Soil mapping and variety-based entry-point interventions for strengthening agriculture-based livelihoods – exemplar case of ‘Bhoochetana’ in India

Girish Chander*, Suhas P. Wani, Kamma Krishnappa, Kanwar Lal Sahrawat, Gazula Parthasaradhi and Lingraj Shivappa Jangawad

IDC, International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, India

Soil health diagnosis in nearly 100,000 farmers’ fields under ‘Bhoochetana’ initiative in Karnataka showed widespread soil degradation. Soil mapping-based fertilizer management was an effective entry-point intervention to take most farmers on-board to initiate the process of upgrading agriculture. Soils of the farmers’ fields showed low levels of micro- and secondary nutrients such as zinc (Zn) (55%), boron (B) (62%) and sulphur (S) (52%) in addition to that of phosphorus (P) (41%), potassium (K) (23%) and soil organic carbon (C) (52%). Soil mapping-based fertilizer management recorded significant productivity benefits that varied from 25% to 47% in cereals, 28% to 37% in pulses and 22% to 48% in oilseed crops. In terms of economics, a rupee spent on soil test-based fertility management brought returns of Rs 3 to Rs 15. Similarly, the participatory trials showed that the use of high yielding varieties of sorghum, pearl millet, finger millet, groundnut, soybean, castor, pigeonpea and chickpea enhanced productivity by 30% to 123%. The tangible benefits through soil mapping and variety based interventions have enhanced the risk-taking ability of farmers to invest in technologies based on use of soil testing and use of improved cultivars of crops. The adoption of simple knowledge-based technologies as entry point interventions along with policy reorientation to ensure knowledge sharing and availability of needed inputs at village level, enabled in a period of four years (2009–2013) to outreach more than 5 million families in Karnataka to transfer improved technologies in more than 7 million ha area. The study indicates that knowledge-based entry point interventions like soil mapping and improved varieties targeted at providing simple solutions are the best options for quick benefits and rapport-building with the majority farmers to initiate a collective action for technological upgradation of dry land agriculture.

Keywords: Impact, knowledge-based entry point, participatory research, productivity.

Introduction

IN the context of general food security and mainstreaming of the smallholders, the urgency to strengthening agriculture in the semi-arid tropics is well conceived; and significant public, private efforts are being directed towards achieving it. Research-based inclusive market oriented interventions have high potential in improving the farm-based livelihoods through minimal investments. Mix of technologies targeted at intensification, diversification and strengthening allied enterprises across the value chain in a system context need to be implemented for a productive and resilient agriculture in the semi-arid tropics. However, the success of any research for impact depends largely on the effective mobilization and participatory action by farmers and other stakeholders. Demand-driven progressive selection of interventions, particularly the entry point interventions to help farmers on a large scale in the shortest possible time, play an important role in initiating collective action for upgrading agriculture. Studies indicate that knowledge-based rather than investment-focused interventions to solve farmers’ issues are more effective for rapport building and initiating collective action with the farmers for sustainable benefits[1].

In rainfed agriculture, low crop yields are the main issue for the farmers and studies have indicated that the yields can be increased by 2 to 4 folds[2–10]. Decrease in soil fertility and water scarcity are the main causes for low crop yields and inefficient utilization of production resources[11–18]. Globally, only half of the nutrients that crops take from the soil are not replenished. The depletion of soil nutrients often leads to low fertility levels that limit production and severely reduce water productivity. The characterization of fertility status of farmers’ fields particularly in India, has indicated micro-, and secondary nutrient deficiencies of boron (B), zinc (Zn) and sulphur

*For correspondence. (e-mail: g.chander@cgiar.org)

Table 1. Important crops, their area and productivity in rainfed areas of Karnataka (during 2011–12)

Crop	India			Karnataka				
	Area (m ha)	Production (million tonnes)	Productivity (kg ha^{-1})	Area (m ha)	% of India area	Production (million tonnes)	% of India production	Productivity (kg ha^{-1})
Pearl millet	8.78	10.28	1,171	0.29	3.3	0.28	2.72	966
Wheat	29.90	94.90	3,177	0.23	0.77	0.19	0.20	826
Maize	8.78	21.76	2,540	1.35	15.38	4.09	18.80	3,030
Sorghum	6.25	5.98	957	1.14	18.24	1.17	19.57	1,026
Paddy	44.01	105.3	2,393	1.42	3.23	3.96	3.76	2,789
Chickpea	8.30	7.70	895	0.80	9.64	0.47	6.10	588
Pigeonpea	4.01	2.65	656	0.77	19.2	0.35	13.21	455
Groundnut	5.26	6.96	1,411	0.68	12.93	0.49	7.04	721
Soybean	10.11	12.21	1,208	0.19	1.88	0.17	1.39	895
Sunflower	0.73	0.52	712	0.38	52.05	0.20	38.46	526
Cotton*	12.18	35.20	491	0.55	4.52	1.20	3.41	341
Sugarcane	5.04	361.04	71,668	0.43	8.53	38.81	10.75	90,256

*Million bales of 170 kg each. Source: ref. 30.

(S) in addition to nitrogen (N), phosphorus (P) and potassium (K). Such nutrient depletion is the chief biophysical factor limiting production[11–18]. Soil health is a pre-requisite to strengthen agro-based enterprises and may prove 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. Similarly, the use of low yielding cultivars is another stumbling block for enhancing productivity of dryland agriculture[19]. Therefore, an introduction of improved cultivars of crops through participatory evaluation is another potential entry point intervention.

Materials and methods

Study site description

The region for this study was Karnataka which has a total geographical area of 19.2 m ha; and of which 10.4 m ha is the net sown area and 12.8 m ha total cropped area[20]. Out of total cropped area, only 4.1 m ha is gross irrigated area and 8.8 m ha is total gross un-irrigated area. About 5.4 m ha is cultivated to cereals and millets like rice, jowar, maize, ragi, bajra, wheat and other millets; and about 2.5 m ha is under pulses like gram, pigeonpea and others. All food crops that include cereals, pulses, fruits, vegetables, condiments, spices and sugarcane cover an area of 9.4 m ha; and non-food crops including oilseed, fiber, dyes, drugs, plantations, fodder and green manuring crops cover an area of 3.4 m ha.

Agriculture is the predominant occupation of about 60% of the population. Analysis of the data (2000 to 2010) indicates that the general productivity of most crops in Karnataka is lower than the national average (Table 1). As compared to the base year 2000–01, the growth in productivity of food grains, pulses and oilseeds has decelerated over the years. Only in 3 out of 9 years, higher food grain productivity over the base year was observed; only 2 out of 9 years showed higher pulses productivity and none of the succeeding years showed higher oilseed productivity over the base year. The deceleration in agricultural growth led to rural distress in Karnataka. According to national sample survey (January–December 2003), out of around 4,041,300 farmer households, 2,489,700 were indebted[21]. Under such circumstances, the flagship initiative ‘Bhoochetana’ meaning ‘reviving the land’ was launched by the state government to initiate the process of improving agriculture in the state. The ICRISAT (International Crops Research Institute for the Semi-Arid Tropics)-led consortium with department of agriculture as nodal agency, adopted soil mapping as an entry point intervention to harness productivity benefits and initiate a collective action for strengthening agro-based livelihoods in the state.

Participatory soil sampling and soil health mapping

Participatory soil sampling was used as an important activity to build rapport with the farmers and to bring awareness for such initiative. The farmers were trained about the importance and process of soil sampling.

Soil samples (>100,000 from 30 districts) were collected from fields by farmers’ themselves with support of experts by adopting stratified soil sampling method[22]. Using stratified soil sampling method, the target villages (~25% representative selected through Remote Sensing and Geographic Information System) in the districts were divided into three topo-sequences. At each topo-sequence location, samples were taken proportionately from small, medium and large farm-holding farmers’ fields to represent different soil colour, texture, cropping system and agronomic management. Eight to ten crores of surface

(0–0.15 m) soil samples were collected and mixed together to make a composite sample. The samples were processed and analysed for pH, organic C, available S, B, Zn, P and K in the Charles Renard Analytical Laboratory, ICRISAT (please see in 'soil and chemical analysis section' for details).

Development of fertilizer recommendations and sharing results with farmers

In contrast to the state (comprising of 30 districts) level fertilizer recommendations for N, P and K only, soil-based fertilizer recommendations were developed at the level of cluster of villages called block/taluk. Micro- and secondary nutrients were also included in the recommendations. As percentage of nutrient deficiency, full dose of a particular nutrient was recommended if deficiency was on >50% fields in a block and half dose of a nutrient if deficiency was on <50% fields. This strategy of fertility management was adopted to target optimum yields considering risks involved in rainfed agriculture and other practical considerations. The critical values for delineating deficiency were 5.0 g kg^{-1} for organic C, 5 mg kg^{-1} for P, 50 mg kg^{-1} for K, 10 mg kg^{-1} for S, 0.58 mg kg^{-1} for B and 0.75 mg kg^{-1} for Zn[11].

Mixes of traditional and innovative tools were adopted to share analysis results and recommendations with the farmers. In addition to formal and informal meetings with the farmers, the soil analysis results and recommendations were provided to the farmers through pocket (soil) health cards. Wall writings were done in local language in each and every village. Soil health atlas was provided to extension agents as a guide and interactive GIS-based maps were put on web.

Soil mapping-based fertilizer management as entry point activity

In order to scale-out the soil health mapping-based fertilizer management to the millions of smallholders in the state, the government of Karnataka provided policy reorientation to facilitate the timely availability of incentivized inputs in the villages. The lead farmers were selected and trained to serve as farm-facilitators to create awareness and transfer soil test-based fertilizer management practices in the farmers' fields.

Within this development-based initiative to evaluate the soil-based fertilizer management, the participatory trials were conducted mainly during the rainy (June–September) and post-rainy (October/November–January/February) seasons during 2009 to 2014. There were two treatments that were evaluated in the farmers' fields every season, i.e. (i) FP: application of N, P and K only, and (ii) BN (balanced nutrition): comprising of FP inputs plus S, B and Zn.

Full dose of inputs under farmers practice varied from 40 to 100 kg N ha^{-1}, 25 to 50 kg P_2O_5 ha^{-1} and 0 to 50 kg K_2O ha^{-1} in non-legumes, and 10 to 25 kg N ha^{-1}, 25 to 60 kg P_2O_5 ha^{-1} and 0 to 25 kg K_2O ha^{-1} in legume crops. The BN treatment consisted adding N, P and K, the deficient S, B and Zn, and the full dose consisted of 30 kg S ha^{-1}, 10 kg Zn ha^{-1} and 0.5 kg B ha^{-1} field[23]. The nutrient/fertilizer recommendations were adjusted at the block (mandal) level in the districts as explained in the previous section. The fertilizer sources for nutrients were urea for N, DAP (diammonium phosphate) for P and N, gypsum for S, zinc sulphate for Zn and borax (10% B) for B. The treatments were followed on 2000–4000 sq. m plot, side by side, and uniform crop management practices were ensured in both the FP and BN treatments. Application of all nutrients was made basal except the N in non-legumes of which 50% was added as basal and the remaining in two equal splits at one month interval.

At maturity, the yields were recorded by harvesting crop from three sub-plots in a treatment measuring 3 m × 3 m and the average of three was taken as the yield in kg ha^{-1}.

Improved crop varieties based entry-point activities

The use of low potential varieties remained as another major stumbling block for achieving higher yields on farmers' fields. Therefore, farmers' participatory evaluation of high-yielding crop varieties was also made as another entry point activity on selected farmers' fields. Improved seeds such as finger millet (MR-1), sorghum (CSV-22), pearl millet (ICTP-8203 and HH-1367), groundnut (ICGV-91114), soybean (JS-9560), castor (DCH-177 and Jyothi), pigeonpea (ICPL-87119 and ICPH-2671) and chickpea (JG-11 and JAKI-9218) were provided to the farmers during 2013–14 to cultivate an area of 2000 sq. m adjacent to the fields with the local variety. Soil test-based fertilizer management along with similar recommended agronomic practices was adopted in both the plots. As in the case of soil mapping based management trials, the yields were recorded at maturity by harvesting crop from three sub-plots in a treatment measuring 3 m × 3 m and the average of three was taken as the final yield expressed in kg ha^{-1}.

Soil chemical analysis

The soil samples collected were air dried, ground and passed through a 2-mm sieve. For organic carbon, the soil samples were ground to pass through 0.25 mm sieve. The processed samples were analysed for pH, soil organic C, available S, B, Zn, P, and K in Charles Renard Analytical Laboratory, ICRISAT. Soil reaction (pH) was measured with the help of glass electrode using soil to water ratio of 1 : 2. Organic C was determined using the Walkley–Black method[24], available P using the sodium bicarbonate ($NaHCO_3$) method[25], available K using the ammonium acetate method[26] and available S using 0.15% calcium chloride ($CaCl_2$) as an extractant[27]. Available Zn was extracted by diethylenetriaminepentaacetic acid (DTPA) reagent[28] and available B by hot water[29]. Available P was determined using colorimetric method and K by Atomic Absorption Spectrophotometer (AAS) (SavantAA, GBC Scientific Equipment, Braeside, VIC, Australia). Analyses of S, B and Zn were made using the Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) (Prodigy High Dispersion ICP, Teledyne Leeman Labs, Hudson, New Hampshire, USA).

Estimation of benefits under improved management

To evaluate the benefits of improved management interventions, crop yields were recorded at maturity, from both the farmers' practice and improved practice treatments. The additional cost of S, B and Zn under BN was worked out on prevailing average market prices of fertilizers used, viz. Rs 33 kg^{-1} zinc sulphate, Rs 50 kg^{-1} borax and Rs 2.20 kg^{-1} gypsum. Similarly, in case of variety-based interventions, the additional costs of seeds were worked out at the rate of Rs 40 kg^{-1} in case of each finger millet (MR-1), pearl millet (ICTP-8203) and pearl millet (HH-1367); Rs 80 kg^{-1} for sorghum (CSV-22); Rs 75 kg^{-1} for groundnut (ICGV-91114); Rs 25 kg^{-1} for soybean (JS-9560); Rs 220 kg^{-1} for castor (DCH-177); Rs 80 kg^{-1} each for castor (Jyothi) and pigeonpea (ICPL-87119); Rs 60 kg^{-1} for each chickpea (JG-11) and chickpea (JAKI-9218).

Additional returns were calculated for crops based on farm gate price of Rs 12 kg^{-1} maize, Rs 12 kg^{-1} pearl millet, Rs 13 kg^{-1} wheat, Rs 15 kg^{-1} sorghum, Rs 13 kg^{-1} paddy, Rs 15 kg^{-1} fingermillet, Rs 23 kg^{-1} soybean, Rs 37 kg^{-1} groundnut, Rs 37 kg^{-1} sunflower, Rs 30 kg^{-1} chickpea, Rs 39 kg^{-1} pigeonpea and Rs 37 kg^{-1} castor.

The benefits to cost ratios were worked out by dividing additional returns through higher yields with additional costs. The currency conversion factor was, Rs 1 = USD 0.016.

Results and discussions

Soil health mapping and awareness

Soils in general are highly degraded in the semi-arid tropics due to heavy mining of nutrients and improper management. Considering this, the ICRISAT-led consortium paid attention on soil health assessment of crop fields across districts in Karnataka. The results of analyses of soil samples indicated multi-nutrient deficiencies (Figure 1). Widespread nutrient deficiency endorses the case of soil mapping-based fertilizer management as an effective entry point intervention to benefit millions of small holders. Therefore, nutrient management strategy was designed at the level of cluster of villages (block/taluk) against usual recommendations at state level to take care of varying soil fertility needs.

As regards fertility levels, soil organic C which is an indicator of general soil health and specifically of N, was deficient in majority of the fields (52%) (Figure 2). Seventeen out of 30 districts were highly impoverished with soil organic C in Bengaluru (U), Bengaluru (R), Bijapur, Chamarajnagara, Chikkaballapur, Chitradurga, Davangere, Gadag, Gulbarga, Haveri, Kolar, Koppal, Mysore, Raichur, Ramanagara, Tumkur and Yadgir. As regards extractable P, 41% fields were deficient, indicating that majority of the fields has sufficient P. This finding provides an opportunity through site-specific nutrient management to reduce the use and cost of P fertilizers. However, 11 districts (Bagalkote, Belgaum, Bellary, Bijapur, Chitradurga, Dharwad, Gadag, Gulbarga, Kodugu, Tumkur and Udupi) showed majority of the farmers' fields (>50%) is deficient in P. In Karnataka available K was low only in 23% fields and a science-based approach calls for a cut on the recommendation of K fertilizer application. But K deficiency was a matter of concern in Belgaum and Kodugu districts where majority fields tested low. The diagnosis results indicated widespread

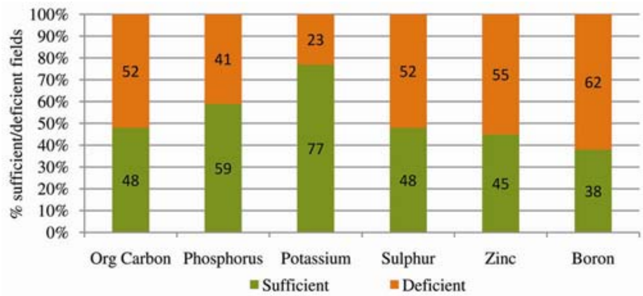

Figure 1. Soil organic carbon and available nutrient status of farmers' fields in Karnataka.

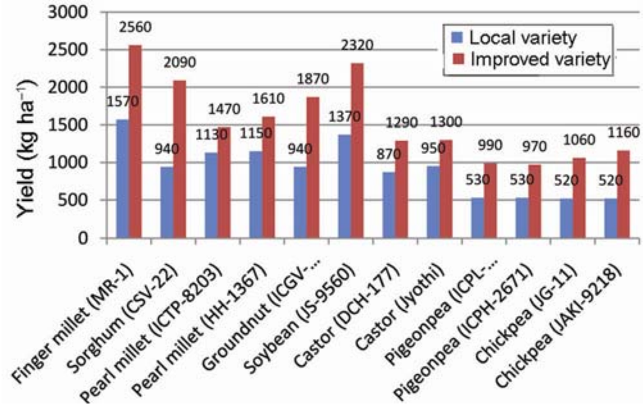

Figure 2. Crop yield levels with local and improved varieties in Karnataka during 2013–14.

deficiencies of secondary and micronutrients in most fields of the state to the tune of 52% in S, 55% in Zn and 62% in B. Such secondary and micro nutrient deficiencies have probably emerged due to use of high dose of NPK fertilizers and no or little application of organic manures and SBZn fertilizers over the past several years. In the state, 11 districts had majority fields which were deficient in all three nutrients (S, B and Zn). The 11 districts with widespread S, Zn and B deficiencies were Bagalkote, Bidar, Chamarajanagara, Chikkaballapur, Chitradurga, Davangere, Gulbarga, Hassan, Tumkur, Udupi and Yadgir. In Shimoga district, the S, B and Zn deficiencies are emerging but still most soils of the farms have sufficient amount of these nutrients. The majority fields in the districts of Bijapur, Gadag, Haveri and Raichur had dual deficiencies of S and Zn; and the districts of Bengaluru (R) and Kolar had dual deficiencies of S and B; and Belgaum, Koppal and Mandya had dual deficiencies of Zn and B. The rest nine districts had widespread individual deficiencies of S or B or Zn. The S deficiencies were high in Bellary, Dharwad and Kodugu; the Zn deficiencies in Chikmagalur, Dakshina Kannada and Uttara Kannada; and B deficiencies in Bengaluru (U), Mysore and Ramanagara districts. Similar soil fertility decline is reported in other rainfed SAT regions of India[11–15,17,19].

Soil mapping-based fertilizer management and crop productivity

Crop wise analysis of yields in Karnataka obtained during 2009 to 2013 showed productivity benefit through improved management over the farmers' practice across all the crops (Table 2). Percentage improvement in productivity was similar in rainy (*kharif*) and postrainy (*rabi*) season crops.

Rainy season crops on an average recorded productivity improvement of 25–45% in cereals, 28–37% in pulses and 22–48% in oilseeds. Similarly in postrainy season crops, productivity improvement varied from 27% to 47% in cereals, 28% to 33% in pulses and 29% to 39% in oilseeds. In cash crops, productivity improvement varied between 22% and 31% in cotton and 11% and 15% in sugarcane.

In rainy season cereals, the additional advantage in quantitative terms amounted to 580–790 kg ha^{-1} in sorghum, 1230–2380 kg ha^{-1} in maize, 980–1150 kg ha^{-1} in paddy, 480–730 kg ha^{-1} in pearl millet and 400–780 kg ha^{-1} in finger millet. In rainy season, the additional yields of pulse and pigeonpea varied between 190 and 430 kg ha^{-1}. In rainy season oilseed crops, the additional yields were to the extent of 360–580 kg ha^{-1} in groundnut, 350–850 kg ha^{-1} in soybean, 190–380 kg ha^{-1} in sunflower. Similarly, in cash crops additional advantage varied between 230 and 1450 kg ha^{-1} in cotton and 14,800 and 16,720 kg ha^{-1} in sugarcane.

In post-rainy cereals, the improved management resulted additional food grains up to 360–620 kg ha^{-1} in sorghum, and up to 400 kg ha^{-1} in wheat. In post-rainy pulse chickpea, the additional advantage was up to 170–440 kg ha^{-1}. Similarly, in post-rainy sunflower, the additional advantage was from 240 to 510 kg ha^{-1}.

An analysis of crop yields across different years showed in general a lower yield level during 2012, which was a drought year (Table 2). However, under improved practice, the percentage increment in crop yields was almost the same as during previous years. Thus soil test-based nutrient balancing not only enhances crop productivity but also adds to resilience-building of production systems[14,17].

The findings from the participatory trials demonstrated the need for adopting science-led improved crop management practices and soil test-based fertilizer management to boost productivity and improve livelihoods in the SAT. Realizing the benefits in initial seasons, many farmers quickly became associated with the initiative and adopted balanced fertilizer management. This indicated that the science-led strategy involving soil mapping-based fertility management can be effective entry point intervention in any initiative to bring farmers on board. In the 'Bhoochetana' initiative, area targeted under balanced fertilization was progressively increased since 2009–10, the starting year to >7 million hectares in 2013–14 with an outreach of >5 million families.

Economic benefits with soil mapping-based fertilizer management

Any intervention is scalable only if it is economically remunerative. The soil test-based application of secondary and micronutrients which was extensively scaled out as an entry point activity, added additional expenditure of Rs 1417 to Rs 1872 ha^{-1} across different crops (Table 3). However, the net economic benefits (additional return – additional cost) due to huge gain in yields over the farmers' practice were substantial – Rs 4646 to Rs 19978 ha^{-1} in case of rainy season cereals, Rs 7890 to Rs 14,859 ha^{-1} in pigeonpea, Rs 4504 to Rs 17,417 ha^{-1} in rainy season oilseeds. Similarly, in postrainy season, the net economic benefit varied between Rs 4761 to Rs 6184 ha^{-1} in cereals, Rs 5033 and Rs 9179 ha^{-1} in chickpea, and Rs 8748 and Rs 14,388 ha^{-1} in sunflower.

In terms of benefit to cost (B : C) ratios, improved management adopted in 'Bhoochetana' proved economically profitable and thus stands out as a scalable option. In case of rainy season crops, B : C ratios varied between 3.40 and 15.6 in cereals, from 4.39 to 9.09 in pigeonpea, from 3.84 to 12.0 in oilseeds (Table 3). In post-rainy crops, B : C varied between 3.05 and 4.98 in cereals, from 2.80 to 7.22 in chickpea and from 5.09 to 10.3 in sunflower.

Table 2. Effects of improved practice/balanced nutrition (IP/BN) vs farmers' practice (FP) on crop yields under 'Bhoochetana' initiative in Karnataka

	2009–10			2010–11			2011–12			2012–13			2013–14		
Crop	FP	IP	% increase	FP	IP	% increase	FP	IP	% increase	FP	IP	% increase	FP	IP	% increase
Rainy/*kharif* season															
Cereals															
Sorghum	–	–	–	1706	2313	36	1945	2735	41	2074	2706	30	1851	2427	31
Maize	5418	7796	44	5279	7113	35	4182	5493	31	3993	5285	32	3932	5157	31
Paddy	–	–	–	–	–	–	4653	5803	25	4016	5130	28	3977	4953	25
Pearl millet	–	–	–	1662	2199	32	1781	2506	41	1245	1720	38	1449	2082	44
Finger millet	1724	2502	45	1752	2397	37	1451	1901	31	1333	1760	32	1452	1849	27
Pulses															
Pigeonpea	–	–	–	1226	1651	35	885	1212	37	716	919	28	543	732	35
Oilseeds															
Groundnut	1270	1712	35	1477	2056	39	1308	1825	40	1078	1441	34	1397	1832	31
Soybean	1767	2617	48	1943	2569	32	1374	1873	36	1060	1405	33	1524	1923	26
Sunflower	812	1121	38	868	1060	22	1127	1509	34	1044	1378	32	859	1175	37
Cash crops															
Cotton	–	–	–	–	–	–	1729	2130	23	1762	3211	31	1056	1284	22
Sugarcane	–	–	–	–	–	–	–	–	–	136,560	151,360	11	114,730	131,450	15
Postrainy/*rabi* season															
Cereals															
Sorghum	1177	1730	47	1420	2041	44	1512	1995	32	–	–	–	1342	1701	27
Wheat	–	–	–	–	–	–	–	–	–	–	–	–	1054	1456	38
Pulses															
Chickpea	1153	1477	28	1401	1838	31	908	1205	33	739	907	23	758	1002	32
Oilseeds															
Sunflower	–	–	–	–	–	–	1312	1826	39	–	–	–	801	1037	29

Table 3. Effects of improved practice/balanced nutrition (IP/BN) on additional costs/returns and benefit to cost (B:C) ratios over the farmers' practice (FP) under 'Bhoochetana' initiative in Karnataka

Crop	2009–10			2010–11			2011–12			2012–13			2013–14		
	Additional cost (Rs)	Additional return (Rs)	B : C ratio	Additional cost (Rs)	Additional return (Rs)	B : C ratio	Additional cost (Rs)	Additional return (Rs)	B : C ratio	Additional cost (Rs)	Additional return (Rs)	B : C ratio	Additional cost (Rs)	Additional return (Rs)	B : C ratio
Rainy/*kharif* season															
Cereals															
Sorghum	–	–		1847	9105	4.93	1643	11,850	7.21	1847	9480	5.13	1723	8640	5.01
Maize	1824	28,536	15.6	1805	22,008	12.2	1605	15,732	9.80	1547	15,504	10.0	1668	14,700	8.81
Paddy	–	–		–	–		1417	14,950	10.6	1582	14,482	9.15	1497	12,688	8.48
Pearl millet	–	–		1829	6444	3.52	1771	8700	4.91	1676	5700	3.40	1708	7596	4.45
Finger millet	1825			1778	9675	5.44	1541	6750	4.38	1515	6405	4.23	1566	5955	3.80
Pulses															
Pigeonpea	–	–		1824	16,575	9.09	1709	12,753	7.46	1684	7917	4.70	1679	7371	4.39
Oilseeds															
Groundnut	1788	16,354	9.1	1783	21,423	12.0	1727	19,129	11.1	1652	13,431	8.13	1684	16,095	9.56
Soybean	1641	19,550	11.9	1813	14,398	7.94	1813	11,477	6.33	1758	7935	4.51	1813	9177	5.06
Sunflower	1824	11,433	6.3	1850	7104	3.84	1774	14,134	7.97	1767	12,358	6.99	1734	11,692	6.74
Postrainy/*rabi* season															
Cereals															
Sorghum	1733	8295	4.8	1872	9315	4.98	1810	7245	4.00	–	–		1764	5385	3.05
Wheat	–	–		–	–		–	–		–	–		1641	5226	3.18
Pulses															
Chickpea	1796	9720	5.4	1815	13,110	7.22	1810	8910	4.92	1801	5040	2.80	1764	7320	4.15
Oilseeds															
Sunflower	–	–		–	–		1838	19,018	10.3	–	–		1717	8732	5.09

Considering area coverage and additional economic benefit through the improved productivity under the improved management for the period of 2009–10 to 2012–13, the state accrued a benefit of 240 million USD.

Improved varieties and benefits

The use of improved crop varieties significantly increased yield over the farmers' current varieties. In case of cereals, productivity improved by 63% in finger millet, 112% in sorghum, and 30–40% in pearl millet. In pulses, productivity increased by 83–87% in pigeonpea and 104–123% in chickpea. Similarly in oilseed crops, the productivity of groundnut increased by 99%, that of soybean by 69% and that of castor by 37–48%. The economic analysis indicated that small additional investments on improved variety seeds resulted in a significant higher additional return with high benefit to cost ratios. One rupee spent on improved variety seed resulted in an additional return by Rs 50 in finger millet, Rs 22 in sorghum, Rs 26–35 in pearl millet, Rs 3 in groundnut, Rs 12 in soybean, Rs 12–27 in castor, Rs 29–30 in pigeonpea and Rs 4 in chickpea.

Conclusions

The widespread deficiencies of major (N and P), secondary and micronutrients drastically affect crop yields. Improving soil health in semi-arid tropical regions is critical for not only ensuring food security, but also for mainstreaming the underprivileged sections of the society. Soil mapping-based entry point activity to rejuvenate agriculture is a common interest for most farmers. Through minimal investments, most farmers can benefit from increased productivity through the scientific interventions. The smallholders in Indian SAT areas in particular and elsewhere in general, need more awareness about soil health and crop variety issues, and the availability of proper technologies. Hence, there is a strong need for enabling policies to adopt soil mapping in terms of assessing soil fertility for scaling-up agriculture and other activities. Appropriate policy orientation to facilitate technical and financial support for precise soil sampling and analysis and timely availability of inputs need special attention.

1. Joshi, P. K., Jha, A. K., Wani, S. P. and Sreedevi, T. K., Scaling-out community watershed management for multiple benefits in rainfed areas. In *Rainfed agriculture: Unlocking the Potential* (eds Wani, S. P., Rockstrom, J. and Oweis, T.), CABI: Wallingford, UK, 2009, pp. 276–291.
2. Rockstrom, J., Hatibu, N., Oweis, T. and Wani, S. P., Managing water in rainfed agriculture. In *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture* (ed. Molden, D.), Earthscan, London, 2007, pp. 315–348.
3. Rockström, J. *et al.*, Managing water in rainfed agriculture-the need for a paradigm shift. *Agric. Water Manage.*, 2010, **97**, 543–550.
4. Wani, S. P., Pathak, P., Jangawad, L. S., Eswaran, H. and Singh, P., Improved management of Vertisols in the semi-arid tropics for increased productivity and soil carbon sequestration. *Soil Use Manage.*, 2003, **19**, 217–222.
5. Wani, S. P., Singh, H. P., Sreedevi, T. K., Pathak, P., Rego, T. J., Shiferaw, B. and Iyer, S. R., Farmer-participatory integrated watershed management: adarsha watershed, Kothapally India – an innovative and upscalable approach. In *Research Towards Integrated Natural Resources Management: Examples of Research Problems, Approaches and Partnerships in Action in the CGIAR* (eds Harwood, R. R. and Kassam, A. H.), Consultative Group on International Agricultural Research: Washington DC, USA and FAO, Italy, 2003, pp. 123–147.
6. Wani, S. P., Sreedevi, T. K., Rockstrom, J. and Ramakrishna, Y. S., Rainfed agriculture – past trends and future prospects. In *Rainfed Agriculture: Unlocking the Potential* (eds Wani, S. P., Rockstrom, J. and Oweis, T.), CAB International, Wallingford, UK, 2009, pp. 1–35.
7. Wani, S. P., Chander, G. and Sahrawat, K. L., Soil health awareness: soil science at doorsteps of the farmers. In Proceedings of national seminar on 'soil security for sustainable agriculture', Akola, Maharashtra, India, 27–28 February 2010 (eds Sarode, S. V. *et al.*), Dr Panjabrao Deshmukh Krishi Vidyapeet, Akola, India, 2012, pp. 1–9.
8. Bhatia, V. S., Singh, P., Wani, S. P., Kesava Rao, A. V. R. and Srinivas, K., Yield gap analysis of soybean, groundnut, pigeonpea and chickpea in India using simulation modeling, Global Theme on Agroecosystems Report No. 31, ICRISAT, Patancheru, India, 2006.
9. Murty, M. V. R., Singh, P., Wani, S. P., Khairwal, I. S. and Srinivas, K., Yield gap analysis of sorghum and pearl millet in India using simulation modeling. Global Theme on Agroecosystems Report No. 37, ICRISAT, Patancheru, India, 2007.
10. Aggarwal, P. K., Hebbar, K. B., Venugopalan, M. V., Rani, S., Bala, A., Biswal, A. and Wani, S. P., Quantification of yield gaps in rain-fed rice, wheat, cotton and mustard in India, Global Theme on Agroecosystems Report No. 43, ICRISAT, Patancheru, India, 2008.
11. Sahrawat, K. L., Wani, S. P., Parthasaradhi, G. and Murthy, K. V. S., Diagnosis of secondary and micronutrient deficiencies and their management in rainfed agroecosystems: case study from Indian semi-arid tropics. *Commun. Soil Sci. Plant Anal.*, 2010, **41**, 346–360.
12. Wani, S. P., Sahrawat, K. L., Sarvesh, K. V., Baburao Mudbi and Krishnappa, K., *Soil Fertility Atlas for Karnataka, India*, ICRISAT, Patancheru, India, 2011.
13. Wani, S. P., Chander, G., Sahrawat, K. L. and Pardhasaradhi, G., Soil test-based balanced nutrient management for sustainable intensification and food security: case from Indian semi-arid tropics. *Commun. Soil Sci. Plant Anal*., 2015, **46**, 20–33.
14. Chander, G., Wani, S. P., Sahrawat, K. L. and Jangawad, L. S., Balanced plant nutrition enhances rainfed crop yields and water productivity in Jharkhand and Madhya Pradesh states in India. *J. Trop. Agric*., 2012, **50**, 24–29.
15. Chander, G., Wani, S. P., Sahrawat, K. L., Kamdi, P. J., Pal, C. K., Pal, D. K. and Mathur, T. P., Balanced and integrated nutrient management for enhanced and economic food production: case study from rainfed semi-arid tropics in India. *Arch. Agron. Soil Sci*., 2013, **59**, 1643–1658.
16. Chander, G., Wani, S. P., Sahrawat, K. L. and Rajesh, C., Enhanced nutrient and rainwater use efficiency in maize and soybean with secondary and micro nutrient amendments in the rainfed semi-arid tropics. *Arch. Agron. Soil Sci*., 2014, **61**(3), 285–298; doi:10.1080/03650340.2014.928928.

17. Chander, G. *et al.*, Soil test-based nutrient balancing improved crop productivity and rural livelihoods: case study from rainfed semi-arid tropics in Andhra Pradesh, India. *Arch. Agron. Soil Sci*., 2014, **60**, 1051–1066.
18. Chennamaneni, S. R., Wani, S. P., Chander, G. and Sahrawat, K. L., Balanced nutrient management for crop intensification and livelihood improvement: a case study from watershed in Andhra Pradesh, India. *Commun. Soil Sci. Plant Anal*., 2014, **45**, 2515–2528.
19. Chander, G., Wani, S. P., Sahrawat, K. L., Pal, C. K. and Mathur, T. P., Integrated plant genetic and balanced nutrient management enhances crop and water productivity of rainfed production systems in Rajasthan, India. *Commun. Soil Sci. Plant Anal*., 2013, **44**, 3456–3464.
20. Ministry of Agriculture, Land use statics at a glance-state wise, 2013; available online: http://eands.dacnet.nic.in/LUS_1999_2004.htm (accessed on 31 August 2014).
21. Ministry of Agriculture, Agricultural statistics at a glance 2011, 2013; available online: http://eands.dacnet.nic.in/latest_20011.htm (accessed on 31 August 2014).
22. Sahrawat, K. L., Rego, T. J., Wani, S. P. and Pardhasaradhi, G., Stretching soil sampling to watershed: evaluation of soil-test parameters in a semi-arid tropical watershed. *Commun. Soil Sci. Plant Anal*., 2008, **39**, 2950–2960.
23. Rego, T. J., Wani, S. P., Sahrawat, K. L. and Pardhasaradhi, G., Macro-benefits from boron, zinc and sulfur application in Indian SAT: a step for grey to green revolution in agriculture, Global Theme on Agroecosystems Report no. 16, ICRISAT, Patancheru, 2005.
24. Nelson, D. W. and Sommers, L. E., Total carbon, organic carbon and organic matter. In *Methods of Soil Analysis, Part 3: Chemical methods* (*Soil Science Society of America Book series No. 5*), (ed. Sparks, D. L.), SSSA and ASA, Madison, Wisc., 1996, pp. 961–1010.
25. Olsen, S. R. and Sommers, L. E., Phosphorus. In *Methods of Soil Analysis, Part 2, 2nd edn* (Agronomy Monograph 9), (ed. Page, A. L.), ASA and SSSA, Madison, Wisc, 1982, pp. 403–430.
26. Helmke, P. A. and Sparks, D. L., Lithium, sodium, potassium, rubidium and cesium. In *Methods of Soil Analysis, Part 3: Chemical methods* (*Soil Science Society of America Book Series No. 5*), (ed. Sparks, D. L.), SSSA and ASA, Madison, Wisc, 1996, pp. 551–574.
27. Tabatabai, M. A., Sulphur. In *Methods of Soil Analysis, Part 3: Chemical Methods* (*Soil Science Society of America Book Series No. 5*), (ed. Sparks, D. L.), SSSA and ASA, Madison, Wisc., 1996, pp. 921–960.
28. Lindsay, W. L. and Norvell, W. A., Development of a DTPA test for zinc, iron, manganese and copper. *Soil Sci. Soc. Am. J*., 1978, **42**, 421–428.
29. Keren, R., Boron. In *Methods of Soil Analysis, Part 3: Chemical Methods (Soil Science Society of America Book Series No. 5)* (ed. Sparks, D. L.), SSSA and ASA, Madison, Wisc., 1996, pp. 603–626.
30. Ministry of Agriculture, Agricultural statistics at a glance-2013, 2013, available online: http://eands.dacnet.nic.in/latest_2006.htm (accessed on 31 August 2014).

ACKNOWLEDGEMENTS. The support from the Government of Karnataka for undertaking the present study is duly acknowledged. We acknowledge help received from the Department of Agriculture, Karnataka and ICRISAT staff, NGOs and participating farmers in collecting data.

doi: 10.18520/cs/v110/i9/1683-1691