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Building Soil Health, Improving Carbon Footprint and Minimizing Greenhouse Gas Emissions through CSR

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Abstract

Unabated soil degradation due to low soil organic carbon (C) levels, multiple nutrient deficiencies including micro- and secondary nutrients, rising salinity and soil loss due to erosion jeopardizes food security of swiftly rising global population projected to be 9.7 billion by 2050. Soils also play a major role in global C cycling and huge C sequestration potential offers opportunities for mitigating carbon dioxide and other greenhouse gas emissions. The lessons learnt from CSR pilot and scaling-up initiatives indicated significant productivity benefits with soil health mapping-based management. The linkages of soil health and food quality are documented. Soil mapping-based management increased C sequestration with higher proportion of biomass C and enhanced uptake and use efficiency of nitrogen fertilizers, and thereby reducing losses through runoff and gaseous emissions. Management at watershed level is proved as one of the most trusted approach to managing natural resources and reducing runoff, soil loss and C and nutrients therein.

3.1 Why Soil Health, Carbon and Greenhouse Gases are Important

Soils are fundamental to life on Earth and careful soil management is one essential element of sustainable agriculture and also a valuable lever for climate regulation and a pathway for safeguarding ecosystem services. Soils provide ecosystem services categorized into four broad classes: provisioning; regulating; supporting; and cultural services (Table 3.1). Provisioning services refer to the products obtained of direct benefit to people; regulating services to the benefits obtained from the regulation of ecosystem processes; supporting services are necessary for the production of all other ecosystem services (their impacts on people are often indirect or occur over a very long time); and cultural services refer to non-material benefits which people obtain from ecosystems (FAO and ITPS, 2015).

As defined in the World Soil Charter, sustainable soil management comprises activities that maintain or enhance the supporting, provisioning, regulating and cultural services provided by soils without significantly impairing either the soil functions that enable those

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Table 3.1. Ecosystem services provided by the soil, and soil functions that support these services. From: FAO and ITPS (2015).

Ecosystem service	Soil function
Provisioning	
Food supply	Providing water, nutrients and physical support for growth of plants for human and animal consumption
Fibre and fuel supply	Providing water, nutrients and physical support for growth of plant for bioenergy and fibre
Refugia	Providing habitat for soil animals, birds, etc.
Genetic resources	Source of unique biological materials
Raw earth material supply	Provision of topsoil, aggregates, peat, etc.
Surface stability	Supporting human habitations and related infrastructure
Water supply	Retention and purification of water
Regulating	
Climate regulation	Regulation of CO_2, N_2O and CH_4 emissions
Water quality regulation	Filtering and buffering of substances in soil water Transformation of contaminants
Water supply regulation	Regulation of water infiltration into soil and water flow within the soil Drainage of excess water out of soil and into groundwater and surface water
Erosion regulation	Retention of soil on the land surface
Supporting	
Soil formation	Weathering of primary minerals and release of nutrients Transformation and accumulation of organic matter Creation of structures (aggregates, horizons) for gas and water flow and root growth Creation of charged surfaces for ion retention and exchange
Nutrient cycling	Transformation of organic materials by soil organisms Retention and release of nutrients on charged surfaces
Primary production	Medium for seed germination and root growth Supply of nutrients and water for plants
Cultural	
Aesthetic and spiritual	Preservation of natural and cultural landscape diversity Source of pigments and dyes
Heritage	Preservation of archaeological records

services or biodiversity. Major threats to soil functions include nutrient imbalances, soil organic carbon (C) loss, soil erosion, salinization, soil acidification, soil contamination, soil compaction, waterlogging, soil sealing and loss of soil biodiversity.

In recent times, increasing land degradation is one of the major challenges and debatable topic. ‘Land degradation’ refers to a temporary or permanent decline in the productive capacity of the land, or its potential for environmental management. The most important on-farm effects of land degradation are declining potential yields or need to use a higher level of inputs in order to maintain yields. The unabated land degradation jeopardizes food security of swiftly rising population. The world population of 7.2 billion in mid-2013 is projected to increase to 8.2 billion by 2025, 9.7 billion by 2050, and to rise to 10.9 billion by 2100 (UN, 2016). Carbon storage is an important ecosystem function of soils that has gained increasing attention in recent years due to its direct relation with soil health and mitigation potential of greenhouse gases (GHGs). There are major opportunities for mitigation of carbon dioxide (CO_2) and other GHG emissions through changes in the use and management of agricultural lands by maintaining or increasing stocks of organic C in soils (and biomass), and reduced emissions by the agricultural sector itself (Paustian *et al.*, 1998; Whitmore *et al.*, 2014). Inefficient nitrogen (N) fertilizer-related pollution is an issue of concern worldwide. Nitrogen fertilizer inputs in excess of crop requirements are linked to the enhanced release of nitrous oxide (N_2O), a GHG 300 times more potent than CO_2, and agricultural soils are the dominant source, contributing over 80% of global anthropogenic N_2O emissions during the 1990s. Nitrous oxide emissions from agricultural soils are projected to increase from just over four million tons N_2O N per year in 2010 to over 5 million tons N_2O N per year by 2030.

The impact of land degradation is especially severe on livelihoods of the poor who heavily depend on natural resources. The annual cost of land degradation at the global level was about US$300 billion (Nkonya *et al.*, 2016). Sub-Saharan Africa accounts for the largest share (22%) of the total global cost of land degradation. The analysis of the cost of land degradation across the type of ecosystem services shows that 54% of the cost is due to the losses in regulating, supporting and cultural services which are considered as global public goods. And hence reversing land degradation trends while improving C footprints and reducing GHG emissions definitely makes economic sense with multiple social and environmental benefits.

3.2 How Soil Health and Ecosystem Service Issues are Aggravated

According to the National Bureau of Soil Survey and Land Use Planning (2005) assessment during 2004, ~146.8 million ha is degraded. Erosion is the most serious degradation problem in India covering around 93.7 million ha under water erosion and 9.5 million ha under wind erosion. Inappropriate land and water management practices in agriculture along with other human interventions like land clearing and careless management of forests, deforestation, overgrazing, surface mining, industrial development, etc. contribute to erosion problem. Further, in the post-Green Revolution era, nutrient mining along with imbalanced use of fertilizers has created multiple nutrient deficiencies which threaten sustainability. Soil fertility degradation coupled with indiscriminate use of N fertilizers is a major factor for low N use efficiency and losses in runoff and as GHG emission. Imbalanced use of fertilizers arises due to fertilizer subsidy, inadequate availability of the required fertilizers at the stipulated time in rural areas and lack of knowledge among farmers as to what nutrients are required by the crops and what is missing in their land. Due to cheaper chemical fertilizers, farmers have moved away from using organic manures, which has led to depletion of soil organic C also. The public infrastructure for soil analysis is also poorly developed and farmers rarely get quality information in time. A fragmented approach to soil analysis has restricted analysis to only macronutrients. Over-exploitation of groundwater has also emerged as one of the major factors contributing to secondary salinization. Out of 42 million ha irrigation through groundwater sources in the country, the surveys indicate that poor-quality waters being utilized in different states are 32–84% of the total groundwater development (Dagar, 2005). Such increase in irrigated area as envisaged would lead to secondary salinization consequentially leading to estimated 16.2 million ha salt affected area by 2050.

3.3 Soil Degradation Challenges in General and in CSR Sites

Increasing soil degradation, if not addressed properly, poses grave challenge to the realization of ambitious Sustainable Development Goals (SDGs), a set of seventeen aspirational 'Global Goals' with 169 targets between them (Wani *et al.*, 2015; UN, 2017). The SDGs came into effect in January 2016 and are largely interconnected. Soil degradation and related issues pose direct challenges in realization of certain goals like – no poverty; zero hunger; good health and well-being; clean water and sanitation; climate action; and life on land.

At global scale, out of 8.7 billion ha of agricultural land, pasture, forest and woodland, nearly 2 billion ha (22.5%) have been degraded since mid-century (Scherr and Yadav, 1996). Nearly half of this vegetated area is under forest, of which about 18% is degraded; 3.2 billion ha are under pasture, of which 21% is degraded; and nearly 1.5 billion ha are in cropland, of which 38% is degraded. Overall, water erosion is the principal cause of degradation and wind erosion is an important cause in drylands and areas with landforms conducive to high winds.

Chemical degradation such as nutrient loss and salinization, a result of cropping practices, accounts for a smaller overall proportion of degraded lands, but more than 40% of cropland degradation. Degradation of cropland appears to be most extensive in Africa, affecting 65% of cropland area, compared with 51% in Latin America and 38% in Asia (Scherr and Yadav, 1996).

The pilot studies supported by seven corporate social responsibility (CSR) projects across eight states in India, viz. Andhra Pradesh, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan and Telangana (Fig. 3.1), showed still higher soil degradation compared to in general 40% of cropland degradation globally under chemical degradation (Table 3.2). Soil organic C is an indicator of general soil health and most fields (5–87% fields with low C levels across pilot sites) are detected with low soil organic C. Low soil organic C also indicate N deficiency. Available phosphorus (P) deficiency ranged between 10% and 89%, while potassium (K) is not an issue of concern in most fields adequate in it except pilot sites in Jharkhand. Along with macronutrients, there are widespread

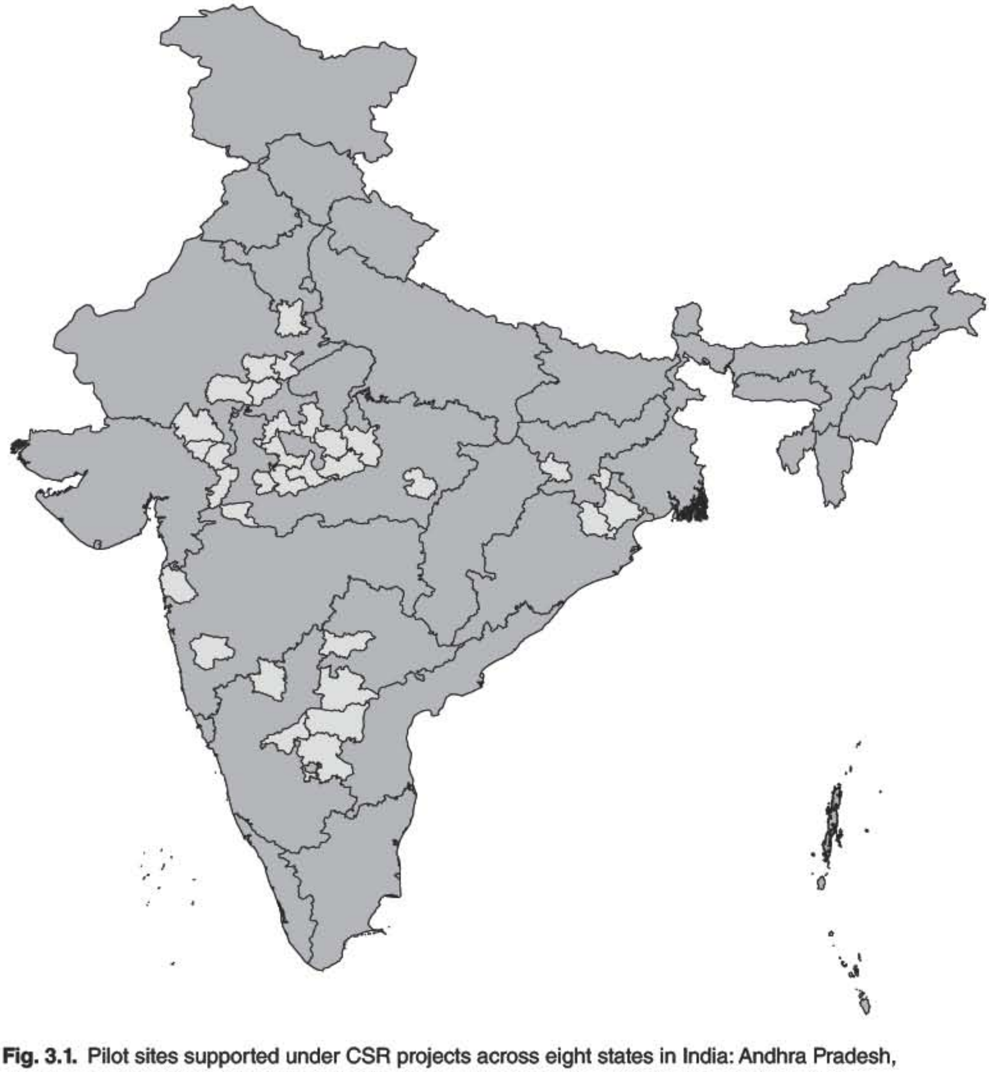

Fig. 3.1. Pilot sites supported under CSR projects across eight states in India: Andhra Pradesh, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan and Telangana.

Table 3.2. Percentage of farm fields found deficient in available nutrients and having low levels of soil organic carbon (C) across CSR pilot sites in India.

CSR project	State	District	Mandal/Taluk/Block	% samples with low soil org C	pH	EC (dS/m)	% deficiency										No. of samples
							P	K	S	Ca	Mg	Zn	B	Fe	Cu	Mn	
Asian Paints	Telangana	Medak	Patancheru	59	8.06	0.44	10	0	35	1	0	62	19	1	0	0	189
Asian Paints	Maharashtra	Satara	Khandala	52	–	0.20	26	3	80	0	0	76	67	5	0	0	324
Jindal South West Steel Ltd	Karnataka	Bellary	Sandur	35	8.0	0.24	30	0	55	–	–	67	23	15	8	0	879
Jindal South West Steel Ltd	Maharashtra	Palghar	Jawhar	5	6.13	0.12	43	3	57	0	0	27	57	0	0	0	95
Rural Electrification Corporation Ltd	Telangana	Mahabubnagar	Wanaparthy	81	7.71	0.12	46	14	83	38	1	81	73	10	0	39	192
Rural Electrification Corporation Ltd	Andhra Pradesh	Anantapur	Penukonda	87	7.93	0.19	69	15	77	29	0	94	77	7	0	44	190
POWERGRID	Andhra Pradesh	Kurnool	Bethamcherla	50	7.48	0.19	15	8	76	80	0	75	35	4	0	12	169
POWERGRID	Karnataka	Bijapur	Basavan Bagewadi	49	8.16	0.27	89	0	71	0	0	94	16	8	0	0	187
SABMiller	Telangana	Medak	Pulkal, Sangareddy	71	7.76	0.29	28	6	55	6	0	66	45	0	0	2	246
Sir Dorabji Tata Trust	Rajasthan	Alwar, Banswara, Bhilwara, Bundi, Dungurpur, Jhalawar, Swai Madhopur, Tonk, Udaipur	Rajgarh, Kushalgarh, Jahajapur, Hindoli, Bichiwara, Jhalarapatal, Khandar, Deoli, Newai, Girwa	38	7.8	0.3	45	15	71	–	–	46	56	–	–	–	422
Sir Ratan Tata Trust	Jharkhand	Gumla, Kharsawan	Raidih, Saraikala	42	5.6	0.15	65	50	77	–	–	71	97	–	–	–	115
Sir Dorabji Tata Trust & Sir Ratan Tata Trust	Madhya Pradesh	Badwani, Dewas, Guna, Indore, Raisen, Rajgarh, Sagar, Sehore, Shajapur, Vidisha, Jhabua, Mandla	Badwani, Devas, Madusudangarh, Samer, Silwani, Rajgarh, JC Nagar, Sehore, Agar, Vidisha, Lateri, Meghnagar, Niwas	22	7.8	0.25	74	1	74	–	–	66	79	–	–	–	341
Sir Ratan Tata Trust	Odisha	Myurbhanj, Kyonjhar	Myurbhanj, Harichandanpur	18	5.5	0.12	73	10	96	–	–	7	99	–	–	–	177

deficiencies of secondary and micronutrients like 35–96% in sulfur (S), 16–99% in boron (B) and 7–94% in zinc (Zn), and 0–80% in calcium (Ca).

Most farmers are not aware of secondary and micronutrient deficiencies and their general practice is to add fertilizers containing only macronutrients NPK in suboptimal or indiscriminate amounts, which creates nutrient imbalances leading to increasing land degradation. Even with regard to macronutrients, the government fertilizer subsidy policy has promoted skewed fertilizer use in the country resulting in more application of N and P fertilizers in the NPK ratio of 8:2.7:1 (Government of India, 2014; Wani *et al.*, 2016). Inadequate availability of the required fertilizers at the stipulated time in rural areas and lack of knowledge is also promoting imbalanced fertilizer use. More importantly, while fertilizer consumption continues to rise substantially, the elasticity of output with respect to fertilizer use, especially N and P, has dropped sharply, i.e. declining fertilizer use efficiency. During the previous decade, while fertilizer consumption grew by 50%, the increase in food grain production was only 11% (Wani *et al.*, 2016). The increase in fertilizer use has increased the cost significantly. The fiscal burden of fertilizer subsidy was ₹60 crore in the years 1976–77, which shot up to over ₹70,000 crore in 2012–13. There are other important costs in the form of long-term soil degradation and stagnation of yields, low C-sequestration and degradation of water resources (in both quantity and quality). Besides, there is build-up of nutrients in pockets which is of concern today.

Along with agricultural fields, horticultural orchards and plantation crops also cover large tracts of land and are bypassed for any systematic soil health mapping and needs-based management. These are potential sites of increasing productivity and incomes, while improving C-footprints. For example, soil health mapping of fruit and plantation crops in Andhra Pradesh showed severely low levels of soil organic C and increasing nutrient deficiencies – 42–90% orchards/plantations in organic C, 3–70% in P, 1–40% in K, 10–89% in Ca, 21–96% in S, 18–80% in Zn, 8–85% in B, 0–45% in magnesium (Mg) and 0–63% in copper (Cu) (Table 3.3).

3.4 Building Soil Health and Ecosystem Services: A Low Hanging Technology

3.4.1 Soil health for food and nutritional security

One of the direct benefits that CSR scaling-up initiatives have demonstrated is improving food security. The strategies to rejuvenate farm soil health have shown significant productivity benefits that varied from 25% to 47% in cereals, 28% to 37% in pulses and 22% to 48% in oilseed crops (Chander *et al.*, 2016; Wani and Chander, 2016; Wani *et al.*, 2017). Even in comparatively drier years, soil health building through application of balanced fertilizers significantly increases grain yield and aboveground dry matter and adds to system resilience (Uppal *et al.*, 2015). Pilot

Table 3.3. Soil fertility status of soils in horticulture plantations across seven districts in Andhra Pradesh, India.

			% deficiency of available nutrients									
Crop	No. of samples	% samples with low soil C levels	P	K	Ca	Mg	S	Zn	B	Fe	Cu	Mn
East Godavari	720	76	63	36	81	9	88	64	71	0	37	2
Guntur	264	42	3	1	10	0	21	18	8	4	0	0
Krishna	2709	68	25	2	80	1	79	59	38	0	33	0
Srikakulam	641	90	41	40	89	45	95	59	85	1	63	1
Visakhapatnam	207	77	49	8	65	5	85	54	68	0	14	0
Vizianagaram	869	89	70	26	71	14	96	80	83	0	18	0
West Godavari	623	77	21	32	79	21	80	41	72	2	42	1
Grand total	6033	74	37	16	76	11	82	59	56	1	33	0

studies also show evidences of relation of soil health with food quality (Sahrawat *et al.*, 2008, 2013; Chander *et al.*, 2013a; Wani and Chander, 2016). Moreover, the outcome of soil degradation in predominant crop–livestock farming system in the drylands is far beyond reducing grain production; it also affects livestock feed quantity and quality (Blümmel *et al.*, 2009; Haileslassie *et al.*, 2011). In view of the increasingly important role of crop residue as feed components, the effects of soil health building through nutrient balancing on feed availability and feed quality are very important and show up in potential milk yield per ha by as high as 40% (Haileslassie *et al.*, 2013). The role of soil health building in enhancing food quantity and quality and helping individuals and communities to build sustainable food security is well demonstrated in Karnataka, India (Wani *et al.*, 2016).

Scaling-up soil health building in degraded drylands is important because out of 1.5 billion ha of cultivated land globally, about 1.1 billion ha (80% of world's physical agricultural area) is rainfed and generates about 60% of the world's staple food (Munir *et al.*, 2010). Evidences in the past few decades indicate that crop productivity growth in irrigated areas has slowed or stagnated and relying on irrigated agriculture for food security is not possible as data on water supply and demand are startling and as much as two-thirds of the world population could be water-stressed by 2025 (Seckler *et al.*, 1999; Richter *et al.*, 2003; Shah *et al.*, 2006). In Indian scenario, in spite of spectacular increase in food grain production from 74 million tons during 1966–67 to 259 million tons during 2011–12, the country still struggles for ensuring food security of its people who have grown from 361 million in 1951 to 1210 million in 2011 and are expected to reach the levels of 1460 million by 2025 and 1700 million by 2050 (Government of India, 2014; FAOSTAT, 2017). Therefore, consistent efforts are needed to increase the current food production levels to more than 300 million tons by 2025 and around 380 million tons by 2050 (Amarasinghe *et al.*, 2007). However, land resources are limited with almost no scope for expanding net sown area which has almost remained stagnant since the Green Revolution at about 141 million ha, but the cropping intensity has increased from about 1.17 in the late 1960s/early 1970s to 1.38 during 2011 (Government of India, 2014). Enhancing productivity is the way forward with limited opportunities in irrigated areas which are already near productivity plateau. The drylands with large yield gaps (Wani *et al.*, 2012b), thus, occupy centre stage and currently cover majority 54% (76 million ha) of cultivable land and in spite of irrigation expansion programmes are projected to still cover 45% (63 million ha) of area by 2050 (Amarasinghe *et al.*, 2007).

3.4.2 Improved nutrient and water use efficiency

Pilot studies (Chander *et al.*, 2014) show that soil health building through balanced fertilization including micro- and secondary nutrient amendments not only increase productivity, but also improve N and most importantly N use efficiency. The results show improvements in uptake and use efficiency of N and thereby reducing pollution through losses in runoff water and as GHG emissions. Moreover, improvements in agricultural productivity, resulting in yield increase and denser foliage will involve a vapour shift from nonproductive evaporation in favour of productive transpiration. Various CSR pilot studies also corroborate the benefits of soil health building in effectively utilizing available water to get higher crop yields (Chander *et al.*, 2013b, 2016).

3.4.3 Soil C sequestration and offsetting GHG emissions

Building soil health and managing C footprint is a great opportunity for CSR consortia to have a win-win proposition. Managing soil organic C is central because it influences numerous soil properties relevant to ecosystem functioning and crop growth. It is essential to improve soil resilience through beneficial impacts on the following processes (Lal, 2011):

- increase in soil aggregation and aggregate stability;
- improvement in total and macro-porosity;
- decrease in loss of soil water through increase in water infiltration rate and reduction in evaporation;

- improvement in plant available water capacity;
- reduction in susceptibility to crusting, compaction and erosion by water and wind, and decrease in non-point source pollution of rivers and lakes;
- increase in soil's cation and anion exchange capacity;
- increase in plant nutrient reserves, both capacity and intensity factors;
- increase in microbial biomass C, along with activity and species diversity of soil biota;
- increase in CH_4 oxidation capacity, and moderation of rates of nitrification and denitrification;
- reduction in leaching losses of soluble plant nutrients;
- increase in soil's buffering capacity, and moderation of elemental balance; and
- improvement in agronomic production, through increase in use efficiency of energy-based inputs (e.g. fertilizers, water and pesticides).

Even small changes in total C content can have disproportionately large impact on key soil physical properties (Powlson *et al.*, 2011). An increase of 1 ton of soil C pool of degraded cropland soils may increase crop yield by 200–400 kg/ha of maize, 20–70 kg/ha of wheat, 20–30 kg/ha of soybean, 5–10 kg/ha of cowpea, 10–50 kg/ha of rice, 50–60 kg/ha of millets and 20–30 kg/ha of beans (Lal, 2011). Thus, an increase in the soil organic C pool within the root zone by 1 ton C per ha per year can enhance food production in developing countries by 30–50 million tons per year including 24–40 million tons per year of cereal and legumes, and 6–10 million tons per year of roots and tubers (Lal *et al.*, 2007).

World soils play an important role in C cycling and represent the largest terrestrial pool of soil C of about 2500 pg/billion ton (1550 pg soil organic C and 950 pg soil inorganic C) compared to about 700 pg in the atmosphere and 600 pg in land biota (Lal and Kimble, 1997; Batjes, 1999; Lal, 2004a,b). Most of the cultivated soils are depleted of soil organic C and far from saturation as is determined by climate, pedological and terrain characteristics (Lal, 2004a,b). The soils of different agroecosystems have lost their original soil organic pool with a global loss of 78±12 billion tons C through historic land misuse and soil degradation (Lal, 2011). Agriculture is important because of not only the potential to reduce its own emissions but also its potentiality to reduce net emissions from other sectors and to enhance the quality of soil, water and other natural resources and resilience-building (Lal, 2011). The global potential of C sequestration in soils of agroecosystems is about 2.1 billion tons C per year and so if the soil organic C pool in world soils can be increased by 10% (+250 billion tons) over the 21st century, it implies a drawdown of about 110 ppm of atmospheric CO_2 (1 billion tons of soil C = 0.47 ppm of atmospheric CO_2).

Pilot studies prove that soil health building through balanced fertilization along with improved crop and water management can sequester 335 kg C per ha per year (Wani *et al.*, 2003). In degraded lands, biofuel plantations of *Jatropha* proved to have potential opportunities to rehabilitate degraded lands through adding to soil around 1450 kg C per ha through leaf fall, pruned twigs, de-oiled cake along with 230 kg C per ha replacement in fossil fuel and 5100 kg C per ha as live plantation (Wani *et al.*, 2012a).

3.5 Framework for Soil Health and Ecosystem Services

3.5.1 Soil health building as an entry point activity

Soil health mapping and building through need-based management addresses the widespread problem the farmers face and hence is one of the best entry point intervention for quick benefits and building rapport with the majority of farmers to initiate a collective action for technological upgradation of dryland agriculture (Wani *et al.*, 2009a; Chander *et al.*, 2016). The main attributes which make it the best entry point activity are: it is knowledge-based and does not involve direct cash payment; it has a high success probability (>80–90%); involves participatory research and development approach; it results in the measurable tangible economic benefits to the farming community with a relatively high benefit–cost ratio; is simple and easy for the participating farmers to undertake; involves participatory evaluation; has a reliable and cost-effective approach to assess the constraints; and most importantly it benefits the majority of farmers in the watershed.

3.5.2 Strengthening analytical framework

In a soil analysis process to start for building soil health, soil sampling is one of the most important and the weakest links. The smallest amount of sample collected must effectively represent the millions of kg soil in the field. Participatory stratified soil sampling method (Sahrawat *et al.*, 2008) takes care of such errors. Under this method, the target region is divided into three topo-sequences. At each topo-sequence location, samples are taken proportionately from small, medium and large farm holdings 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 are chosen carefully to represent different soil colour, texture, cropping systems and agronomic management practices. At ultimate sampling unit in a farmer's field, 8–10 cores of surface (0–0.15 m) soil samples are collected and mixed together to make a composite sample.

Analysis is the next step followed and unless soil samples are thoroughly diagnosed for all essential elements and key parameters, holistic recommendations are unlikely to be developed. A fragmented approach of soil analysis is no longer workable. Precision is another important requirement as small errors in especially micronutrients may result in different interpretation and recommendations. Therefore, establishing state-of-the-art laboratories makes better sense technically as well as operationally as only one such laboratory can effectively cater to the requirements of a district. In current scenario, out of around 1600 laboratories (1500 static, 100 mobile) in the country, only about 150 are equipped to analyse B and about 450 for S and about 600 can analyse diethylene triamine pentaacetic acid (DTPA) extractable micronutrients (Zn, Cu, Fe, Mn). Therefore, streamlining soil-plant-water diagnostic services through upgrading current half-functional laboratories into state-of-the-art laboratories is better technically as well as operationally and one such laboratory per district could be a better proposition to improve operational efficiency and precision, rather than many half or non-functional laboratories (Wani *et al.*, 2016).

The GIS (geographical information system) interpolation of analysis results across CSR and other pilot sites show that individual nutrient deficiencies are scattered differently across regions, and multiple nutrient deficiencies are also observed. In this scenario, current general practice of fertilizer recommendations at state or agroecoregion level does not effectively meet soil requirement and hence more precise recommendations at block/cluster-of-villages/village/farmer level need to be developed and promoted.

The CSR pilot areas are sites of learning of using soil health building as an entry point activity, by using stratified soil sampling and promoting and evaluating block/village level soil test-based recommendations for soil health rejuvenation. The experience of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Telangana in these pilots demonstrates the benefits of these and subsequently, as awareness develops amongst the farmers, and the government is geared up to handle knowledge dissemination especially for smallholders, farmer-based recommendations can be followed.

3.5.3 Regulating soil C pools

It is important to realize that low-input agricultural systems deplete soil organic C and accentuate the risk of greenhouse effects (Lal and Kimble, 1997). Long-term studies at ICRISAT (Wani *et al.*, 2003) showed that improved system comprising landform management (broad-bed and furrow cultivation), soil test-based balanced fertilization and crop management increases not only crop productivity but also soil organic C content. In this historical study, an additional quantity of 7.3 tons C per ha (335 kg C per ha per year) was sequestered in soil under the improved system compared with the traditional system over the 24-year period (Table 3.4). The C inputs were found to increase with continuous cropping, particularly where fertilizers were applied and when legumes were included

Table 3.4. Biological and chemical properties of semi-arid tropical Vertisols after 24 years of cropping under improved and traditional system at ICRISAT, Patancheru, India. From: Wani *et al.* (2003).

		Soil depth (cm)	
Properties	System	0 to 60	60 to 120
Microbial biomass C (kg/ha)	Improved	2676	2137
	Traditional	1462	1088
Organic C (t/ha)	Improved	27.4	19.4
	Traditional	21.4	18.1
Microbial biomass N (kg/ha)	Improved	86.4	39.2
	Traditional	42.1	25.8
Total N (kg/ha)	Improved	2684	1928
	Traditional	2276	1884
Olsen-P (kg/ha)	Improved	6.1	1.6
	Traditional	1.5	1.0

in the system (Paustian *et al.*, 1997; Wani *et al.*, 2003). Leguminous plants are considered to have a competitive advantage under global climate change because of increased rates of symbiotic N fixation in response to increased atmospheric CO_2 (Serraj, 2003; Wani *et al.*, 2003). Soil microbial biomass responds more rapidly than soil organic matter as a whole to changes in management that alter the annual input of organic material into soil C (Powlson and Jenkinson, 1981). Although small in mass, microbial biomass is one of the most labile pools of organic matter and thus serves as an important reservoir of plant nutrients such as N and P (Jenkinson and Ladd, 1981; Marumato *et al.*, 1982). Biomass C, as a proportion of total soil C, serves as a surrogate for soil quality (Jenkinson and Ladd, 1981). In on-station study at ICRISAT (Wani *et al.*, 2003), improved management practices of Vertisols resulted in higher values (10.3 vs 6.4%) of biomass C as a proportion of soil organic C.

In a study on monitoring changes in soil C between 1980 and 2005 (Bhattacharyya *et al.*, 2007), in two important food production zones of India, viz. the Indo-Gangetic Plains (IGP) (Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal) and the black and associated red soils (BSR) (Andhra Pradesh, Madhya Pradesh, Karnataka, Gujarat and Maharashtra), soil organic C stock of both the soils was found to increase due to the turnover of more biomass to the soils (however, the increase was more in the IGP than the BSR). Thus, scaling-up improved management is needed as the soil organic C stocks of Indian soils demonstrate enough potential to sequester organic C (Pal *et al.*, 2015). It is observed that vast areas of land in arid, semi-arid and drier part of sub-humid India are impoverished in soil organic C, but are high in soil inorganic C up to 30 cm depth. These specified areas are the prioritized ones for organic C management in soil. These areas cover 155.8 million ha of which, arid areas cover 4.9, semi-arid 116.4 and dry sub-humid 34.5 million ha. Under different land use systems, soil organic C sequestration within the first 100 cm is observed to be higher in soils under forest, followed by horticultural and agricultural system (Pal *et al.*, 2015).

To maintain soil organic matter status, there is need to add organic materials including manures, and crop residues on a regular basis to compensate the loss of organic matter by various processes. On-farm studies at ICRISAT (Chander *et al.*, 2013a) have shown that the use of manures like vermicompost increased biomass production and apparently recycling and C sequestration, while cutting cost of chemical fertilizers and making it a profitable option for farmers to adopt. Recycling large quantities of C and nutrients contained in agricultural and domestic wastes (~700 million tons organic wastes are generated annually in India) (Bhiday, 1994) are needed to rejuvenate soil health for enhancing productivity (Nagavallemma *et al.*, 2006; Chander *et al.*, 2013a; Wani *et al.*, 2014) (Fig. 3.2). To start with, focus on agricultural regions, producing large quantities of residues which have little alternate uses, could be the best strategy. In this context, the hardy stems of crops like pigeonpea, cotton, maize, pearl millet, sorghum and others are best target biomass for recycling. These five crops are grown in around 37 million ha in India and produce more than 100 million t hardy straw biomass per year which has little economic value or effective alternate use by farmers. This biomass is a potential opportunity to recycle plant nutrients worth more than Rs 3000 crores per year. For effective composting, these hardy residues need to be chopped into small pieces. Pilot studies in Andhra Pradesh have shown that arranging shredder machines on a sharing basis could be a good business

Fig. 3.2. Shredder machine piloted in Kadapa, Andhra Pradesh used to chop hardy biomass for composting.

model for chopping biomass for composting which prove to be economically remunerative from the first year. Alongside, composting technologies need to be scaled-out to farmers. Vermicomposting is a proven technology, but in many case desired success is not achieved due to the need for continuously maintaining moisture and arranging feeding material to earthworms. So, technologies like use of microbial consortium culture for composting needs to be promoted for undertaking it as and when needed and adding convenience to the farmers. Along with mapping for potential recyclable biomass in agriculture and horticulture, regions with current low chemical fertilizer use could also be prioritized and promoted as niche areas for organic farming without compromising with yield and harnessing premium price for the farmers. Also converting biomass into *Biochar*, having highly stable form of C, may be a good option of building soil C for long term (Sohi *et al.*, 2009); however, the long-term effects need to be evaluated.

Conservation agriculture (CA) may be a suitable technique for control of soil and C through erosion, lesser exposure for decomposition along with increased inputs of C as mulch. Some other studies indicate that crop rotations also play an important role in improvement in soil C. However, the results in on-station experiment at ICRISAT showed no significant effect on maize, chickpea and pigeonpea yield with or without residue addition (Jat *et al.*, 2012). Retained residues reduced total seasonal runoff under both the tillage practices (Jat *et al.*, 2015). These results imply that under CA high rainwater filters into the soil to add to the green water. Similarly, peak rate of runoff, which indicates erosive capacity of runoff water is also decreased with residue addition. No significant benefit is observed of retaining residues in improving water use efficiency. The difficulty in sowing through surface retained residues and poor seed to soil contact under residue retained plots apparently led to lower plant stand and crop yield

(Jat *et al.*, 2015). The residue addition, though, tended to improve soil organic C levels.

In context of promoting biofuels for C replacement in fossil fuels, on-farm research results (Wani *et al.*, 2009b, 2012a; Wani and Chander, 2012) show plants like *Jatropha* (a hardy plant) to grow successfully and rejuvenate degraded lands without compromising on the food security in heavily populated countries like India which could help strengthen local livelihoods and income diversification. In wastelands planted with *Jatropha*, around 4000 kg/ha/year organic matter (through leaf fall, pruned twigs and de-oiled cake) added not only 1450 kg C per ha per year, but also 85.5 kg N, 7.67 kg P, 43.9 kg K, 5.20 kg S, 0.11 kg B and 0.12 kg Zn per ha per year plus other essential nutrients (Wani *et al.*, 2012a). Out of the total C accumulated by seeds, 185–230 kg C per ha per year is as biodiesel/oil C and an apparent replacement in the fossil fuel. The live plant (shoot and root) biomass in the fields serves as a sink for C at 5120 kg C per ha (Table 3.5). The soil samples from one on-farm plantation location (Velchal, Rangareddy district, Andhra Pradesh) recorded increased microbial biomass C by 22%, soil respiration by 2.46% and microbial biomass N by 24% as compared to the adjoining grasslands (Wani *et al.*, 2012a).

Management practices to reduce soil C loss by erosion is an important component as ecosystems in the semi-arid tropics are prone to land degradation, which may be aggravated by climate change. Soil erosion by water and loss of soil C and nutrients along with it is a major global environmental problem (Boardman and Favis-Mortlock, 2001). In climate change scenario, the frequency and intensity of extreme rainfall events are expected to increase in some regions, which could lead to increased erosion rates (Michael *et al.*, 2005). In general, a 1% change in precipitation is expected to result on average a 2.4% change in soil loss (Zhang *et al.*, 2005). In context of impending climate change scenario, development of the watershed/catchment is one of the most trusted and ecofriendly approaches to managing natural resources and reducing runoff, soil loss and C therein (Wani *et al.*, 2012b). Desilting water tanks and application of tank sediment to agricultural fields (which are integral part of villages especially in India) is also an economically feasible (benefit–cost ratio of 1.23) option to return organic C and nutrients (Padmaja *et al.*, 2003). The sediment samples in Medak district, Telangana contained 720 mg N, 320 mg P and 10.7 g C per kg of sediment. During 2001, under Government of Andhra Pradesh initiative, namely 'Neeru-Meeru', 246,831 tons of sediment desilted and added to the farms returned 183 tons N, 86 tons P and 2873 tons of organic C.

Table 3.5. Balance sheet of carbon (C) under *Jatropha* plantation as C returned to soil, biodiesel C replacement per year and live plant C. From: Wani *et al.* (2012a).

C through *Jatropha* plantation	Plant part involved	Organic C (kg per ha)
C returned back to soil	Leaf fall	800[a]
	Pruned twigs	150[a]
	De-oiled cake	495[b]
C replacement in fossil fuel	*Jatropha* oil	230[b]
C in live plant	Shoots and roots	5120

[a] Leaf and pruned twigs added C every year.

[b] *Jatropha* oil C (fuel replacement) and de-oiled cake added C from fourth year onwards every year.

3.5.4 GHG emissions and management

Global warming induced climate change caused by CO_2 (and other GHGs) emissions through fossil fuel combustion (IPCC, 2007) is an issue of concern worldwide. The CO_2 concentration has increased markedly in the 21st century at a rate of 2 ppm (parts per million) per year during 2000 onwards. The CO_2 concentration was 280 ppm in the pre-industrial times, and has crossed 400 ppm (Fig. 3.3). Atmospheric CO_2 levels are increasing at a rate of 0.4% per year and are predicted to double by 2100 (Lal, 2005; IPCC, 2007). The Intergovernmental Panel on Climate Change has shown that the earth temperature has increased by 0.74°C between 1906 and 2005 due to the increase in anthropogenic emissions of GHGs (Aggarwal, 2008). Global temperatures are predicted to increase by 1.1 to 6.4°C between 1990 and 2100 depending on CO_2 emission scenarios, with CO_2 atmospheric concentration projected to increase in the range 550 to 850 ppm (Stockle *et al.*, 2011). These

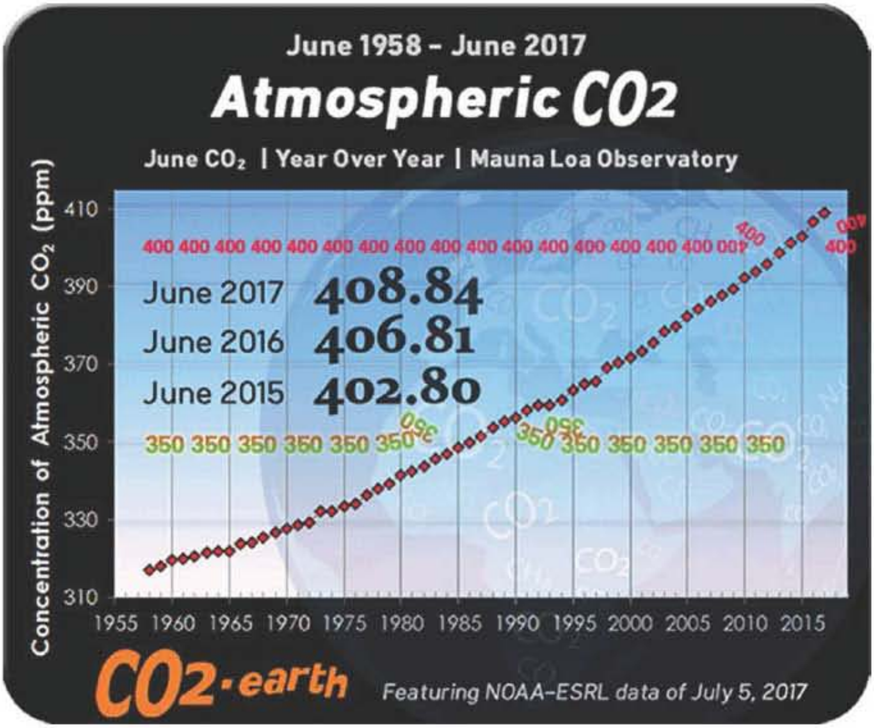

Fig. 3.3. Atmospheric CO_2 levels measured at Mauna Loa Observatory, Hawaii (NOAA-ESRL), 2017. From: Mauna Loa Observatory, 2017.

changes will have a profound impact on the natural resource base that agriculture depends upon. It is likely that climate variability and change will exacerbate food insecurity in areas currently vulnerable to hunger and undernutrition. Climate change is now being viewed as the single gravest threat to food security worldwide. There is a strong link between food insecurity, soil degradation and climate change, yet the twin crisis of climate change and food insecurity may be significantly addressed through restoration of soil organic C.

Current global GHG emissions (in terms of CO_2 equivalents (CO_2e)) are about 49 Gt CO_2e/year, 74% of which are CO_2, 16% of CH_4 and 10% of N_2O. Agriculture accounts for around 13.5% of the total global anthropogenic GHG emissions, contributing about 25%, 50% and 70 % of CO_2, CH_4 and N_2O respectively (Montzka *et al.*, 2011). As food crops production needs to be increased at a rate not less than 1.3% annually (Cassman *et al.*, 2003), GHG emissions are also expected to increase, if adequate measures to minimize the emissions are not taken. The GHG emissions from agriculture in the form of N_2O emit from fertilizer management practices. Agricultural activities add into the atmosphere about 4.2 to 7 Tg N annually in the form of N_2O (Del Grosso *et al.*, 2008). Nitrous oxide has high global warming potential of 298-fold. Increased soil temperatures coupled with high moisture conditions during cooler months will increase N_2O production in soil. Elevation in CO_2 concentrations is also projected to increase N_2O emissions from upland agricultural soils (Van Groeningen *et al.*, 2011). Regarding CO_2, soil respiration is an important source, but the majority of the farm operations and inputs, such as fertilizers, pesticides and energy, also have embodied CO_2 content. Rice cultivation is a major source of CH_4, currently accounting for 10–15% of all global GHG emissions from agriculture and 10–12% of the world's total anthropogenic CH_4 emissions (IPCC, 2014).

In agriculture, increasing soil C represents the greatest mitigation potential. About 50–66%

of the cumulative historic C loss from soil can be recovered through proper management (Lal, 2004a). Increasing soil organic C content in soil may lock the C out of the atmosphere for centuries by C sequestration. Managing agricultural land to increase soil C has a mitigation potential of 5340 million tons CO_2e/year. Much of this mitigation effort has an economic cost and this technical potential equates to an economic potential of 4300 million tons CO_2e/year at C price of US$100 per ton CO_2e (Murphy-Bokern and Kleemann, 2014). About 89% of this mitigation potential lies in soil C sequestration, and the remaining 11% arises from reducing emissions of methane (9%) and N_2O (2%). Identification and adoption of better management practices as discussed in the chapter can be used as a GHG offsetting tool. In rice cultivation, zero tillage reduces CH_4 and N_2O emissions, but increases CO_2 emissions (Pandey *et al.*, 2012; Ladha *et al.*, 2016). Tillage, moisture and aeration, and C supply affect CH_4 emissions (Wassmann *et al.*, 2000; Venterea *et al.*, 2005). The management practices such as alternate wetting and drying, alternative rice land preparation and crop establishment were reported to cause lower methane emissions from rice paddies (Adhya *et al.*, 2014; Linquist *et al.*, 2015; Ladha *et al.*, 2016). In areas where cropping system diversification is feasible, there is also scope for mitigation of GHG emissions in the rice-based ecosystem, while enhancing crop production (Ladha *et al.*, 2016). Improved agronomic practices, increased N use efficiency, use of diversified cropping systems, adoption of crop cultivars with high harvest index, and the use of soil bioresources such as P-solubilizers and arbuscular mycorrhizal fungi in crop production were reported to lower the average C footprint in semi-arid areas (Gan *et al.*, 2011). The over-exploitation of groundwater by agriculture for irrigation during recent years has lowered aquifer levels in many Asian countries, and pumping water from lower strata in the future would result in a greater use of energy, which is mostly generated by coal combustion, and would therefore result in increased emissions of GHG (Zhang *et al.*, 2013). Improved water use efficiency is likely to become a critical criterion for many grain-producing areas in South Asia, in part due to necessary adaptation to the anticipated adverse effects from climate change (Elliott *et al.*, 2014). Land use change and emission reduction in agriculture will be key elements in achieving an 80% reduction in GHG emissions by 2050 (Rockström *et al.*, 2013).

The industry, with its high level of emissions, waste generation and fossil fuel consumption, is the major contributor to GHG emissions and climate change. However, industries in India are determined to become responsible corporations by undertaking CSR programmes. Data of the Ministry of Corporate Affairs on CSR expenditure of Indian companies in 2014–15 showed that 14% (₹1,213 crore) of total CSR expenses in India was made on activities focusing on conserving the environment. Carbon Disclosure Project survey conducted in UK by Doda *et al.* (2016) revealed little evidence that commonly adopted management practices by industry are reducing emissions. However, Murphy-Bokern and Kleemann (2014) felt that considering the commercial constraints and the obligations of firms to shareholders, CSR is contributing to climate protection. Corporates need to invest more in agricultural research and extension and should play a key role in enabling farmers to produce more food with minimal GHG emissions.

3.5.5 Scaling-out soil health management

Bhoochetana scaling-up initiative, with the support of Government of Karnataka and ICRISAT-led consortium as a technical partner, is an exemplary initiative of rejuvenating degraded farm lands and C-building which have shown significant productivity benefits. With this initiative in Karnataka state during 2009 to 2013, more than 5 million farmers benefited and net economic benefits through increased production were estimated at ~US$353 million (₹1963 crore) (Wani *et al.*, 2017).

Taking the lead from *Bhoochetana*, the government-supported Rythu Kosam initiative in Andhra Pradesh is unique in targeting system productivity through embracing allied sectors along with focus on core agricultural crops (i.e. Primary Sector). The Department of Agriculture, Government of Andhra Pradesh along with ICRISAT as a technical partner have used scaling-out soil health building to harness benefits due to these interventions having high levels of success in more than 2 million ha during 2015 and 2016, and pilot-tested innovative C-building technologies using microbial consortia cultures. Soil health building initiatives have monetary benefits through higher productivity in agricultural and horticultural crops to the tune of around ₹1100 crore.

Lessons learnt in such initiatives in Karnataka and Andhra Pradesh states in India indicated that improving food security and livelihoods of people need not wait for any new major scientific breakthrough, but a political will, collective action and innovations in technologies to reach farmers' doorsteps and soil health building and improving C footprints is the most effective entry point activity to harness benefits.

3.5.6 Innovative extension and information and communication technology in soil health management

Innovative extension ways for information dissemination have been explored during watershed projects and other productivity improvement programmes to improve the awareness and adoption rate among the farmers. In the context of soil health management, the key information dissemination tools were soil health cards, wall writings and android-based mobile App. Soil health cards are customized information cards of soil fertility status and crop-wise fertilizer recommendation. This is one of the entry point activities, which built good relationship with the community. The soil health card has information about the farmer, location information of the farm, status of major and micronutrients, and crop-wise fertilizer recommendation for the major crops based on fertility status. The soil health card programme is also widely adopted by Government of India for doubling the farmers' income.

Information related to soil fertility status has been also disseminated among the farmers through writing the information on the walls of common infrastructure in villages. This tool provides wider dissemination channel as all people from the village get access to this information. This tool has been also used in a watershed project for disseminating weather information and project details. Information written on the wall will be available for all the farmers from villages. However, this information is not customized like the crops or landholding. Soil health cards may provide customized fertilizer management solution, but that information is too static in nature. Thus, a dynamic information dissemination and monitoring tool is required to strengthen the local extension agent by providing a channel for information flow and to monitor the real time agriculture status on ground. In this context, the digital technologies with three important tools were piloted in *Bhoochetana* programme: *Krishi Gyan Sagar*, *Krishi Vani* and farmer-to-farmer video dissemination (Wani *et al.*, 2017).

A mobile App is another potential opportunity in soil health management and key features of this are the soil fertility maps and soil test-based fertilizer management (Fig. 3.4). Geospatial digital maps were prepared based on the results from state-wide soil samples. The same soil analysis data was adopted in mobile app in two forms: (i) district level soil fertility maps including status of organic C, P, K, S, B and Zn are embedded in the app; and (ii) site-specific fertilizer recommendation for the major crops. Thus, with the power of a geospatial database of soil fertility, this application provides dynamic customization that is not possible with soil health cards or information written on walls.

3.6 Summary and Key Findings

- Rejuvenating soil health is needed for food and nutritional security of the rising population, while contributing to improving C footprints through C sequestration and minimizing GHGs.
- A holistic soil health mapping and needs-based management that encompasses stratified sampling, quality analysis and timely availability of required inputs along with desired policy support are needed.
- Desired policies to promote quality organic manures by recycling organic wastes generated both in urban and rural areas along with biofertilizers are desired.
- For sustainability, land use planning based on land and agroecological capability is needed through policy.
- Pilot sites need to be established as exemplary sites for training as well as developmental purposes.

Fig. 3.4. District-wise soil fertility maps in *Krishi Gyan Sagar* App.

- There is an urgent need to reform the knowledge delivery systems by using innovative partnerships, tools, approaches and methods. Information and communication technology-based knowledge dissemination, etc. need to be developed.
- To address multifarious issues in soil health building and improving C footprints, a range of actors need to act together in a consortium model to harness their strengths and synergies with the local community as the primary implementing unit.
- Public–private partnerships are required as the governance strategy to minimize the transaction costs and coordinating and enforcing relations between the partners engaged in production of goods and services.

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