andhra Pradesh, rainy/kharif season 2012

Table 19.3 Effects of soil test-based balanced nutrient management on paddy yield in Andhra Pradesh during post-rainy/rabi 2013–2014 season

District	Mandal	Grain yield			B:C ratio
		FP	BN	% increase	
East Godavari	U Kothapalli	7180	8360	16	11
Guntur	Karempudi	5920	7360	24	13
	Nekarikallu	5160	6440	25	12
	Rompicherla	4600	6170	34	14
Kadapa	Duvvur	5320	6260	18	5
	Khajipeta	5330	6550	23	7
Krishna	Gudlavalleru	4830	7150	48	13
	Kalidindi	4740	5770	22	6
Prakasam	Kandukoor	3300	3910	18	6
	Maddipadu	3820	5170	35	12
	Ongole	4220	5210	23	9
	Singarayakonda	4780	6040	26	12
Srikakulam	Rajam	6000	7370	23	13
Vijayanagaram	Gajapathinagaram	4540	5490	21	9

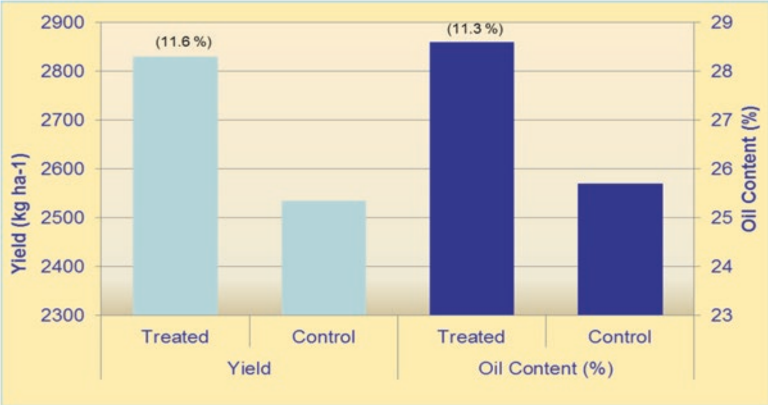

Fig. 19.4 Effects of balanced nutrient management on sunflower yield and oil content in Kadapa, post-rainy/rabi 2011–2012

Along with productivity and economic benefits, crop quality like oil content in sunflower also improved (Fig. 19.4). In our efforts to linking farmers with the markets, it is not only the produced quantity that matters, but also the quality. Therefore, science-led soil management strengthens farmers in effectively linking with the markets.

19.8 Scaling Out Soil Management for Improving Livelihoods: Exemplar Case of Bhoochetana in Karnataka

19.8.1 Yield Increase Through Soil Health Rejuvenation

Bhoochetana was implemented strategically on phased manner to make essential gains in the struggle for improved agricultural productivity, rural incomes, and nutrition. The scaling-up process in this particular project adopted a multilevel "refinement strategy" to increase the effectiveness of technologies and reach greater number of people. It is part of a broader process of innovation and learning. With effective monitoring and evaluation processes, the knowledge acquired from the initial year was used to scaling up the model to create larger impacts in the entire state. The process occurred in an iterative and interactive cycle, as the experience from scaling up feeds back into new ideas and learning.

The unique mechanism of scaling up with comprehensive planning, review, and monitoring along with new institutions like Farm Facilitators (FFs), lead farmers, RSKs, and supporting policies enabled the consortium to cover large rainfed areas in the state. The initiative began with six districts with an area of 0.2 million ha covered mostly cereal crops and extended to nearly 5 million ha in the subsequent years covered all major cereals, legumes, and oilseed crops. As the cropping system is diverse, during 2011, the focus was shifted to include even irrigated crops like paddy and sugarcane to realize their potential yield level. Crop cutting experiments data was the base to undertake yield analysis by comparing improved management practices with farmers' own practice. To estimate average values for farmers' practice and improved practice, boxplots were used to identify extreme cases and outliers for the major crops. The average yields of cereal crops in improved practices were higher than in farmers' practice. Maize is grown more extensively in almost all the districts, except coastal areas, had impressive yield benefits during normal rainfall year. However, poor rainfall and soil fertility status reduced grain yield especially during 2011–2012 and 2012–2013 (Table 19.4). Average maize productivity significantly reduced from 5420 to 3700 kg ha^{-1} in 2012 in case of farmers' practice; from 7800 to 4850 kg ha^{-1} in 2012 ($P < 0.01$) with improved practice. As a result, the incremental gain also reduced from 44 to 31% over farmers' practice. The drastic difference is also due to difference in the type of maize hybrids used, plant spacing, and application of supplemental irrigation.

Although, finger millet is considered as drought-tolerant crop, the average productivity declined from 1680 to 1460 kg ha^{-1} ($P < 0.01$) in case of farmers' practice and 2550 to 1870 kg ha^{-1} ($P < 0.01$) with improved practice during 2009 and 2013, respectively. Given the perception that finger millet responded to improved management practices very meagerly, the increased rate of yield in Bhoochetana is significant. The improved practice helped farmers to harness better yield compared to conventional practice despite drought condition. Rabi sorghum (post-monsoon) is grown in considerable area was also registered productivity loss compared to wet year. During normal (2010) and dry (2011) rainfall year, the rabi sorghum yield was highest as it recorded around 1370 and 1960 kg ha^{-1} ($P < 0.01$) and 1450 and 1910 kg ha^{-1} ($P < 0.01$) under farmers' practice and improved practice, respectively. Pearl millet, one of the staple food grains in northern Karnataka, had shown mixed response to water stress situation between 2010 and 2013. Wheat cultivated in few districts showed positive response to improved management practices as increased yield from 610 and 810 kg ha^{-1} in 2012 to 1000 and 1380 kg ha^{-1} in 2013 under farmers' practice and improved practice, respectively.

Similarly, the average grain yields of legumes and oilseed crops also presented in Table 19.5 revealed that the rainfall had major influence on grain yield. The average yield of blackgram was 930 and 1260 kg ha^{-1} in 2010; 670 and 890 kg ha^{-1} in 2011 ($P < 0.05$); 1220 and 1640 kg ha^{-1} in 2012 ($P < 0.01$); 570 and 760 kg ha^{-1} in 2013 ($P < 0.05$) under farmers' practice and improved practice, respectively. Chickpea is a post-monsoon crop which is generally grown with residual soil moisture performed better under improved practice compared to farmers' practice. The average chickpea yield was 1140 and 1470 kg ha^{-1} in 2009; 1380 and 1810 kg ha^{-1} in 2010; 920 and 1210 kg ha^{-1} in 2011; 630 and 820 kg ha^{-1} in 2012; 770 and 1020 kg ha^{-1} in 2013 ($P < 0.01$) under farmers' practice and improved practice, respectively (Table 19.5). The average groundnut yield was ranging between 1300 and 2100 kg ha^{-1} between 2009 and 2013, respectively, under improved practice and 930 and 1500 kg ha^{-1} under farmers' practice during the same period. Similarly, average Soybean yield was ranging between 1060 and 1930 kg ha^{-1} between 2009 and 2013 under farmers' practice and 1400–2620 kg ha^{-1} under improved practice during the same period (Table 19.5). The productivity difference between farmers' practice and improved practice ranged between 30 and 42% with changing rainfall variability.

Table 19.4 Total grain yield (kg ha^{-1}) of cereals, pulses, and oilseed crops under Bhoochetana between 2009–2010 and 2013–2014 in Karnataka

Cereals					Pulses				Oilseeds			
		Yield (kg ha^{-1})				Yield (kg ha^{-1})				Yield (kg ha^{-1})		
Crop year	Crop	FP	IP	LSD	Crop	FP	IP	LSD	Crop	FP	IP	LSD
2009–2010	Maize	5420	7800 (44)	356**	Chickpea	1140	1470 (29)	178**	Groundnut	1080	1490 (39)	122**
	Finger millet	1680	2550 (52)	157**					Kharif Sunflower	810	1120 (38)	188**
	Rabi sorghum	1230	1780 (45)	103**					Soybean	1770	2620 (48)	231**
2010–2011	Kharif sorghum	1710	2300 (35)	387**	Blackgram	930	1260 (36)	424NS	Groundnut	1500	2130 (42)	134**
	Maize	5820	7560 (30)	441**	Greengram	470	660 (42)	122**	Kharif Sunflower	590	720 (21)	280NS
	Pearl millet	1690	2250 (33)	275**	Pigeonpea	1200	1620 (35)	135**	Soybean	1930	2540 (32)	228**
	Finger millet	1910	2620 (37)	112**	Chickpea	1380	1810 (31)	170**				
	Rabi sorghum	1370	1960 (43)	368**								
2011–2012	Kharif sorghum	2080	2910 (40)	428**	Blackgram	670	890 (34)	200*	Groundnut	1160	1610 (39)	291**
	Maize	3900	5110 (31)	440**	Cowpea	270	400 (45)	34**	Kharif Sunflower	1080	1460 (35)	530NS
	Paddy	4340	5120 (18)	325**	Fieldbean	1490	1940 (30)	607NS	Soybean	1480	1990 (35)	213**
	Pearl millet	1830	2540 (39)	459**	Greengram	540	760 (41)	167*	Rabi Safflower	730	960 (31)	133**
	Finger millet	1500	1960 (31)	215**	Pigeonpea	915	1260 (38)	166**	Rabi Sunflower	1420	1970 (38)	737NS
	Rabi sorghum	1450	1910 (32)	268**	Chickpea	920	1210 (32)	145**				

2012–2013	Kharif sorghum	2050	2670 (30)	400**	Blackgram	1220	1640 (35)	128**	Groundnut	930	1220 (31)	140**
	Maize	3700	4850 (31)	437**	Fieldbean	870	1160 (33)	283*	Kharif Sunflower	1010	1320 (31)	232**
	Paddy	3630	4600 (27)	310**	Greengram	840	1110 (33)	125**	Soybean	1060	1400 (33)	409NS
	pearl millet	1300	1790 (38)	253**	Horsegram	100	130 (26)	90NS	Rabi Safflower	510	650 (29)	171NS
	Rabi Maize	2190	3100 (41)	978NS	Pigeonpea	980	1250 (27)	274NS	Rabi Sunflower	720	950 (32)	250NS
	Finger millet	1380	1830 (32)	204**	Chickpea	630	820 (29)	128**				
	Rabi sorghum	1210	1590 (31)	138**								
	Wheat	610	810 (32)	145**								
2013–2014	Kharif sorghum	2110	2770 (31)	352**	Blackgram	570	760 (34)	145*	Groundnut	1310	1700 (30)	126**
	Maize	4100	5340 (30)	220**	Cowpea	320	430 (34)	71**	Kharif Sunflower	1020	1390 (36)	240**
	Paddy	3990	4940 (24)	164**	Fieldbean	640	880 (38)	189*	Soybean	1480	1860 (26)	121**
	Pearl millet	1410	1960 (39)	177**	Greengram	450	590 (30)	99**	Rabi Safflower	730	950 (30)	109**
	Finger millet	1460	1870 (28)	116**	Pigeonpea	650	870 (34)	105**	Rabi Sunflower	580	780 (34)	203NS
	Rabi sorghum	1330	1690 (27)	168**	Chickpea	770	1020 (32)	81**				
	Wheat	1000	1380 (37)	158**								

Note: *FP* farmers' practice, *IP* improved practice, figures in parentheses indicate percentage over farmers' practice, $^{**}P < 0.01$; $^{*}P < 0.05$, *NS* not significant

Table 19.5 Gross and additional income for cereals, legumes, and oilseed crops under FP and IP in Bhoochetana, Karnataka

Crop year	Cereals				Legumes				Oilseeds			
	Major Crop	Income ($Rs.\ ha^{-1}$) FP	Income ($Rs.\ ha^{-1}$) IP	Addl. income ($Rs.\ ha^{-1}$)	Major crop	Income ($Rs.\ ha^{-1}$) FP	Income ($Rs.\ ha^{-1}$) IP	Addl. income ($Rs.\ ha^{-1}$)	Major Crop	Income ($Rs.\ ha^{-1}$) FP	Income ($Rs.\ ha^{-1}$) IP	Addl. income ($Rs.\ ha^{-1}$)
2009–2010	Maize	45,528	65,520	19,992	Chickpea	20,064	25,872	5808	Groundnut	22,680	31,290	8610
	Finger millet	15,372	23,333	7961					Kharif sunflower	17,942	24,808	6867
	Rabi sorghum	10,578	15,308	4730					Soybean	23,895	35,370	11,475
2010–2011	Kharif sorghum	15,390	20,700	5310	Blackgram	19,530	26,460	6930	Groundnut	34,500	48,990	14,490
	Maize	51,216	66,528	15,312	Greengram	14,899	20,922	6023	Kharif sunflower	13,865	16,920	3055
	Pearl millet	14,872	19,800	4928	Pigeonpea	36,000	48,600	12,600	Soybean	27,020	35,560	8540
	Finger millet	18,432	25,283	6852	Chickpea	28,980	38,010	9030				
	rabi sorghum	12,330	17,640	5310								
2011–2012	Kharif sorghum	20,800	29,100	8300	Blackgram	22,110	29,370	7260	Groundnut	31,320	43,470	12,150
	Maize	38,220	50,078	11,858	Cowpea	9450	14,000	4550	Kharif sunflower	30,240	40,880	10,640
	Paddy	46,872	55,296	8424	Fieldbean	29,800	38,800	9000	Soybean	24,420	32,835	8415
	Pearl millet	17,934	24,892	6958	Greengram	18,900	26,600	7700	Rabi safflower	13,140	17,280	4140
	Finger millet	15,750	20,580	4830	Pigeonpea	29,280	40,320	11,040	Rabi sunflower	35,500	49,250	13,750
	Rabi sorghum	14,500	19,100	4600	Chickpea	25,760	33,880	8120				

2012–2013	Kharif sorghum	31,160	40,584	9424	Blackgram	52,460	70,520	18,060	Groundnut	34,410	45,140	10,730
	Maize	43,475	56,988	13,513	Fieldbean	21,750	29,000	7250	Kharif sunflower	37,370	48,840	11,470
	Paddy	45,375	57,500	12,125	Greengram	36,960	48,840	11,880	Soybean	23,320	30,800	7480
	Pearl millet	15,275	21,033	5758	Horsegram	5500	7150	1650	Rabi safflower	14,280	18,200	3920
	Rabi maize	25,733	36,425	10,693	Pigeonpea	37,730	48,125	10,395	Rabi sunflower	26,640	35,150	8510
	Finger millet	20,700	27,450	6750	Chickpea	18,900	24,600	5700				
	Rabi Sorghum	18,392	24,168	5776								
	Wheat	8235	10,935	2700								
2013–2014	Kharif sorghum	32,072	42,104	10,032	Blackgram	24,510	32,680	8170	Groundnut	52,400	68,000	15600
	Maize	53,710	69,954	16,244	Cowpea	12,800	17,200	4400	Kharif sunflower	37,740	51,430	13,690
	Paddy	52,269	64,714	12,445	Fieldbean	19,200	26,400	7200	Soybean	37,000	46,500	9500
	Pearl millet	17,625	24,500	6875	Greengram	20,250	26,550	6300	Rabi safflower	21,900	28,500	6600
	Finger millet	21,900	28,050	6150	Pigeonpea	27,950	37,410	9460	Rabi sunflower	21,460	28,860	7400
	Rabi sorghum	20,216	25,688	5472	Chickpea	23,870	31,620	7750				
	Wheat	14,000	19,320	5320								

In percentage terms, the improved practices were very much effective as the improved practice helped to improve the profitability by 18–52% across cereal crops from 2009 to 2013. The highest yield profitability was observed in finger millet (52%) during 2009. It is significant to note that the soil test-based fertilizer application along with micro and secondary nutrients resulted in enhanced yield of finger millet. Similarly, rabi sorghum (45%) and maize (44%) also showed impressive yield benefits during the same period. Although the percentage increase in yield benefits was impressive, the absolute numbers showed a declining trend during dry and very dry years. In terms of legume crops, the highest percentage of yield increment was achieved in cowpea (45%) followed by green gram (42%) between farmers' practice and improved practice. There is a mixed yield response over farmers' practice in different rainfall years. Similarly, soybean (48%) and groundnut (42%) showed significant yield improvement over farmers' practice during 2009 and 2010, respectively (Table 19.5).

It was clearly demonstrated that rainfall variation had impact on crop yield, and as a result, the yield gain was reduced during low rainfall years. However, crop yield was considerably higher when compared with farmers' practice. It showed that the use of micronutrients, new cultivars, and other improved practices had greater effect on the crop yield. Legume crops and oilseed crops also performed well throughout the project period. Since legumes form major part of staple food crops in the state, efforts are needed to revive the legume-based cropping system with new knowledge, practices, methods, and approaches.

19.8.2 Economic Benefits and Livelihood Improvement

Table 19.5 compares the gross income and net additional income for different crops between Farmers' Practice (FP) and Improved Practice (IP) in different years. Among cereal crops, maize is more remunerative as the additional income was highest (ranging between Rs. 11,850 and 19,900 ha^{-1}) in all the years over other cereal crops followed by paddy (ranging between Rs. 8424 and 12,400 ha^{-1}), kharif sorghum (ranging from Rs. 5300 to 10,000 ha^{-1}), finger millet (ranging between Rs. 4830 and 7961 ha^{-1}), and rabi sorghum (ranging between Rs. 4600 and 5770 ha^{-1}). Similarly, blackgram, pigeonpea, and green gram are more remunerative among legume crops in different rainfall years. The highest additional income of Rs. 18,000 ha^{-1} was obtained from blackgram during 2012–2013 followed by pigeonpea (Rs. 12,600 ha^{-1}) and greengram (Rs. 11,800 ha^{-1}) during 2010–2011 and 2012–2013 season, respectively. Chickpea was grown in major areas and the additional income was ranging between Rs. 5700 ha^{-1} during 2012–2013 and Rs. 9000 ha^{-1} during 2010–2011 seasons, respectively. Among oilseed crops, groundnut recorded highest additional income (Rs. 15,600 ha^{-1} during 2013–2014) followed by sunflower (Rs. 13,600 ha^{-1} during 2013–2014) and soybean (Rs. 11,400 ha^{-1} during 2009–2010).

The impact of rainfall on crop yield and income was analyzed for major cereals, legumes, and oilseed crops in normal, dry, and very dry rainfall years (Table 19.6). To compare economic benefit from different crops, we have presented net additional

Table 19.6 Average crop yield, net income, and benefit-cost ratio of selected crops under improved practice and conventional farming practice with full cost in normal (2010), dry (2011), and very dry rainfall year (2012) in Karnataka

Crop	Mean rainfall (mm)	Yield (kg ha^{-1})			Net income (Rs. ha^{-1})	BC ratio
		IP	FP	Increase (%)		
2010–2011 (Normal rainfall year)						
Chickpea	759	1820	1350	34	9770	5.3
Greengram	800	760	550	40	7970	4.4
Pigeonpea	836	1630	1210	35	14,670	7.9
Groundnut	572	1810	1300	40	11,900	6.7
Soybean	863	2650	2010	32	9250	5.1
Pearl millet	685	2390	1710	40	6030	3.3
Maize	655	7250	5410	34	16,220	9.1
Finger millet	624	2320	1700	36	5960	3.5
Sorghum	614	2410	1780	36	5710	3.1
Mean	712	2560	1891	36	9720	5.4
2011–2012 (Dry year)						
Chickpea	407	1110	830	35	8030	4.4
Greengram	484	830	580	41	9620	5.4
Pigeonpea	473	1230	890	38	12,450	7.5
Maize	470	5270	3950	33	12,930	8.5
Paddy	2720	5580	4480	25	12,160	9.7
Pearl millet	415	2370	1710	38	6460	3.6
Finger millet	485	2040	1550	31	5100	3.8
Sorghum	451	3010	2150	40	8640	5.1
Groundnut	389	1900	1340	42	15,210	9.0
Soybean	520	1850	1320	41	9020	5.0
Mean	681	2519	1880	36	9962	6.2
2012–2013(Very dry year)						
Chickpea	382	780	600	30	5330	3.1
Greengram	592	1090	820	33	11,730	6.3
Pigeonpea	367	1040	810	29	9030	5.2
Maize	318	5080	3850	32	14,450	9.2
Paddy	1375	4770	3760	27	12,950	8.9
Pearl millet	380	1980	1490	33	5750	3.4
Finger millet	283	1680	1260	33	6300	4.4
Sorghum	388	2510	1940	29	8650	4.7
Groundnut	274	1030	780	33	9400	6
Soybean	465	1570	1170	34	8980	5.1
Mean	482	2153	1648	31	9257	5.6

income after subtracting the cost of cultivation from gross income both for farmers' practice and improved practice. Maize, pigeonpea, and groundnut are more remunerative during normal rainfall year (2010) as the yield of these crops were ranging from 7275 to 5435 kg ha^{-1}; 1631 to 1212 kg ha^{-1}; and 1814 to 1297 kg ha^{-1} under improved and farmers' practice, respectively. The increased yield was resulted in enhanced net additional income of Rs. 14,466, 10,634, and 10,157 ha^{-1} from maize, pigeonpea, and groundnut, respectively. On the other hand, other rainfed crops such as chickpea, soybean, and blackgram also performed better as the median yield increment was around 35% resulting in increasing net income of Rs. 6596, 7335, and 7784 ha^{-1} under moderate to good rainfall conditions.

The economic benefit due to improved technologies was evident even during low rainfall years. During dry year (year 2011), the crop yield of maize, pigeonpea, groundnut, and paddy increased significantly over farmers' practice but observed declining trend compared to 2010 (normal year) yield level. The net additional income obtained from improved practice was Rs. 11,836, 9561, 14,160, and 10,595 ha^{-1} for maize, pigeonpea, groundnut, and paddy, respectively. The same trend can be observed during 2012 (very dry year) also where the net income reduced compared to 2011 in the case of groundnut (Rs. 8160 ha^{-1}) and pigeonpea (Rs. 7748 ha^{-1}) but marginally increased for maize (Rs. 13,508 ha^{-1}) and paddy (Rs. 11,043 ha^{-1}). The effect of declining rainfall was more evident in all the years, except greengram and soybean, the yield of all other crops was reduced by almost 21–133% under improved practice when compared between normal (2009) and very dry year (2012). However, improved management practice helped to withstand the shock and subsequently increased net income.

19.8.3 Return on Investment

Table 19.4 compares the return on investment between IP and FP for different rainfall years from 2010–2011 to 2012–2013 and revealed that IP performed better in terms of return on investment (B:C ratio) during all the years. The mean additional B:C ratio for the year normal (2010–2011), dry (2011–2012), and very dry year (2012–2013) for major crops was 5.4, 6.2, and 5.6, respectively. Interestingly, IP has contributed to enhance the B:C ratio above the mean level for maize (9.1), pigeonpea (7.9), and groundnut (6.7) during normal rainfall year (2010–2011), while the same crops performed low during very dry year (2012–2013) due to poor rainfall. The BC ratio ranges from 3 to 10 depending on crop type, soil type, and rainfall condition. The comparison of IP with FP revealed that the improved management system as such performed better in terms of achieving higher return on investment by above 2.3:1 compared to 1.9:1 by FP even with full cost of cultivation including micronutrients over three different rainfall years. At the state level, the improved crop yield contributed to enhanced net income and additional value of the product. By the end of fourth year, the net profit accrued from the program is about Rs. 1248 crores (242 million US$) from 30 districts.

19.8.4 Social Impact of Bhoochetana

Bhoochetana program witnessed significant changes in terms of social as well as economic condition of farming households in Karnataka. To substantiate this view, we carried out a rapid survey of beneficiary households in selected districts. The results are most revealing.

19.8.4.1 Asset Formation

Most of the farm households who have adopted Bhoochetana technologies have reinvested additional crop income on asset formation particularly on agriculture and agriculture-related infrastructure (40% of households). The major proportions (13%) of households have also invested on white goods (luxury goods) such as fridge, ceiling fan, mixer grinder, mobile, and vehicles. It is important to note that about 10% of the households have invested income obtained from Bhoochetana on loan repayment, house infrastructure, and education, respectively. The additional income was useful for majority of households (7%) to overcome health-related expenditure which is significant as it ensures better working condition for the family members. The Bhoochetana program also helped to take care of domestic expenditures as it facilitates small savings due to crop improvement (Fig. 19.5).

19.8.4.2 Knowledge Improvement

Bhoochetana is a holistic process-based mission project which intended to not only increase crop productivity but also enhance stakeholders' knowledge regarding agriculture operations. The analysis covered major activities which are part of Bhoochetana mission project, and periodic trainings/capacity building programs

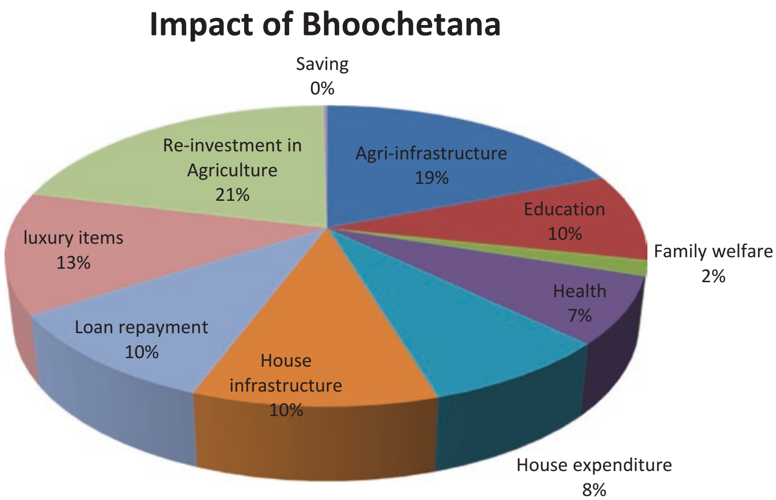

Fig. 19.5 Contribution of Bhoochetana for household asset formation, reinvestment on agriculture, health, and education due to increased income in Karnataka

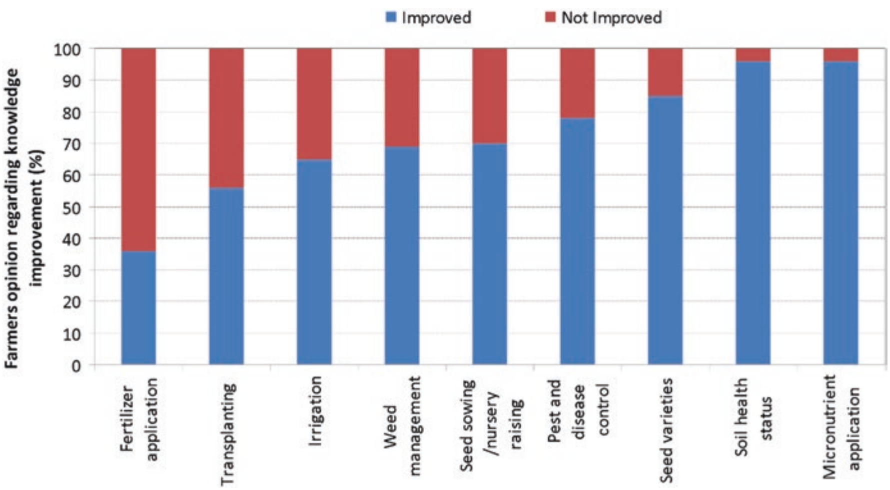

Fig. 19.6 Bhoochetana contributed to increased farmers' knowledge regarding agriculture development in Karnataka

were organized to disseminate the knowledge. The results are more revealing. First, the knowledge dissemination process initiated by ICRISAT through master trainers from University of Agricultural Sciences and Department of Agriculture impacted most positively on farmers as more than 50% of the households have acknowledged improved knowledge on major aspects of agriculture development in the state. Second, the knowledge about soil health status, micronutrient application, and seed varieties improved significantly which are critical components of agriculture development. More than 85% of rural households reported that their knowledge enhanced on these critical components. Third, nearly 80% of households have learnt new methods to control pests and diseases to enhance their crop yield in the rainfed agriculture (Fig. 19.6).

19.8.4.3 Gender Equity

Gender equity issue was addressed by analyzing the decision-making process by men and women farmers who are following Bhoochetana practices. The analysis revealed that women exclusively have very meager role in decision making with regard to selection of crop, variety, land preparation, fertilizer and manure application, irrigation, harvesting, threshing, and marketing (Fig. 19.7). However, most of the critical decisions related to above-mentioned activities were taken jointly which shows that there is a consensus among men and women to carry out agriculture activities in the dryland areas. It is evident that women are mostly involved in laborious activities on which they have decision-making control, viz., transplanting (23%), hand weeding (19%), and interculture (12%). It is worth mentioning that men have greater control over decision making in marketing which is the critical aspect of financial management. More than 70% of the men and women farmers

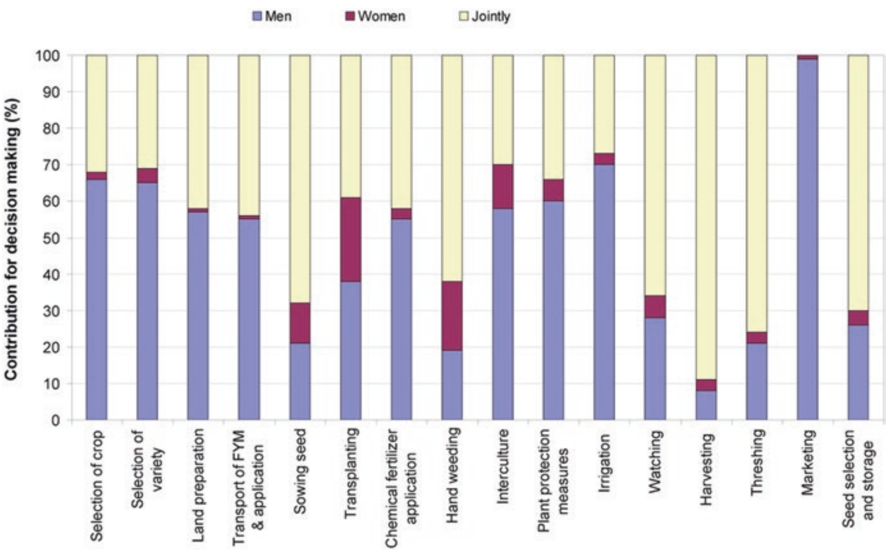

Fig. 19.7 Bhoochetana implementation helped to minimize gender inequality and enhanced decision making of women and men in agriculture-related activities

jointly made decision regarding harvesting, threshing, seed selection, and storage. This reflects that certain activities essentially benefited with women's decisions which are critical in agricultural operations.

19.8.5 Taking Soil Management at Farmers Doorsteps: The Innovations

Bhoochetana initiative originated with the proposition to explore new ways of thinking about interventions that could promote agricultural development by better enabling the partnership process. *Bhoochetana* provided a platform for better resource allocation with added responsibility among partners. The convergence of programs/schemes and knowledge was useful in allocating human as well as financial resources in this program. In *Bhoochetana*, all major programs in the Department of Agriculture converged and treated as "single file system." The major chunk of resource is from central government (75%) and the remaining share is from the state government (25%). One lesson emerged out of which is that research and development practitioners, line departments, and non-state actors must be willing to work with emerging concepts and must recognize that the interventions that they are planning will evolve while they learn. The partnership concept provides a framework for inclusive, knowledge-intensive agricultural development, but more focused, committed efforts are required to accomplish the goal of disseminating pro-poor technologies for small and marginal farmers for better impact.

The Bhoochetana partnership has explored new ways of extension system which is unique in its composition and functioning. It is essential that the traditional extension system may be exchanged for this model where research supports innovation at the local level. The important lesson was that research systems need to be supported in developing interface with other sectors to prioritize and address research issues to achieve desired growth in agriculture sector. Major attention must be given to how and why the research system is governed and to the ability and the attitudes required for engaging in partnerships. Attention must also be given to putting public awareness strategies in place through print and mass media along with training and exposure activities. These types of changes are not necessarily expensive, but they are preconditions for effective investment in research that can contribute to innovation. Similarly, extension investments should create the capacity to identify new, promising alternatives at the farm level and ensure that they are supported in the right way through engaging potential partners.

The soil health mapping was one of the entry point interventions in this initiative and based on the soil health mapping of the whole state in 2009–2010, taluk-wise balanced and integrated nutrient management recommendations were developed as against to state-level recommendations and disseminated to the farmers through farmer facilitators, wall writings, soil health cards, and internet. In addition, it also ensured the availability of these inputs at the village level through appropriate institutional mechanism.

Soil health cards were provided in local language (Kannada) to individual farmers whose fields were sampled with details of individual nutrient status and critical limits along with a comment on the nutrient status of the field. The card was printed both sides containing basic information about the farmer field and recommended dose of nutrients for each crop as well as quantity of nutrients available in commercially marketed fertilizers, for the understanding of farmers. For maximum reach of information to farmers/stakeholders, a multi-pronged information dissemination systems was adopted. Wall writing is one such mechanism through which appropriate information was disseminated in each and every village to create awareness among the farmers. Wall writings were quite conspicuous with details of soil health status, input quantities supplied to the farmer per hectare, component of subsidy, crop cultivars, etc. Wall writings were the effective communication channels in rural areas which has gained movement in Bhoochetana on a large scale helping farmers to understand their soil and agricultural practices, objective of the program, and areas to be covered by the program. Additionally, thousands of brochures and handouts were published and distributed in each district on improved management practices, information on nutrients status, nutrients recommended taluk-wise, and widely distributed in all districts. In addition, print media news coverage was extensive to introduce Bhoochetana program to farmers and also on activities during the season in all districts, besides field facilitators and lead farmers contacts with individual farmers in selected village.

An innovative extension system coupled with institutional intermediaries and high level monitoring helped to reach more than 4 million farming families in the state covering almost 5 million ha area. The cumulative effect of integrated management approach helped to achieve higher benefit-cost ratio for major crops in the state. The soil test-based nutrient management along with other improved technologies increased crop yields up to 66% as compared to farmers' practice (Wani et al. 2012a). The adoption of improved management practices such as soil test-based nutrient application, improved crop cultivars, pest management and suitable land, and water management practices helped to sustain the crops and tolerant to increasing droughts situation and pests and diseases resulting in increased yield compared to conventional farmers' practice. This is evidenced not only during normal years but also during dry and very dry years, thereby indicating improved management practices are critical in building the resilience of the farming system with increased climate variability.

In case of Bhoochetana, science-led innovative approaches were implemented to realize higher yield with modifications in soil, water, and crop management technologies. These kinds of modifications in crop management often require significant changes in technological and economic support to the farmers especially in regions where farmers are not accustomed to using micronutrients to rejuvenate the soil and enhance the yield. Thus, rainfed areas of semiarid regions could be more favorable for adoption of this integrated approach because farmers are more receptive towards new interventions and familiar with integrated technologies to enhance the crop yield.

The Bhoochetana program demonstrated the technical performance of science-led interventions at field level through action research. There is a need to understand major drivers and hindrances beyond field level. An understanding of market conditions, interactions among stakeholders, and other institutional and political dimensions become important to achieve large number of farmers and ensuring profitability for the farmers. The availability of inputs such as seeds, fertilizers, micronutrients, and crop protection chemicals ensures agricultural operations easy, and timely sowing and planting is possible. The same applies to farmers' access to credit and to markets for agricultural inputs and produce. The innovative institutional arrangements helped to reach out millions of farmers with improved knowledge at their door step.

19.9 Organic and Biological Fertilizers for Sustainable Soil Health

Role of soil organic C in maintaining soil health is well documented (Wani et al. 2012b) and low soil organic C in tropical soils is a major factor for poor crop productivity (Lee and Wani 1989; Edmeades 2003; Ghosh et al. 2009; Materechera 2010). Therefore, improving soil organic C levels through additions of organic manures to improve soil physical, chemical, and biological functions is need of the day for sustainability. The large quantities of about 700 million ton of organic wastes are generated in India (Bhiday 1994) which offers opportunities to convert those into valuable composts rich in organic C and macro, micronutrients.

The vermicomposting is an effective technology to produce quality compost using *Eudrilus Eugeniae* and *Eisenia fetida* species of earthworms. Rock phosphate (a cheap source of P) may be added at 3–4% of composting biomass to improve P content in vermicompost due to solubilization action of humic acids and phosphate solubilizing bacteria (Hameeda et al. 2006) during vermicomposting process. Similarly, a microbial consortia culture of 21 bacterial isolates belonging to genus Bacillus (8 isolates), Halobacillus (3), Staphylococcus (3), Microbacterium (1), Streptomyces (1), and one actinomycetes isolated from microbial culture (Excel Crop Care Ltd) is equally effective in rapidly converting wastes into useful compost, wherein the bacterial population in consortium culture found is 4.5×10^{-7} cfu ml^{-1} at 10^{-6}.

In field studies, the integrated nutrient management (INM) involving the use of enriched compost has been found effective to cut cost of chemical fertilizers up to 50% while recording at par yields or more than balanced nutrition solely through chemical fertilizers (Chander et al. 2013a). As the composts are prepared from on-farm wastes, the benefit-cost ratios are significantly improved. Similarly, plant part nutrient contents also tended to improve under INM. Further, applied compost along with secondary and micronutrients found to show residual benefits as increased crop yields for succeeding three seasons. So, results showed that INM is economically beneficial for producing more food, while leading to resilience building of SAT production systems.

The microbial activities in soil-plant systems are responsible for nutrient transformation and so are major component of good soil health. Their external addition can enhance their activities for increasing fertilizer use efficiency. The non-symbiotic group of bacteria (*Azotobacter/Azospirillum)* in nonleguminous, while symbiotic (*Rhizobium)* in leguminous plants may be used to fix the atmospheric nitrogen and make it available to plants. Phosphorus solubilizing microorganisms (PSMs) can solubilize the complex insoluble form of phosphorus into simple soluble forms that can be taken up by plants. Similarly, vesicular arbuscular mycorrhizae (VAM) infects roots, increases effective root surface, and soil volume explored for nutrient uptake through extensive mycelia along with solubilizing effect by chemicals released.

19.10 Landform Management for Cultivating Rainy Fallows in Vertisols

Vertisols and associated soils which occupy large areas globally (approximately 257 million ha, Dudal 1965) are traditionally cultivated during the post-rainy season on stored soil moisture. Due to poor infiltration rates and water logging, farmers are facing difficulties to cultivate during the rainy season. It is perceived that the practice of fallowing Vertisols and associated soils in Madhya Pradesh, India have decreased after the introduction of soybean. However, 2.02 M ha of cultivable land is still kept fallow in Central India, during the kharif season (Dwivedi et al. 2003). On-farm soybean trials conducted by ICRISAT involving improved land configuration (BBF) and short-duration soybean varieties along with growing chickpea with minimum tillage in *rabi* season enhanced the cropping intensity in Guna, Vidisha, and Indore districts of Madhya Pradesh. Increased crop yields (40–200%) and incomes (up to 100%) were realized with landform treatment, new varieties, and other best-bet management options (Wani et al. 2008, 2016) through crop intensification.

19.11 Soil Management for Intensifying Rice Fallows

Rice fallows are big opportunities to improve productivity and livelihoods through proper soil fertility management to support two good crops. Considerable amount of green water is available after the monsoon, especially in the rice-fallow systems, which could be easily utilized by introducing a short duration legume crop with simple seed priming and micronutrient amendments (Kumar Rao et al. 2008; Wani et al. 2009a, b; Singh et al. 2010). About 14.29 million ha (30% of rice growing area) rice fallows are available in Indo Gangetic Plains (IGP) spread in Bangladesh, Nepal, Pakistan, and India, out of which 11.4 M ha (82%) are in Indian states of Bihar, Madhya Pradesh, Chhattisgarh, Jharkhand, West Bengal, Odisha, and Assam (Subbarao et al. 2001). Taking advantage of the sufficiently available soil moisture after harvesting the rice crop, during the winter season in the eastern India, growing of early maturing chickpea in rice-fallow areas with best-bet management practices provides opportunity for intensification (Kumar Rao et al. 2008; Harris et al. 1999). An economic analysis has shown that growing legumes in rice fallows is profitable for the farmers with a B:C ratio exceeding 3.0 for many legumes. In addition, utilizing rice fallows for growing legumes could result in the generation of 584 million person-days employment for South Asia and make the country self-sufficient in pulses production.

19.12 Soil Management and Ecosystem Services

19.12.1 Nitrogen Use Efficiency

Soil management for correcting deficiencies of emerging secondary and micronutrients like S, B, and Zn is found not only improving productivity and incomes directly, but also nitrogen use efficiency (NUE) (Chander et al. 2014a; Wani et al. 2015b). Nitrogen (N) is often the most limiting nutrient for crop yield in many regions of the world (Giller et al. 2004) and in a quest to achieve high yields, it is applied in large quantity from external sources, resulting in low nitrogen use efficiency (NUE) which is approximately 33% for cereal production (Raun and Johnson 1999). Inefficient use of N fertilizer is causing serious environmental problems associated with the emission of NH_3, N_2, and N_2O to the atmosphere and contamination of ground and surface water resources via nitrate leaching or runoff (Singh and Verma 2007). In response to continually increasing economic and environmental pressures, there is an urgent need

Table 19.7 Effects of balanced nutrient management strategies on nitrogen efficiency indices in maize at ICRISAT, Patancheru, India, rainy season 2010

Treatment	NUpE	NUtE	NUE	NHI
Control	1.00	60.2	60.2	46.8
NP	0.37*	80.7*	30.1*	67.3*
NP+SBZn (every yr)	0.46*	78.5*	36.0*	60.5*
NP+50%SBZn (every yr)	0.51*	92.5*	47.3*	65.8*
NP+SBZn (alternate yr)	0.47*	84.4*	39.7*	69.3*
NP+50%SBZn (alternate yr)	0.42*	80.8*	34.1*	67.0*
LSD (5%)	0.11	17.4	8.85	11.3

NUpE (Nitrogen uptake efficiency) = Total plant N uptake/N supply [*N supply means sum of N applied as fertilizer and total N uptake in control*]; *NUtE* (N utilization efficiency) = Grain yield/Total plant N uptake; *NUE* (N use efficiency) = Grain yield/N supply; NHI (N harvest index) = N in grain/Total N uptake
*significant at $p \leq 0.05$
Source: Chander et al. (2014a)

to enhance efficient use of nitrogenous fertilizers and increase profitability by developing sustainable farming systems (Mahler et al. 1994). The results (Table 19.7) have shown that the addition of deficient S, B, and Zn records the highest uptake efficiency, utilization efficiency, use efficiency, and harvest index in cereal production and 50% dose of S, B, and Zn is better than 100% S, B, and Zn addition once in 2 years (Chander et al. 2014a; Wani et al. 2015b). Nutrient uptake efficiency (NUpE/PUpE) reflects the efficiency of the crop in obtaining it from the soil (Rahimizadeh et al. 2010). Uptake of supplied nutrient is the 1st crucial step and an issue of concern worldwide, and hence increased nutrient uptake efficiency has been proposed as a strategy to increase nutrient use efficiency by Raun and Johnson (1999). Nutrient utilization efficiency (NUtE/PUtE) reflects the ability of the plant to transport the nutrient uptakes into grain (Delogu et al. 1998). Nutrient harvest index (NHI/PHI), defined as nutrient in grain to total nutrient uptake, is an important consideration in cereals. NHI/PHI reflects the grain nutritional quality (Hirel et al. 2007).

19.12.2 Rainwater Use Efficiency

Water is a scarce resource and chief determinant of poverty and hunger in rural areas, so improving rainwater use efficiency (RWUE) is important for achieving food security and better livelihoods. Soil test-based balanced fertilizer use is found to produce more food with less water and significantly increased rainwater use efficiency in crops by channelizing unproductive evaporation loss into productive transpiration (Chander et al. 2014a). In studies in Rajasthan (Table 19.8), the RWUE of existing farmers' cultivars with applied N and P in maize varied between 3.36 and 7.39 mg kg^{-1} ha^{-1}(Chander et al. 2013b). The introduction of improved cultivar in on-farm trials in target districts increased it from 5.43 to 10.8 mg kg^{-1} ha^{-1} and

Table 19.8 Integrated improved crop cultivar and balanced nutrient management enhance maize grain yield and rainwater use efficiency in Rajasthan during rainy/kharif season 2009

District	Yield (kg ha^{-1})			LSD (5%)	B:C ratio	Rainwater use efficiency (kg mm^{-1} ha^{-1})			LSD (5%)
	FP	IC	IC+BN			FP	IC	IC+BN	
Tonk	1150	1930	3160	280	4.26	3.36	5.52	9.13	0.73
Sawai Madhopur	1430	2030	3000	420	3.33	4.09	5.77	8.59	0.95
Bundi	1380	2180	4240	714	6.05	3.59	5.68	10.93	1.68
Bhilwara	2990	4340	6510	860	7.45	7.39	10.76	16.15	1.69
Jhalawar	2550	3520	4960	316	5.11	4.21	5.82	8.20	0.52
Udaipur	2530	3090	6320	509	8.03	4.45	5.43	11.11	0.89

Note: *FP* farmers' practice, *IC* improved cultivar, *BN* soil test-based balanced nutrition, *B:C* benefit to cost ratio
Source: Chander et al. (2013b)

thereby proved the ability of improved cultivars to best utilize the limiting water resources. The integrated approach involving soil test-based addition of fertilizers including micronutrients to improved cultivar, however, recorded the maximum RWUE (8.20–16.2 mg kg^{-1} ha^{-1}) (Chander et al. 2013b). Therefore, integrated soil and crop management involving improved crop cultivars and 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).

19.12.3 Soil Organic C and Health

Results at long-term experiment at ICRISAT headquarter showed that improved system comprising of landform management (broadbed and furrow cultivation), soil test-based balanced fertilization, and crop management not only increased crop productivity, but also increased soil organic C content (Table 19.9). An additional quantity of 7.3 t C ha^{-1} (335 kg C ha^{-1} $year^{-1}$) was sequestered in soil under the improved system compared with the traditional system over the 24-year period (Wani et al. 2003a). It was concluded that C inputs increased with continuous cropping, particularly where soil test-based fertilizers were applied and when legumes were included in the system. Soil microbial biomass C responds more rapidly than soil organic C to changes in management, and serves as a surrogate for soil quality. Improved management of Vertisols also resulted in higher (10.3 vs. 6.4%) biomass C as a proportion of soil organic C up to 120 cm soil depth. Along with improvements in soil organic C, the contents of available nutrients are also found to be improved under soil test-based managed plots (Chander et al. 2014b). The addition of needed nutrients and a positive relationship of soil organic C with available nutrients explain improvement in soil health (Wani et al. 2003a; Chander et al. 2014b).

Table 19.9 Effect of balanced nutrient and best practices on soil C and other properties

Property	System	Soil depth (cm)	
		0–60	60–120
Organic C (t C ha^{-1})	Improved	27.4	19.4
	Traditional	21.4	18.1
Microbial biomass C (kg C ha^{-1})	Improved	2676	2137
	Traditional	1462	1088
Microbial biomass N (kg N ha^{-1})	Improved	86.4	39.2
	Traditional	42.1	25.8
Total N (kg N ha^{-1})	Improved	2684	1928
	Traditional	2276	1884
Olsen-P (kg P ha^{-1})	Improved	6.1	1.6
	Traditional	1.5	1

Source: Wani et al. (2003a)

19.12.4 Resilience Building

Soil need based management is found to improve soil health through balancing deficiencies of secondary and micronutrients and low levels of soil organic C (Fig. 19.8). In pilot studies in Madhya Pradesh and elsewhere (Wani et al. 2016), the applied secondary and micronutrients (the alternate years) showed residual benefits in crop yields between 5 and 27% up to three succeeding seasons. In economic terms, added micro and secondary nutrients produced more food worth 1840 to 6900 ha^{-1} during each of the succeeding three seasons. The results clearly showed that balanced nutrition is not only economically remunerative in the season-1 of application but also leads to resilience building of production systems.

19.13 Experiences and Learnings

19.13.1 Soil Health Mapping: A National Strategy

Soil sampling is most important, but the weakest link in soil health assessment process as the smallest of amount of sample collected should represent millions of kilogram of soil in the field. Considering the huge financial and human resources required, samples cannot be collected in very large numbers, while there should not be compromise with the quality of results. There should be a balance between what is desirable and what is achievable through the following stratified sampling technique (Sahrawat et al. 2008). Soil samples need to be collected in grids representing effectively the topography, soil texture, soil color, farm sizes, cropping systems, and management practices. The involvement of farmers in collecting soil samples is important; though it is time consuming, but this will generate ownership and make it easier to scale up the soil test-based recommendations.

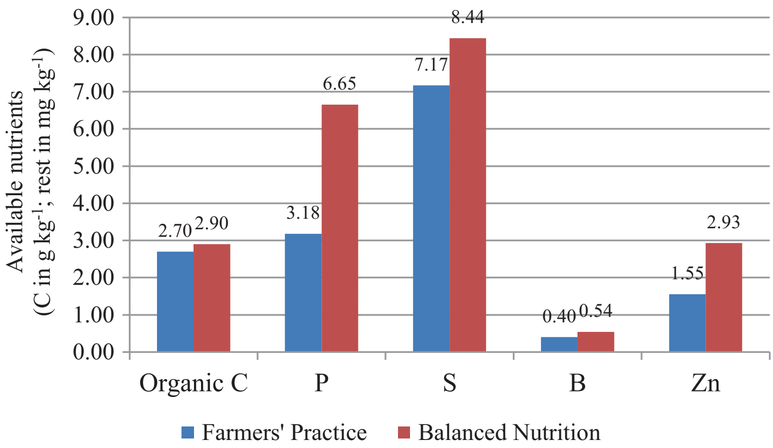

Fig. 19.8 Effect of farmers' practice and balanced nutrition on postharvest soil fertility status under rainy/kharif season groundnut in Nalgonda district (Andhra Pradesh) during 2010

The ensured quality, protocols, and processes for accreditation of laboratories are most important. The quality assurance standards as well as mechanisms to ensure quality analysis by the accredited labs by empowering leading institutions are another important aspect to be taken care of.

Soil test-based fertilizer recommendations including deficient micro and secondary nutrients should be developed at block (cluster of villages) level. ICRISAT's experience in pilot studies demonstrates the benefits of this approach. Subsequently, we can move towards village and farmer-based recommendations as awareness develop among the farmers, and the government is geared up to handle knowledge dissemination for villagers and individuals.

Over the years, farmers have increased their reliance on chemical fertilizers and have abandoned or reduced the use of organic manure drastically. Long-term experiments have clearly demonstrated increased sustainability of systems with Integrated Nutrient Management (INM) strategies including harnessing the biological sources and using legumes in crop rotation, organic manure, and soil test-based inorganic fertilizers for different crops. Incentives are required to promote the use of organic manure/fertilizers as well as biological sources like bio-fertilizer in order to encourage farmers to adopt integrated nutrient management approach. These recommendations need to be tethered to the soil test results. This presents a major challenge as the nutrient content of organic manures and fertilizers is highly variable. There is an urgent need to look at policies and innovative institutional arrangements for ensuring quality supply of bio-fertilizers and organic manure to the farmers by recycling organic wastes generated both in urban and rural areas. Mechanisms should be developed for recycling the organic wastes through aerobic-compost, vermicomposting, or other methods so that the farmers can use the recycled organic matter for crop production.

Moreover, micro-irrigation systems can be effectively used for the regulated supply of essential plant nutrients through fertigation and addition of micronutrients and secondary nutrients based on soil tests.

19.13.2 Micro Watershed as Implementation Unit

Managing soil and water efficiently under different agro-ecosystems is a challenging task and it can be done in the best possible way in a micro catchment, i.e., watershed scale. These watersheds can be integrated into meso- and macro-watersheds and further into subbasins and basin level for the effective planning, management, monitoring, and achieving the impact.

19.13.3 Land Use Planning Based on Land and Agro-Ecological Capability

However, such land use planning could be promoted through incentivizing the farmers to adopt the recommended cropping system. Penalties shall also be applied in terms of not providing the incentives and market support for crops that are not to be grown in a given agro-ecoregion.

19.13.4 Seeing is Believing: Sites of Learning and Innovations

Undertaking the innovations and piloting new developments in each district would require pilot sites to be established as exemplar sites for training as well as developmental purposes. Such sites of learning need to be developed by the scientific institutions by adopting the consortium approach and building public–private partnership. These sites of learning would also provide field laboratories for undertaking strategic research in the area of soil management strategies as well as impact assessment, monitoring, and evaluation studies.

19.13.5 Skill Development

For holistic development, new skills such as soil health mapping and precise fertility management, simulation modeling, use of remote sensing, online monitoring, and ICT-based knowledge dissemination need to be developed. This can be accomplished by retooling the present actors and bringing in the new actors having expertise in the new science areas. The stakeholders should be aware about the importance of various activities and their benefits in terms of economic, social, and environmental factors. Therefore, organizing various training at different scales is important.

19.13.6 Rejuvenating Extension System

Main reason for the existing large yield gaps between what farmers' harvest and the researchers pilot site yield is largely due to the knowledge gap between What to Do and How to Do it? In spite of a number of new/improved technologies, the farmers continue to do their farming business in a traditional manner. The reasons are multifarious as the current knowledge delivery system to the farmers, i.e., extension system is very inefficient and does not benefit the farmers. Therefore, there is an urgent need to reform the knowledge delivery systems by using innovative partnerships, tools, approaches, and methods. Past experiences suggest that the information delivery mechanism can be strengthened by utilizing the services of practicing farmers in the villages through Farmers' Field Schools and Farmer Facilitators who stay in the villages for most of their time, unlike the outside experts who visit villages once in a while (Wani et al. 2012a). The mix of tools like soil health cards, wall writings, awareness campaigns, traditional folk media, learning sites, ICT tools like mobile and internet-based soil health maps, farmer-to-farmer videos, pico projectors, and other tools has proved very effective in disseminating soil health and other management options in the watersheds.

19.13.7 Use of High-Science Tools and ICT for Planning, Implementation, and Monitoring

Science tools like remote sensing images and data, soil health mapping, scenario development simulations along with Geographical Information System (GIS), and soft skill planning participatory tools need to be used. GIS techniques help in estimating the important variables such as soil nutrient status based on interpolation technique. In addition, system modeling is also one of the emerging techniques which guides about resource availability, its management, and various alternatives to achieve yield potential. As trained human resource is major constraint in agriculture extension system, various information communication tools (ICT) are available which can bridge the gap between farmer and knowledge generator.

19.13.8 Building Partnerships Through Consortium and Convergence Approach

A watershed is a complex system with a multitude of problems. It requires a holistic approach that considers social, economic, political, and institutional factors to achieve specific social objectives (Dixon and Easter 1986; Wani et al. 2003b). The past experience showed that enhancing partnerships and institutional innovations through the consortium approach was the major impetus for harnessing the potential of community watershed management to reduce poverty and environmental degradation (Shambu Prasad et al. 2006). The underlying element of the consortium approach is to engage a range of actors to harness their strengths and synergies with the local community as the primary implementing unit. Through the consortium approach, complex issues can effectively be addressed by the joint efforts of key partners, namely the National Agricultural Research System (NARSs), nongovernmental organizations (NGOs), government organizations, international institutions, agricultural universities, community-based organizations, and other private interest groups, with farm households as the key decision makers. Thus, consortium approach brings together the expertise of different areas to expand the effectiveness of the various watershed initiatives and interventions.

19.13.9 Public–Private Partnership

The Public–Private Partnerships (PPPs) are viewed as the governance strategy to minimize the transaction costs and coordinating and enforcing relations between the partners engaged in the production of goods and services. They enable an optimal policy approach to promote the social and economic development, thus bringing together efficiency, flexibility, and competence of the private sector along with the accountability, long-term perspective, and social interest of the public sector. For soil health management, there is a need to identify business models for devolving the responsibilities of sample collection and soil analysis while ensuring quality standards as well as economic feasibility and also explore public–private partnerships involving fertilizer manufacturers, private service providers, state agricultural universities, and selected Krishi Vigyan Kendras.

19.14 Conclusions

Soil management for correcting fertility levels proved an effective technology to improve productivity levels and livelihoods, and this is a low hanging big opportunity in drylands for benefitting the farmers. Lack of awareness and required infrastructure are big hurdles to take these benefits to large number of farmers. Majority of farmers in the drylands are the smallholders and therefore would need policy support to implement soil fertility management for improving system productivity and livelihoods. Increasing soil fertility levels can also facilitate taking 2nd chickpea crop in rice fallows. Soil landform management in Vertisols is an effective technology to cultivate rainy fallow without compromising with 2nd post-rainy season crop; however, required capacity building of farmers and stakeholders is most important for effectively implementing it. Efficient soil management needs to be promoted not only for improving productivity and livelihoods, but also for beneficial effects on ecosystem services like enhanced fertilizer and water use efficiency and C-sequestration.

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