Managing soil fertility constraints in market-led shift to high value agriculture for benefiting smallholders in the semi-arid tropics

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Abstract

Low productivity and cultivation of low value crops in the Indian semi-arid tropics (SAT) is the main cause for poor farm-based livelihoods. Poverty leading to low risk-taking ability of farmers and production related constraints like widespread multi-nutrient deficiencies are major stumbling blocks for shifting to high value agriculture. Realizing the need to support poverty-entrapped smallholders to connect to markets, the government of Karnataka state in India supported market-led shift to high value agriculture through a consortium of technical institutions and convergence of agricultural schemes. New widespread deficiencies of secondary and micronutrients like sulfur (52% farms), zinc (55%) and boron (62%) along with earlier known deficiencies of nitrogen (52%) and phosphorus (41%) were identified as main constraints for realizing productivity potential and a threat for sustainability. Policy supported initiative during 2011/12 showed more economic returns with diversified high value crops and strengthened 0.23 million smallholders. On-farm evaluations of soil test-based nutrient balancing to tomato, okra, brinjal, chilies, onion, cabbage and beans increased productivity by 5 to 58% over the farmers' practice of adding macronutrients only. Small additional cost (` 770 to 1520 per ha) of balanced nutrition significantly increased additional benefits (` 5300 to 74,000 per ha) with fairly high cost-benefit ratio (1:4 to 1:82). Substantial returns enhanced risk-taking ability of smallholders to manage productivity constraints in future by themselves. Results showed that initial little investments in science and market-led social assistance programs should be a way forward for mainstreaming poverty-entrapped smallholders in other parts of SAT.

Introduction

The semi-arid tropics (SAT) are home to world's poor and malnourished people, and almost all population growth is taking place in these developing regions. Current productivity in farmers' fields in the SAT is very low (Wani et al. 2012) and therefore the current scenario poses challenges in terms of improving farmers' livelihoods. Similarly in Indian SAT particularly in Karnataka state, the growth in agriculture has lagged behind. The deceleration in agricultural growth has been rightly recognized as the root cause of rural distress. Low farm income due to inadequate productivity growth and low price for farm output have pushed farmers to crippling debt. The Karnataka state economy is largely dependent on agriculture which directly accounts for 18% of gross domestic product, while the share of agriculture in total employment is as high as 61% (GoK 2011). The years 2000 to 2008 witnessed negative to very low agricultural growth rate in Karnataka. In this background, the Government of Karnataka (GoK) supported the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) consortium led mission mode initiative namely, "Bhoochetana" – meaning reviving the land – to unlock the potential of rainfed agriculture in Karnataka by adopting a science-led development approach. The initiative tested new development pathway by putting in place the consortium of stakeholders, a novel extension mechanism through trained farm facilitators and convergence of agricultural schemes. The Bhoochetana initiative showed very good impact with farmers during 2009/10 and 2010/11 by increasing productivity of dryland crops by 32–66% over the farmers' practice with the adoption of knowledge-based improved management practices. Karnataka's agriculture sector as a whole has shown a satisfying growth of 5.9% during 2009/10 and 11.2% during 2010/11.

The cause of poor-farm based livelihoods in the SAT is not only low crop productivity, but also the cultivation of low value crops. Therefore, building on the successes and increased growth rate under Bhoochetana (ICRISAT 2012a, 2012b), the GoK initiated innovative policy support for marginal and smallholder farmers to shift from low value agriculture to high value agriculture through providing monetary help for purchase of inputs under the "Suvarna Bhoomi Yojane" (SBY) scheme. Understanding the poverty trap in which the poor are stuck, such social assistance programs are needed to help them to connect to markets in a way that improves their livelihoods and builds their own resilience for sustainability. The high value agriculture like vegetable cultivation in selected watersheds in SAT in India, China and Thailand has shown significant increase in farm net incomes through efficient resource utilization (Srinivasarao et al. 2010, Wani et al. 2012). Soil fertility related degradation in the SAT poses a challenge to success and sustainability of such initiative to shift to high value agriculture. Rainfed soils in the SAT are multi-nutrient deficient and need proper nutrient management strategies to realize potential yields (Sahrawat et al. 2010). In view of observed deficiencies, the application of major nutrients, nitrogen (N), phosphorus (P) and potassium (K), as currently practiced is important for the soils in the SAT (El-Swaify et al. 1985, Rego et al. 2003, Sharma et al. 2009), but very little attention has been paid to diagnose and take corrective measures for deficiencies of secondary and micronutrients in various crop production systems (Rego et al. 2005, Sahrawat et al. 2007, 2011) followed in millions of small and marginal farmers' fields in the SAT. Therefore, for any diversification to high value crops, there is a need for a dimension of research-for-development to diagnose and manage soil fertility related risks that could otherwise keep the poorest away from the market opportunities.

We hypothesized that small and marginal farmers would need technical support along with financial incentive to grow high value crops and if so a technical backstopping through consortium approach would enable farmers to grow high value crops and harness more benefits and help the government to ensure more economic gains from the investments made through SBY. The specific objectives were:

1. To diagnose soil fertility related constraints and design need-based fertilizer management strategy.
2. To conduct farmer participatory trials with prominent diversified crops across the districts to assess and quantify benefits of shift to high value agriculture and particularly of improved nutrient management practices in terms of increased crop yields, economic returns and economic viability over the farmers' practice.

Materials and methods

Government policy supported flagship initiative for smallholders. Out of 7.58 million operational holdings in Karnataka (GoK 2011), more than 70% consist of marginal (<1 ha landholding size) and small (1 to 2 ha landholding size) farmers who together hold around only 30% of the total cultivated area. Understanding the vicious trap in which marginal and small holders in Karnataka are entrapped and unable to improve their livelihoods, the GoK launched a social assistance scheme namely SBY to kick-start the engine of agricultural development in the state. Under this initiative, the government provided external assistance as an incentive of ` 10,000 per family for transforming up to 0.8 ha of their land from low value to high value agriculture during 2011/12. During this period, 231,703 farm families were identified amongst the marginal and small farmers and provided external monetary assistance to shift to high value agriculture in 154,145 ha throughout the state (Table 1). The monetary incentive was disbursed among farmers in two equal instalments, one before sowing of crop and the other after verification during the crop growth period. The scheme was unique among many other government schemes because this showed a great political will through bringing in required policy change and guidelines to ensure the delivery of a holistic solution at farm level. To address human resource issues, 1200 farm facilitators were appointed and trained to provide services at farm level, with each facilitator taking care of maximum 300 beneficiaries/farmers. The Department of Horticulture, GoK acted as nodal agency to implement the initiative with support from more than 20 consortium partners to provide input/output linkages and reach out to the large number of farmers. The overall coordination and documentation was undertaken by ICRISAT. The concurrent monitoring and fixing issues at government level ensured proper implementation.

Consortium and convergence approach. The initiative adopted the Inclusive Market-Oriented Development (IMOD) strategy through science-led crop diversification by the small and marginal farmers while ensuring the availability of critical quality inputs, and market linkages for the high-volume crop produce. This was achieved through a multidisciplinary consortium formation and the concept of collective action among consortium partners.

Table 1. Farmer participatory research trials for development conducted under Suvarna Bhoomi Yojane (SBY) initiative in Karnataka, India during rainy season 2011.

District	Total no. of SBY beneficiaries	Total area covered (ha)	Crop (No. of farmer participatory trials)	Targeted blocks/taluks for trials
Bagalkote	6601	8304	Onion (20)	Badami, Hunagund, Bagalkote
Belgaum	10698	18170	Brinjal (8), onion (5), cabbage (2), dry chili (7)	Bailhongal, Belgaum, Khanapur, Gokak
Bellary	5419	3858	Onion (25)	Hadagalli, HB Halli, Kudlagi
Bengaluru-Rural	6626	3652	Beans (2)	Nelamangla, Doddaballapura
Bengaluru-Urban	4857	3335	Beans (3)	Anekal
Bidar	6319	6119	NA[1]	NA
Bijapur	6937	2577	Onion (9)	Bijapur, Sindagi
Chamrajanagara	5560	6628	Tomato (8)	Chamrajanagara, Gundlupet
Chikballapur	6427	5572	Tomato (3), cabbage (2)	Sidlaghattta, Chintamani
Chikmagalur	14202	2279	Onion (6)	Tarikere
Chitradurga	6274	6881	Onion (25)	Chitradurga, Hosadurga, Challakere
Dakshina Kannada	17176	3648	Okra (3), beans (2)	Mangalore
Davangere	5593	2410	Tomato (17), onion (16)	Harihara, Honalli, Jagaluru, Harpanhalli
Dharwad	9099	7145	Brinjal (10), okra (2), onion (10), dry chili (15)	Dharwad, Kalagatagi, Hubali, Kundgol
Gadag	5014	5539	Onion (32), dry chili (9)	Gadag, Mundargi, Shiahatti, Ron, Nargund
Gulbarga	6181	8842	Tomato (2), onion (14)	Sedam, Afzalpur, Chittapur, Gulbarga
Hassan	25837	6152	Tomato (9)	Arsikere, Belur
Haveri	8453	6721	Brinjal (10), okra (7), onion (5), cabbage (10), dry chili (15)	Shiggaon, Haveri, Hirekerur, Ranebenur, Byadagi, Savanur
Kodugu	1966	621	NA	NA
Kolar	8096	3948	NA	NA
Koppal	4123	3101	Dry chili (21)	Koppal, Yelburga, Kustagi, Gangawati
Mandya	4735	2195	Tomato (40), cabbage (9)	Maddur, Srirangapatana, Malavalli, Nagamangala, KR Pet, Mandya
Mysore	7762	5364	Brinjal (2)	Mysore
Raichur	3771	6617	Tomato (7), onion (30),	Raichur, Manvi, Deodurg, Lingasugar
Ramnagara	2471	2193	Tomato (19)	Ramnagara, Channapatna, Kanakapura, Magadi
Shimoga	13904	7833	Tomato (16)	Shimoga, Shikaripur
Tumkur	13958	9387	Brinjal (3)	CN Halli, Turvekere
Udupi	4294	1260	Okra (10)	Udupi, Karkal
Uttar Kannada	7542	1692	NA	NA
Yadgir	1808	2105	Onion (10)	Yadgir
Total	231703	154145		

1. NA = Data not available.

The SBY consortium was unique in its composition. It brought together hard-core researchers in the area of horticultural research like Indian Institute of Horticultural Research (IIHR), Bangalore and University of Horticultural Sciences (UHS), Bagalkot. For on-farm and strategic research on crop management and capacity building, ICRISAT, University of Agricultural Sciences (UAS)-Dharwad, UAS-Bangalore, UAS-Raichur and Bangalore University were involved. For community mobilization as well as training component, NGOs like BAIF Development Research Foundation, Mysore Resettlement and Development Agency (MYRADA), BASIX Krishi Samruddhi Limited, VIKASANA Institute for Rural & Urban Development, Basava Seva Trust, Sadana Centre, Advi Siddheshwar Rural Development Society and Hindulida Guddagadu Janara Vikasa Sangh located in different parts of the state were also involved in the consortium. The Department of Horticulture was the nodal agency implementing the SBY scheme and playing crucial role in facilitating dialogue between consortium partners and rendering required administrative help as it is the overall authority of horticulture sector at the state level. Different state government departments like Department of Agriculture, Watershed Development Department, Directorate of Economics and Statistics, Department of Agricultural

Marketing and Karnataka State Horticultural Marketing Federation were also involved in the consortium for convergence of related activities of GoK departments so as to enhance the impact of the SBY. As an effort to introduce public-private-partnership concept in the project, Mother Dairy/SAFAL and Jain Irrigation Systems Ltd were identified for providing possible market linkages to the products.

Many developmental programs/schemes implemented by governments in the past could not achieve the desired level of success, because those focused on any single aspect only and ignored others. A success in any agriculture related initiative depends largely on synergizing many factors affecting it. Therefore, keeping this in mind, all major schemes running in the Department of Horticulture and other state departments were converged with the SBY initiative so that incentives are used efficiently by the smallholders to kick-start market-led diversification of crops. Most prominently, the current scheme was converged with the mission mode project Bhoochetana (ICRISAT 2012a, 2012b), which already has established supply of inputs through frontline Raitha Sampark Kendras (RSKs) with 50% incentive on newly diagnosed deficient secondary and micronutrients to use balanced nutrient approach. To inculcate a sense of ownership among farmers and ensure sustainability, the initiative adopted a participatory and demand-driven approach right from the beginning.

Capacity building and regular monitoring and evaluation. The role of capacity strengthening of stakeholders was well understood for effective implementation and sustainability of the initiative. Therefore, ICRISAT, the consortium leader, initially conducted a team building and orientation exercise about the initiative with all consortium partners. All technical institutes like ICRISAT, IIHR and state universities of agriculture and horticulture conducted extensive and regular training of staff of Department of Horticulture and NGOs at district level, who then trained the line staff and farm facilitators. Each farm facilitator trained and took care of technical needs of 300 farmers to implement the initiative. Farm facilitators were chosen amongst the educated innovative farmers, trained extensively and regularly and paid an honorarium to help other farmers. Thus, farmers had an expert amongst themselves to help them anytime when needed, and who was in regular contact with experts for solutions to farm problems.

Bureaucratic delays may completely fail agriculture related initiatives where timing is very crucial. This initiative, therefore underlined the need to take quick decisions to immediately fix issues in on-farm research for impact. So, coordination committees were constituted at state, district and block/taluk level with responsibility and authority to take decisions to facilitate implementation. Weekly meetings were conducted to monitor and evaluate the progress.

Site soil sampling and analysis. An inclusive market oriented development strategy for strengthening smallholder agriculture in the SAT encompasses efficient resource utilization for sustainable intensification and profit maximization. Soils are one of the most important resources, but in general are highly degraded in the SAT due to nutrient mining and improper management. Healthy soils are needed for agriculture. With this in view, the ICRISAT-led consortium implemented the flagship SBY project in Karnataka with focus on diagnosing and managing soil related constraints using soil testing as a tool.

A large number of soil samples were collected from farmers' fields/farms across all districts in Karnataka through a stratified soil sampling technique (Sahrawat et al. 2008) under Bhoochetana initiative and analyzed (Wani et al. 2011). Under this method, we divided target ecoregions in the districts into three topo-sequences. At each topo-sequence location, samples were taken proportionately from small, medium and large farm-holding sizes to address the variations that may arise due to different management practices because of different economic status in each farm size class. Within each farm size class in a topo-sequence, the samples were chosen carefully to represent all possible soil fertility variations as judged from soil color, texture, cropping system and agronomic management. At selected sampling point in a farmer's field, we collected 8 to 10 cores of surface (0–0.15 m) soil samples and mixed together to make a composite sample. The collected samples were air-dried, ground and then passed through 2 mm sieve. For organic carbon (OC), the soil samples were passed through 0.25 mm sieve. The processed samples were analyzed for OC, available sulpfur (S), boron (B), zinc (Zn), phosphorus (P) and potassium (K) in ICRISAT's soil, plant and water analytical laboratory. Soil pH was measured by glass electrode using soil to water ratio of 1:2, while OC was analyzed following the Walkley-Black method (Nelson and Sommers 1996). Available P was extracted using the sodium bicarbonate ($NaHCO_3$) extractant (Olsen and Sommers 1982), exchangeable/available K using ammonium acetate (Helmke and Sparks 1996) and available S using 0.15% calcium chloride ($CaCl_2$) as an extractant (Tabatabai 1996). Available Zn was extracted by diethylene triamine pentaacetic acid (DTPA) reagent (Lindsay and Norvell 1978) and available B by hot water (Keren 1996). Available P was determined using colorimetric method, while K was determined by Atomic

Absorption Spectrophotometer (AAS). Sulfur, B and Zn were estimated by using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES).

Development of fertilizer recommendations to meet varying soil fertility needs. Based on soil analysis results and understanding the need to cater to the variable soil fertility across the region, fertilizer recommendations were developed at the level of cluster of villages called block (taluk), a lower administrative unit in a district. In India in general or Karnataka specifically, the blanket fertilizer recommendations are followed for N, P and K at the state (comprising of some districts) level which rarely matches soil fertility need, while totally ignoring the secondary and micronutrients. In this study, soil test-based fertilizer recommendations were designed at block level by considering practical aspects like available infrastructure, human power and economics in research for impact for smallholders in the Indian SAT. The critical values for delineating deficiency were 0.5% for OC, 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 (Sahrawat et al. 2010). As percent nutrient deficiency is indicative of nutrient mining, we recommended to apply full dose of a particular nutrient if deficiency for that nutrient was in more than 50% farms in a block and half dose of a nutrient if deficiency for that nutrient was in less than 50% farms. This way of nutrient recommendation was adopted with a view to manage existing risks in rainfed agriculture in the SAT while targeting optimum yields to improve livelihoods of poor farmers in the SAT. The general nitrogen (N), P and K recommendation for non-leguminous vegetables like tomato (*Solanum lycopersicum*), brinjal (*Solanum melongena*), okra (*Abelmoschus esculentus*), chili (*Capsicum annuum*), onion (*Allium cepa*) and cabbage (*Brassica oleracea* var *capitata*) varied and was 115–150 kg N ha^{-1}, 50–100 kg P_2O_5 ha^{-1} and 50–125 kg K_2O ha^{-1}, while for leguminous vegetables like beans (*Phaseolus vulgaris*) it was 60 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 75 kg K_2O ha^{-1}. Similarly, for newly emerged deficiencies of S, B and Zn, the per ha general recommendations of 30 kg S (through gypsum), 5 kg Zn and 0.5 kg B to be added once in two years evaluated and standardized earlier (Rego et al. 2005) were adjusted on the principle of deficiency to meet soil fertility needs.

On-farm participatory trials for development. Majority of the farmer beneficiaries under the SBY scheme diversified their farming from traditional to vegetable crops, while others to fruits and other high value crops. Good agronomic practices were promoted on all diversified crops. Keeping in mind the soil degradation, the soil test-based application of deficient S, B and Zn is an important component of good agronomic practices to realize full potential and benefits of diversification. Farmers in the region in general were not aware of secondary and micronutrient deficiencies and the need for application of these fertilizers. Therefore, farmer participatory research trials were conducted during 2011/12 with the prominent crops in different districts of Karnataka to document the benefits of balanced nutrition (Table 1). For trials, we identified farmers among SBY beneficiaries who purchased S and two micronutrients (B and Zn) and applied them in their designated vegetable fields and also followed farmers' management treatment (ie, control without S, B and Zn) in the adjoining plot. In the absence of control plot in the same farmer's field, we identified other adjoining farmers' fields with same management in the village. The treatments were imposed on 4000 to 8000 m^2 plots, side by side. The treatments were: (i) Farmers' practice (application of N, P and K); and (ii) Balanced nutrition (application of N, P, K, S, B and Zn). The fertilizer sources for nutrients were urea for N, DAP (diammonium phosphate) for P and N, MOP (muriate of potash) for K, gypsum for S, zinc sulfate for Zn and borax for B. Application of all the nutrients except N was made as basal. Fifty percent N to non-legumes was added as basal and the remaining in two equal splits at one month interval, while in legumes the whole of the recommended N was added as basal.

Crop yields and economic analysis. At maturity, the yields were recorded by the harvesting crop from three sub-plots in a treatment measuring 5 m × 5 m and average of the three was taken as final yield and converted into tons ha^{-1}. The data recorded was subjected to statistical analysis using the Genstat 13th statistical package, VSN International Ltd, UK (Ireland 2010). Each farmer's field in a district was treated as replication for statistical analysis of the data.

For economic analysis, the additional cost of balanced fertilizer application was worked out on per kg market prices at ` 2.20 for gypsum, ` 33 for zinc sulfate and ` 50 for borax. Gross and additional returns due to balanced nutrition in case of vegetables were calculated based on per kg farm gate price of marketable produce at the rate of ` 5 for tomato, ` 10 for brinjal, ` 12 for okra, ` 6 for onion, ` 6 for cabbage and ` 10 for beans. The currency conversion factor is ` 1 = US$ 0.016. The benefit-cost ratio was also worked out for comparative evaluation of balanced nutrition over the control by dividing additional returns by additional costs.

Prior to shifting to high value agriculture during 2011, beneficiary farmers used to grow traditional crops like maize (*Zea mays*), finger millet (*Eleusine coracana*), pearl millet (*Pennisetum glaucum*), sorghum (*Sorghum* *bicolor*), black gram (*Vigna mungo*), green gram (*Vigna radiata*), pigeonpea (*Cajanus cajan*), groundnut (*Arachis hypogaea*), soybean (*Glycine max*) and sunflower (*Helianthus annuus*). Therefore, to have an analysis of comparative benefit of cultivating market-led vegetables over traditional crops, the yields and returns from traditional crops in Karnataka were also worked out. The results of earlier initiative Bhoochetana recorded during 2010/11 were used to compute returns from traditional crops in Karnataka, which represented yields and returns from all important traditional crops in the region both under farmers' practice and improved practice.

Results and discussion

Diagnosis of soil fertility related constraints. The results of analysis done on the sampled soils revealed multi-nutrient deficiencies scattered differently across the state, and thereby a need for soil test-based nutrient management strategy at the level of cluster of villages (block/taluk) to take care of varying soil fertility needs. Soil OC is an indicator of general soil health and specifically of N but majority of the farm (52%) soils have low levels of OC. Fast oxidation under tropical climate and little recycling through organic manures is the apparent reason for low levels of soil OC. The following 17 out of 30 districts were found heavily degraded in soil OC – Bengaluru-Urban, Bengaluru-Rural, Bijapur, Chamarajanagara, Chikkabalapur, Chitradurga, Davangere, Gadag, Gulbarga, Haveri, Kolar, Koppal, Mysore, Raichur, Ramanagara, Tumkur and Yadgir. As regards P in Karnataka as a whole, 41% farms were deficient indicating majority farms rather sufficient in P and thus representing an opportunity through site specific nutrient management to cut cost on current recommendations. However, 11 districts had majority farmers' fields (>50%) deficient in P and that included Bagalkote, Belgaum, Bellary, Bijapur, Chitradurga, Dharwad, Gadag, Gulbarga, Kodugu, Tumkur and Udupi. Available K as such is not a problem in Karnataka and only 23% fields tested low and a science-led approach calls for a cut on recommended K. But K deficiencies were a matter of concern in Belgaum and Kodugu where majority farms tested low.

Further, most farms in Karnataka showed widespread deficiencies of secondary and micronutrients to the tune of 52% in S, 55% in Zn and 62% in B. Such secondary and micronutrient deficiencies have probably emerged due to use of high analysis N, P and K fertilizers and no or little application of organic manures and S, B and Zn fertilizers over the past years. Eleven districts have majority farms deficient in all three nutrients (S, B and Zn). The 11 districts with widespread S, Zn and B deficiencies are Bagalkote, Bidar, Chamarajanagara, Chikkabalapur, Chitradurga, Davangere, Gulbarga, Hassan, Tumkur, Udupi and Yadgir. In Shimoga district, S, B and Zn deficiencies are emerging but still most farms are sufficient in these nutrients. Majority of the farms in the districts of Bijapur, Gadag, Haveri and Raichur have dual deficiencies of S and Zn; while those in the districts of Bengaluru-Rural and Kolar have dual deficiencies of S and B; and in the districts of Belgaum, Koppal and Mandya they have dual deficiencies of Zn and B. Nine districts have widespread individual deficiencies of S or B or Zn. Sulfur deficiencies are more in Bellary, Dharwad and Kodugu; Zn deficiencies in Chikmagalur, Dakshina Kannada and Uttar Kannada; and B deficiencies in Bengaluru-Urban, Mysore and Ramanagara districts.

These results are on expected lines as soils of the SAT are generally marginal compared to those in the irrigated or assured rainfall regions. Poor soils with low nutrient reserves are brought under cultivation due to population pressure and that too without much external input of nutrients for a long time, resulting in mining and depletion of scanty stocks of nutrients. Further, the rate of organic matter degradation in the SAT is relatively higher than in the temperate region due to prevailing high temperatures and drying and wetting cycles. These soils are prone to erosion, which take away nutrient rich top soil layer. Thus, soil erosion along with mining of nutrients by continuous cropping, without adequate additions of nutrients, have impoverished the soils over the years. In dryland tropics, the usual practice of farmers is to add N, P and K fertilizers only. Thus, crops in the SAT mine the limited stocks of micronutrients and secondary elements from the marginal soils, resulting in their decline in these soils. Even though the quantities of nutrients removed are small when compared to irrigated crops because of low yields, deficiencies do occur due to relatively small reserves in these marginal soils. In recent years, the availability of farmyard manure (FYM) and organic manures and the quantity applied have declined drastically resulting in micronutrient deficiencies (Chander et al. 2013, Wani et al. 2013). However, farmers are unaware of the deficiencies of secondary and micronutrients like S, B and Zn and do not include them in their fertilization practices. Similar soil fertility related degradation due to secondary and micronutrient deficiencies along with primary nutrients have been reported in other rainfed regions of Indian SAT and the application of soil test-based balanced nutrition has shown that crop yields and incomes increased across a range of crops (Sahrawat et al. 2010, Srinivasarao et al. 2010, Chander et al. 2012, 2013). So, soil analysis results have provided a basis to include deficient S, B and Zn in fertilization practices along with N, P and K and enhance farmers risk-taking capacity while shifting to high value agriculture.

Marketable yields of vegetables. A shift to cultivation of high value vegetable crops across the districts in Karnataka showed good results in terms of productivity and strengthened 0.23 million smallholder farmers. Farmers' practice of application of only N, P and K in solanaceous vegetables recorded yields in the range of 11.8 to 34.8 t ha^{-1} in tomato, 9.9 to 26.3 t ha^{-1} in brinjal, 7.93 to 11 t ha^{-1} in okra and 1.13 to 2.45 t ha^{-1} in dry chilies (Table 2). Onion, cabbage and beans were other important diversified vegetables which yielded in the range of 10 to 27.4 t ha^{-1}, 10.8 to 36.5 t ha^{-1} and 9.5 to 28.9 t ha^{-1}, respectively (Table 3). But the soil test-based balancing of nutrients through the addition of deficient S, B and Zn in addition to only N, P and K significantly increased marketable yields in tomato (6–36%), brinjal (15–31%), okra (6–33%), chilies (16–29%), onion (5–38%), cabbage (15–47%) and beans (14–58%). Balanced nutrition recorded more produce from the same water as in farmers' practice, and thus also enhanced water productivity. In current context of the economic and environmental limitations to increase the supply of water to meet the increased demand, the prospects for water scarcity are increasing. The looming climate related risks and probability of occurrence of extreme events (Zhang et al. 2007) call for enhancing rainwater use efficiency. It is estimated that more than 50% of rainwater falling on agricultural land in the rainfed SAT is lost as unproductive evaporation (Rockström et al. 2011). Many limiting factors such as poor soil fertility do not allow effective utilization of available water. So, soil fertility management with a purpose to increase proportion of water balance as productive transpiration, is also one of the most important rainwater management strategies to improve water productivity (Rockström et al. 2010). Similarly, same amount of applied N fertilizer produced more yield under soil test-based nutrient management as compared to farmers' practice and thus improved N use efficiency. So, it is apparent that deficiencies of S, B and Zn are important factors in observed declining response to N fertilizers. Soil test-based fertilization is thus critical in efficient resource utilization. The cultivation of vegetable crops in watersheds in Dharwad, Haveri and

Table 2. Effect of improved management on marketable yield of solanaceous vegetables in Karnataka during rainy season 2011[1].

	Yield (t ha^{-1})			Gross returns (` ha^{-1})				
District	FP	BN	LSD –5%	FP	BN	Additional cost (` ha^{-1})	Additional benefit (` ha^{-1})	B:C of BN over FP
Tomato								
Chamrajanagara	22.1	27.3	5.3	110500	136500	1520	26000	17
Chikballapur	26.2	35.3	12.2	131000	176500	1120	45500	41
Davangere	11.8	16	1.73	59000	80000	1340	21000	16
Hassan	14.4	15.6	0.45	72000	78000	1320	6000	5
Mandya	27.1	33.4	1.72	135500	167000	1230	31500	26
Raichur	19	20.2	1.46	95000	101000	1520	6000	4
Ramnagara	27.5	34.8	3.19	137500	174000	1100	36500	33
Shimoga	14.8	18.9	1.38	74000	94500	770	20500	27
Gulbarga	34.8	37.8	1.92	174000	189000	1520	15000	10
Brinjal								
Dharwad	26.3	30.9	2.13	263000	309000	1060	46000	43
Haveri	23.9	31	1.42	239000	310000	1320	71000	54
Mysore	24.2	31.6	7.3	242000	316000	900	74000	82
Tumkur	9.9	11.4	1.43	99000	114000	1520	15000	10
Belgaum	13.7	15.7	0.99	137000	157000	1030	20000	20
Okra								
Dakshina Kannada	11	14.6	0.49	132000	175200	1170	43200	37
Dharwad	8.52	10.8	0.93	102240	129600	1120	27360	24
Haveri	8.3	10.5	0.79	99600	126000	1060	26400	25
Udupi	7.93	8.43	0.35	95160	101160	1520	6000	4
Red chili								
Dharwad	1.24	1.44	0.15	124000	144000	1250	20000	16
Gadag	1.77	2.29	0.23	177000	229000	1390	52000	37
Haveri	1.16	1.41	0.09	116000	141000	1250	25000	20
Koppal	2.45	2.99	0.48	245000	299000	1300	54000	42
Belgaum	1.13	1.43	0.11	113000	143000	1300	30000	23

1. FP = Farmers' practice; BN = Balanced nutrition; and B:C = Benefit-cost ratio.

Table 3. Effect of improved management on marketable yield of some vegetables (onion, cabbage and beans) in Karnataka during rainy season 2011[1].

District	Yield (t ha^{-1})		LSD –5%	Gross returns (` ha^{-1})		Additional cost (` ha^{-1})	Additional benefit (` ha^{-1})	B:C of BN over FP
	FP	BN		FP	BN			
Onion								
Bagalkote	10	12.4	1.03	60000	74400	1520	14400	9
Bellary	24.5	31.8	3.1	147000	190800	1090	43800	40
Bijapur	8.9	11.4	2.8	53400	68400	1390	15000	11
Chitradurga	20.6	23.3	1.65	123600	139800	1520	16200	11
Davangere	14	18.6	1.83	84000	111600	1520	27600	18
Dharwad	14.2	15.2	0.99	85200	91200	990	6000	6
Gadag	12.5	13.6	0.8	75000	81600	1390	6600	5
Haveri	10.9	15	2.14	65400	90000	1390	24600	18
Raichur	11.9	13.8	0.66	71400	82800	1430	11400	8
Yadgir	15.7	19.2	0.85	94200	115200	1520	21000	14
Gulbarga	27.4	31	6.11	164400	186000	1520	21600	14
Chikmagalur	15.3	16.1	0.58	91800	96600	1170	4800	4
Belgaum	13.7	16.5	1.06	82200	99000	1300	16800	13
Cabbage								
Chikballapur	21.4	29.3	7.61	128400	175800	1520	47400	31
Haveri	21	30.9	4.77	126000	185400	1390	59400	43
Mandya	36.5	44.3	5.72	219000	265800	1300	46800	36
Belgaum	10.8	12.4	1.96	64800	74400	1300	9600	7
Beans								
Bengaluru-Rural	28.9	34	29.6	289000	340000	1120	51000	46
Bengaluru-Urban	27.8	31.7	3.12	278000	317000	770	39000	51
Dakshina Kannada	9.5	15	2.45	95000	150000	1170	55000	47

1. FP = Farmers' practice; BN = Balanced nutrition; and B:C = Benefit-cost ratio.

Chitradurga districts of Karnataka during 2006/07 season has also showed an impressive yield response to balanced nutrition as compared to the farmers' practice (Srinivasarao et al. 2010). These results are important for the farmers of Karnataka because they are already on the path of policy supported intensification of traditional crops. Though experts suggest increase in agricultural productivity as a strategy for poverty reduction with evidence of 1% increase in agricultural yields translating to 0.6% to 1.2% decrease in the percentage of absolute poor (Thirtle et al. 2002), frequent instances also suggest that producing more is no sure bet of getting remunerative farm gate price and so overall returns and net benefits. The surplus of traditional crops beyond certain level may not bring dividends to the farmers. Therefore, results of the present study provided in farmers hands a well-tested option of market-led diversification to vegetables from their traditional crops through soil test-based nutrient balancing to manage soil fertility related risks for higher production. But in diversification to high value crops also, it is very important to go up to a production level till there is demand in a particular region or adopt staggered production or else it may lead to distress sale and losses to farmers.

Economic and social benefits. An economic analysis showed fairly high gross returns from vegetables even under farmers' practice (Tables 2 and 3). Gross returns under farmers' practice were ` 59,000 to 174,000 $ha^{-1}$ in tomato, ` 99,000 to 263,000 ha^{-1} in brinjal, ` 95,000 to 132,000 $ha^{-1}$ in okra, ` 113,000 to 245,000 ha^{-1} in chilies, ` 53,000 to 164,000 $ha^{-1}$ in onion, ` 65,000 to 219,000 ha^{-1} in cabbage and ` 95,000 to 289,000 $ha^{-1}$ in beans. However, with soil test-based nutrient balancing, gross returns raised to ` 78,000 to189,000 ha^{-1} in tomato, ` 114,000 to 316,000 $ha^{-1}$ in brinjal, ` 101,000 to 175,000 ha^{-1} in okra, ` 141,000 to 299,000 $ha^{-1}$ in chilies, ` 68,000 to 191,000 ha^{-1} in onion, ` 74,000 to 266,000 $ha^{-1}$ in cabbage and ` 150,000 to 340,000 ha^{-1} in beans. The improved soil fertility management through balancing of deficient S, B and Zn in solanaceous and other vegetables brought in additional per ha expenditure of only ` 770 to 1520, but resulted in additional benefits varying from ` 4800 to 74,000 with cost-benefit ratio of 1:4 to 1:82, thus proving it a profitable proposition to scale-up at farm level (Tables 2 and 3). Other studies by ICRISAT (Srinivasarao et al. 2010) have also demonstrated that balanced nutrition is economically viable and remunerative.

An analysis of average yields and returns from traditional crops in Karnataka is given in Table 4. An economic analysis for traditional crops has shown gross returns of approximately ` 15,000 to ` 45,000 per ha under farmers' management practice and ` 18,000 to ` 60,000 per ha under improved fertilizer management practice. In contrast to total expenditure on inputs like seed, fertilizers, pesticides for vegetables (` 20,000 to 30,000 per ha) and traditional crops (` 4000 to 6000 per ha), the higher net returns in vegetables support the idea of market-led shift to high value agriculture to increase farm incomes where possible. Simple means for different traditional and vegetable crops in Karnataka indicate that traditional crops can bring in per ha net returns (benefits excluding cost of inputs) to the tune of ` 19,000 under farmers' practice and about ` 27,000 under improved nutrient management practice. The market-led shift to vegetables can increase per ha net returns about five to six times as compared to traditional crops; ie, about ` 115,000 under farmers' nutrient management practice and about ` 148,000 under balanced nutrient management practice. Thus for each rupee the government spent (` 10,000 for 0.8 ha per beneficiary) on smallholders, the cost-benefit ratio of shifting to vegetables was 1:9 for farmers' practice and 1:12 for balanced nutrition practice. In addition to overall higher income with vegetables, farmers got income at regular intervals to meet farm or household expenses resulting in higher level of satisfaction as documented in farmers' responses. One real challenge for diversification to high value agriculture lies in more labor requirement. However, this challenge proved a boon in providing gainful employment to 0.23 million smallholders. Seventy percent of total farm holdings in Karnataka and similarly majority in other parts of Indian SAT are smallholders and this on-farm research showed a way to turn their subsistence farming into business enterprises. The initial small monetary investments for poverty-entrapped smallholders as in the "SBY initiative" to undertake a science- and market-led shift to high value agriculture is the best strategy of strengthening and making smallholders self-sustaining.

Conclusions

Smallholder farmers in the SAT do not earn and save enough to pump in investments for shifting to high value agriculture to improve incomes and livelihoods. Moreover, their unawareness about real technical constraints lowers their risk-taking capacity. Therefore, a large population of smallholders in the SAT is stuck in subsistence agriculture and so upliftment of agriculture in these regions should be the priority of governments to improve livelihoods and bring in social equity for millions of smallholders. In similar scenario in Karnataka, a policy supported consortium and convergence mechanism was put in place to operationalize inclusive market oriented development through enabling farmers to shift to high value agriculture in a farmer participatory research for impact mode. Diagnostic soil health assessment of famers' fields identified widespread low levels of S, B and Zn along with N and P responsible for holding back the realization of potential yields of vegetable crops, and also a threat for sustainability of the initiative. The initiative supported smallholders through technical and monetary backstopping and uplifted the status of 0.23 million smallholders in Karnataka during 2011/12 through diversification to high value agriculture like vegetables. Demand-driven diversification through handholding by technical institutions enabled smallholders to earn far more than their traditional crops. On-farm research showed significant yield advantage and benefits through

Table 4. Crop yields and benefits from traditional crops in Karnataka during 2010/11[1].

	Grain/pod yield (kg ha^{-1})		Gross returns (` ha^{-1})	
Crop	FP	BN	FP	BN
Finger millet	1710	2330	20500	27900
Maize	4980	6690	44800	60200
Pearl millet	1670	2210	15000	19800
Sorghum	1610	2280	14500	20500
Green gram	500	680	15400	21200
Pigeonpea	1220	1650	36700	49400
Groundnut	1430	2000	37300	52100
Soybean	1800	2490	25900	35900
Sunflower	640	780	15000	18200

1. FP = Farmers' practice; and BN = Balanced nutrition.

nutrient balancing by addition of deficient secondary and micronutrients to vegetables. This science-led initiative just kick-started the engine of development for millions of smallholders in Karnataka region in India by enhancing their net returns five- to sixfold and bringing them out of the trap of subsistence farming. Strengthening of beneficiary smallholder farmers this way has reduced their dependence on monetary assistance through such programs. So, spending on such science-led interventions do not involve heavy and regular expenditure, but play a critical role in mainstreaming and social resilience building of masses. This provides opportunities to build on successes through converting huge quantities of straw biomass produced into nutrient-rich composts to cut use and cost of all chemical fertilizers and build soil health while enhancing productivity levels. Such programs also fulfill government commitment of ensuring nutrition through enhanced consumption of quality food particularly for vulnerable sections like women and children. This study clearly showed a way forward to transform smallholder subsistence farms in the SAT into self-sustaining business units through connecting to markets by policy supported program comprising technical and monetary intervention leading to mainstreaming of rural masses. Working together of technical institutions as consortium with farmers in a participatory mode and convergence of schemes, with capacity building of stakeholders and regular monitoring and evaluation are crucial for the success of such flagship initiatives to improve farm-based livelihoods.

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