1 Soil Amendments for Sustainable Intensification

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1.1 INTRODUCTION: SOIL HEALTH KEY FOR SUSTAINABLE AGRICULTURE AND ECO-SERVICES

Maintaining proper soil health is one essential element of sustainable agriculture and safeguarding ecosystem services. Beyond rendering provisioning services like food, fiber and fuel supply, soils play a critical role in services like climate regulation, water quality and supply regulation through soil functions of regulation of greenhouse gas (GHGs) emissions, filtration/buffering of substances in water, water infiltration and water flow in soil, etc. (FAO and ITPS 2015). Supporting cultural services and soil functions like nutrient cycling, soil formation, medium for seed/root growth and natural and cultural landscape diversity also depends on the state of soil health.

The swiftly rising population, however, has put pressures on soil resources globally and in the country and altered equilibriums for the various soil functions leading to the soil degradation. The world population of 7.2 billion in mid-2013 is projected to increase to about 8.2 billion by 2025, 9.7 billion by 2050 and 10.9 billion by 2100 (UN 2016). Sustainable food security, thus, is the biggest challenge of the 21st century. In India as well, in spite of good progress in food-grain production from 74 Mt during 1966–1967 to 259 Mt during 2011–2012, the challenge of ensuring food security still persists as the population has grown tremendously from 361 million in 1951 to 1.21 billion in 2011 and is expected to reach the levels of 1.4 billion by 2025 and 1.69 billion by 2050 (Government of India 2016; FAOSTAT 2013). Therefore, consistent efforts are needed to increase the current food production levels to more than 300 Mt by 2025 and around 380 Mt by 2050 (Amarasinghe et al. 2007).

Carbon (C) storage is an important ecosystem function of soils that has gained increasing attention in recent years due to its direct relation to soil health and mitigation potential of GHGs. There are major opportunities for mitigation of CO_2 and other greenhouse gas 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 fertilizer related pollution is an issue of concern worldwide. Nitrogen fertilizer inputs in excess of crop requirements are linked to the enhanced release of the N_2O, a GHG 300 times potent than CO_2, and agricultural soils are the dominant source, contributing over 80% of global anthropogenic N_2O emissions during the 1990s.

The impact of soil 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 found to equal about US$300 billion (Nkonya et al. 2016). 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 soil degradation trends makes economic sense and need-based selection and use of soil amendments make critical components of the process.

1.2 WIDESPREAD SOIL DEGRADATION: THREAT TO SUSTAINABILITY

Soil fertility decline is a major hindrance in enhancing food production and realizing productivity potential. Out of 1.5 billion hectares of cropland globally, nearly 38% is degraded (Scherr and Yadav 1996). Chemical degradation such as nutrient loss and salinization, a result of cropping practices, accounts for more than 40% of cropland degradation. Land in India suffers from varying degrees and types of degradation stemming mainly from inappropriate management practices. And the increased rate of soil degradation is contributing towards a decline in agricultural productivity leading to food insecurity.

Since soil resources are finite, requisite measures are required to rejuvenate degraded and wastelands, so that areas going out of cultivation due to social and economic reasons are replenished by reclaiming these lands and by arresting further loss of production potential.

1.2.1 Low Soil Organic C levels

A fallout of the fertilizer subsidy is that chemical fertilizers are cheaper than organic fertilizers and so, farmers have moved away from using organic manure, which is very critical for preserving good soil health. Little addition of organics coupled with mismanagement has led to depletion of soil organic carbon (C), resulting in its low levels, which is one of the major factors in declining soil productivity. Soil analysis in crop fields across pilot mandals/blocks in Andhra Pradesh under the primary sector mission for prosperous and climate smart agriculture during 2015 shows most fields with low soil organic C levels (Table 1.1). The percentage of fields with low C levels across the districts varied between 34 and 89%, and ten out of 13 districts in Andhra Pradesh were detected with most fields having low soil organic C. Earlier studies (Sahrawat et al. 2011) have also showed similar low levels of soil C in farmers' fields across districts in Karnataka (31 to 81% of fields), Madhya Pradesh (0 to 53% of fields) and Rajasthan (1 to 84% of fields).

1.2.2 Multiple Plant Nutrient Deficiencies

Nutrient mining in the post green-revolution era coupled with the imbalanced use of fertilizers has created multiple nutrient deficiencies, which threaten sustainability. An imbalanced use of fertilizers arises from the following causes: (1) The fertilizer subsidy of the government skewed the fertilizer consumption pattern in the country. This has resulted in more application of N and P

TABLE 1.1
Soil Fertility Degradation in Farmers' Crop Fields Across Pilots in Andhra Pradesh, 2015

District	Pilot Mandal	No of Samples	pH	EC	% Fields with Low Soil Org C (Mean Content % in Soil)*	% Deficiency of Available Nutrients (Mean Content mg kg^{-1} in Soil)[1]									
						P	K	Ca	Mg	S	Zn	B	Fe	Cu	Mn
Guntur	Kollur, Sattenapalli	368	8.09	0.74	43 (0.54)	5 (22.5)	0 (247)	0 (6213)	0 (1024)	3 (63.7)	37 (1.36)	1 (1.49)	3 (10.6)	0 (3.24)	0 (10.4)
Prakasam	Kanigiri, Konakana Mitta, Ongole	485	7.69	0.33	**76** (0.37)	22 (12.4)	5 (201)	39 (1852)	6 (414)	**67** (18.9)	**84** (0.53)	40 (1.20)	5 (10.8)	12 (1.19)	2 (11.7)
Nellore	Indukurpeta, Podalakuru, TP Gudur	435	7.94	0.62	39 (0.60)	26 (13.0)	2 (190)	4 (3502)	0 (770)	31 (93.1)	34 (1.94)	6 (1.54)	3 (39.9)	1 (3.05)	3 (11.8)
Krishna	G Konduru, Ghantasala	270	7.87	0.88	34 (0.60)	3 (21.0)	0 (212)	1 (5140)	0 (1433)	7 (105)	37 (1.15)	1 (1.76)	2 (35.1)	0 (7.63)	0 (22.2)
West Godavari	Akividu, Kamavarau Kota	333	7.08	1.19	**51** (0.52)	10 (28.6)	6 (157)	38 (1384)	13 (507)	33 (194)	35 (1.48)	26 (1.99)	0 (67.0)	2 (7.22)	0 (18.1)
East Godavari	Gangavaram, Yeleswaram	368	6.82	0.2	**57** (0.49)	38 (14.8)	4 (150)	44 (1388)	2 (462)	**68** (14.2)	**52** (1.19)	**53** (0.80)	0 (34.0)	1 (2.16)	0 (30.8)
Anantapur	Penukonda, Raptadu, Kothhachervu	315	7.77	0.21	**83** (0.33)	32 (10.1)	9 (101)	31 (1684)	2 (258)	**79** (11.6)	**87** (0.55)	**61** (0.91)	8 (6.33)	21 (0.86)	0 (8.83)
Chittoor	Santipuram, V Kota	495	7.35	0.27	**55** (0.51)	17 (30.6)	22 (104)	27 (1485)	0 (324)	**51** (25.5)	23 (1.90)	**60** (0.54)	1 (12.5)	3 (1.34)	1 (11.4)
Kadapa	Porumamilla, B Mattam, Veeraballe, Sambepalle	439	7.98	0.61	**65** (0.42)	19 (15.2)	5 (150)	29 (1755)	0 (399)	47 (28.2)	**64** (0.77)	30 (1.36)	4 (13.1)	7 (1.41)	0 (13.3)
Kurnool	Banaganpalli, Devanakonda	443	8.09	0.5	**89** (0.34)	29 (13.1)	2 (148)	26 (4192)	1 (614)	**56** (37.3)	**81** (0.58)	32 (1.22)	2 (8.53)	10 (1.04)	0 (10.9)
Vizianagaram	Parvathipuram, Pusapatirega	499	6.76	0.29	**57** (0.48)	35 (11.6)	12 (129)	46 (1221)	2 (300)	**50** (16.3)	**58** (0.88)	41 (0.96)	0 (46.1)	2 (2.19)	0 (33.4)
Srikakulam	Polaki, Ranasthalam, Seethampeta	447	6.97	0.4	**61** (0.46)	27 (14.3)	13 (151)	**58** (1051)	2 (359)	46 (30.9)	38 (1.24)	31 (0.97)	0 (54.5)	3 (2.29)	0 (27.7)
Visakhapatnam	Butchayyapeta, Chintapalle, Padmanabham	422	7.08	0.16	44 (0.6)	32 (14.4)	3 (152)	36 (1377)	0 (362)	**80** (8.68)	49 (1.05)	31 (0.90)	0 (34.0)	1 (1.96)	0 (35.9)
Andhra Pradesh		5319	7.48	0.47	**58** (0.48)	**23** (16.9)	**6** (159)	**29** (2377)	**3** (526)	**47** (45.6)	**52** (1.13)	**32** (1.17)	**2** (28.2)	**5** (2.51)	**0.5** (19.1)

[1] Figures in the parentheses indicate the mean contents in soil.

containing fertilizers, which is currently in the NPK ratio of 8:2.7:1 instead of 4:2:1; (2) Inadequate availability of the required fertilizers at the stipulated time in rural areas; (3) Lack of knowledge among farmers as to what nutrients are required by the crops and what is missing in their land. For inputs such as improved cultivars, seeds, pesticides, etc., private companies and their dealer networks provide information to the farmers. However, it is limited, or in some cases, no such practice exists for balanced fertilizers. Recently, based on the development research undertaken by the research institutions like ICRISAT and ICAR, now the government has undertaken an awareness campaign for balanced nutrient management and soil analysis. The public infrastructure for soil analysis is poorly developed, and farmers rarely get information in time. Recent diagnostic results in Andhra Pradesh under the primary sector mission (Table 1.1) showed low soil organic C, which also indicates nitrogen (N) deficiency. Phosphorus (P) is the second most studied nutrient in fertilizer application by the farmers, and its deficiency across the districts ranged between 3 and 38%. With regard to potassium (K), soils in Andhra Pradesh and India, in general, are adequate. However, there are emerging widespread deficiencies of secondary and micro nutrients like sulphur (S), zinc (Zn) and boron (B). Secondary nutrient S deficiencies across the districts in Andhra Pradesh ranged between 3 and 80%. Among micronutrients, Zn deficiencies ranged between 23 and 87%; while B deficiencies ranged between 1 and 61%. Earlier studies (Sahrawat et al. 2011) have indicated similar macro, micro nutrient deficiencies in other states like Karnataka (16 to 80% for P, 64 to 94% for S, 32 to 90% for Zn, 36 to 91% for B), Madhya Pradesh (25 to 96% for P, 9 to 100% for S, 5 to 97% for Zn, 17 to 100% for B) and Rajasthan (10 to 73% for P, 48 to 86% for S, 0 to 83% for Zn, 25 to 100% for B).

1.3 CHALLENGES OF DIAGNOSIS: KEY IN DECIDING RIGHT AMENDMENTS

Precise diagnosis of soil health is the foremost challenge to choosing appropriate amendments. In the process, soil sampling is one of the most important and the weakest link. The smallest amount of sample collected must effectively represent the millions of kg soil in the field. Sampling issues can be taken care of through the participatory stratified soil sampling method (Sahrawat et al. 2008) wherein the target region is divided into three topo-sequences and samples are taken proportionately from small, medium and large farm-holding sizes to address the variations that may arise due to different management because of the different economic status in each farm size class. Within each farm size class in a topo-sequence, the samples are chosen carefully to represent all possible soil fertility variations as judged from soil color, texture, cropping system and agronomic management. At the sampling unit in a farmer's field, eight to ten cores of surface (0–0.15 m) soil samples are collected and mixed together to make a composite sample.

Sample chemical analysis is the next important step. A fragmented approach to soil analysis has restricted analysis to only macronutrients. Unless samples are thoroughly diagnosed for all key parameters with required precision, holistic recommendations are unlikely to come out. For example, currently, out of more than 1,600 static and mobile laboratories in India, only around 150 can diagnose for available B, while 450 can do so for available S. Therefore, establishing state of the art laboratories makes better sense 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.

GIS interpolation of analysis results shows that various soil health parameters vary differently in different regions and hence more specific recommendations for the amendments at block/cluster-of-villages/village/farmer level need to be developed and promoted, while taking into account the practical issues as well. There is an urgent need to have state of the art laboratories spread across the country which are accredited and follow the common methods using internal as well as external standards and more importantly put all the data in public domain for use by the policy makers, researchers and farmers as needed (Wani et al. 2016b).

1.4 AMENDMENTS FOR BALANCING SOIL NUTRIENT STOCKS

Taking into account the widespread mining of secondary and micro nutrients like sulphur, zinc and boron, along with primary nutrients, their amendments into the soil assume the most importance for sustainable productivity improvements to meet the challenges of food security in the country. Tracking and including amendments for other emerging deficiencies of secondary and micro nutrients is also critical.

1.4.1 Food Production and Economic Benefits

Under exemplar 'Bhoochetana' initiative in Karnataka, the soil test-based micro and secondary nutrient amendments recorded 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). One rupee spent on these nutrient amendments brought returns of value Rs 3 to Rs 15. With this initiative in Karnataka state during 2009 to 2013, more than 5 million farmers are benefitted and net economic benefits through increased production were estimated at ~US$353 million (Rs 1963 crores) (Wani et al. 2017). Various pilot studies have also shown similar productivity and economic benefit with need-based amendments for micro and secondary nutrients (Wani et al. 2016a, 2015; Chander et al. 2014a, b, 2013a, b, 2012). Even in comparatively drier years, the application of balanced nutrients through including micro and secondary nutrients significantly increases grain yield and above ground dry matter, which provides resilience against drought and food security (Uppal et al. 2015). So, it is quite evident that imbalance in fertilizer use substantially increases the cost of cultivation and also lowers its efficiency.

Good soil health is required to ensure the quality of food, and for food and nutritional security. There is evidence of relation of soil quality and balanced fertilization with food quality. Along with higher food production with balanced fertilization, the food nutritional quality including micronutrients tends to improve (Sahrawat et al. 2008, 2013; Chander et al. 2013a; Wani and Chander, 2016). To address malnutrition in India, it is more economical and efficient to address food quality issues through soil health and diet diversification rather than through nutritional amendments externally. For example, pearl millet has large variability for iron and zinc, i.e. 300–600% more than that of rice and wheat, and is a major target crop for iron biofortification (Wani and Govindraj, 2017). 'Dhanshakti' in pearl millet marks the first high-iron biofortified cultivar of any crop variety officially released and already adopted by farmers in India. Studies indicate the amounts of total iron and zinc absorbed from biofortified pearl millet variety were higher than those from the non-biofortified variety. Thus, a holistic approach starting with identifying the soil nutrient deficiencies, meeting the crop demands through balanced soil nutrient management and using biofortified cultivars can have increased micronutrient uptake capacity as well as the capacity to have nutrient dense grains and fodder by increased nutrient-use efficiency and would significantly contribute to improved nutrition by increasing the daily micronutrient intakes as evidenced by bioavailability studies in millets (Wani and Govindraj, 2017).

The implication of such nutrient deficiencies is most often perceived in their impacts on reduced grain production and quality, but the outcome of soil nutrient depletion in crop-livestock faming system in the drylands is far beyond. It affects livestock feed quantity and quality (Haileslassie et al. 2011, 2013; Blümmel et al. 2009a, b). Crop residues are important feed components in the crop-livestock systems, and the effects of improved nutrients input on feed availability and feed quality are very important. Improved fertilizer inputs affect crop residue yield and the quality. It increases metabolizable energy (ME) productivity (ME ha^{-1}) and thereof the potential milk yield ha^{-1} by as high as 40% (Haileslassie et al. 2013). Thus, adding deficient micro and secondary nutrient inputs on crop land positively impacts productivity of the crop production and livestock compartment of mixed crop-livestock farming system and quality of the food and diversity of diets.

A great learning of the scaling-up initiative in Karnataka, India is that ensuring food and nutritional security need not wait for any new major scientific breakthrough, but a political will, collective action and innovations in a system to take simple technologies to farmers' doorsteps (ICRISAT, 2016). Soil health mapping to diagnose critical nutrients, and institutional arrangements for awareness and capacity building along with access to critical micro and secondary nutrient amendments, brought significant growth in agriculture and rural economy. It promoted inclusive growth through improved incomes and livelihoods of the poor, and is therefore an effective strategy in the fight against hunger and malnutrition.

1.4.2 Improvement in Nutrients Use Efficiency

Subsidies and increased awareness about fertilizers have led to an increase in fertilizer consumption from 11 kg ha^{-1} in 1970 to 89 kg ha^{-1} in 2004, and to 128.3 kg ha^{-1} in 2010–2011 (Wani et al. 2016b). More importantly, while fertilizer consumption continues to rise substantially, the elasticity of output with respect to fertilizer use has dropped sharply. The average crop response was 25 kg of grain per kg of fertilizer during the 1960s, which fell to only 8 kg of grain per kg of fertilizer by the late 1990s (Kapur, 2011). During the previous decade, while fertilizer consumption grew by 50%, the increase in food grains production was only 11%. The increase in fertilizer use has come at significant cost. The fiscal burden of fertilizer subsidy was ₹ 60 crore in the years 1976–1977, which shot up to over ₹ 70,000 crore in 2012–2013. In this context, it is high time to improve fertilizer use efficiencies and increase farm profits.

Studies (Chander et al. 2014a; Figure 1.1) show that need-based micro and secondary nutrient amendments not only bring in productivity benefit, but also improve nutrient and most importantly nitrogen use efficiency. The results showed that the addition of deficient S, B and Zn bring in improvements in uptake efficiency, utilization efficiency, use efficiency and harvest index in N and P. The yearly doses (half of recommended dose of 30 kg S, 10 kg Zn and 0.5 kg B, the alternate year) prove more efficient from a fertilizer efficiency as well as productivity point of view.

1.4.3 Improvement in Water Use Efficiency

Moreover, improvements in agricultural productivity, resulting in yield increase and denser foliage, will involve a vapor shift from nonproductive evaporation in favor of productive transpiration (Rockström et al. 2007). Various on-farm studies also corroborate the benefits of application of

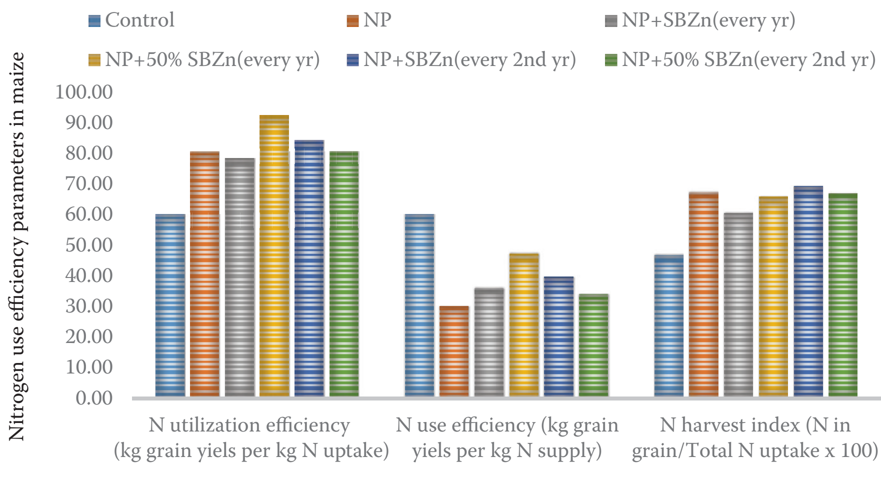

FIGURE 1.1 Effects of balanced nutrient management strategies on nitrogen use efficiency indices in maize at ICRISAT, Patancheru, India, rainy season 2010.

TABLE 1.2
Effects of Balanced Nutrient Management Strategies on Rainwater Use Efficiency in Maize and Soybean at ICRISAT, Patancheru, Rainy Season, 2010

	Rainwater Use Efficiency (kg mm^{-1} ha^{-1})	
Treatment	**Maize**	**Soybean**
Control	0.88	2.08
NP	3.50*	2.15
NP+SBZn (every yr)	4.02*	2.48
NP+50%SBZn (every yr)	5.33*	2.75*
NP+SBZn (every 2nd yr)	4.62*	2.67*
NP+50%SBZn (every 2nd yr)	3.97*	2.55

* Significant at $p \leq 0.05$.

deficient secondary and micronutrients in effectively utilizing available water to get higher crop yields (Chander et al. 2016, 2013b; Table 1.2). Keeping in mind the projected water scarcity, this favorable vapor shift leading into higher water use efficiency is desirable in modern agriculture. In rainfed agriculture, poor soil condition does not enable plants to effectively use the green water (water held in soil matrix) which is an issue of concern resulting in low use efficiency of rainwater. The contribution of green water in generating global food production is very high, as nearly 85% of total consumptive fresh water use in crop land and 98% in grass land (Rost et al. 2008; Hoff et al. 2010). So, this vapor shift enhancing rainwater use efficiency through nutrient amendments is most important in sustainability of production systems.

1.4.4 Soil Fertility Built-Up and C-Sequestration

Soil test-based micro and macro nutrient amendments are intended to rejuvenate soil health through balancing plant nutrients, while exerting productivity benefit. Various on-farm studies show improved soil health in terms of soil organic C and available nutrients like P, S, B and Zn under the balanced nutrition (Table 1.3). Better root growth and more shoot biomass addition under balanced nutrient management apparently accounts for higher soil organic C. Moreover, addition of deficient micro and secondary nutrients in balanced nutrition plots are expected to improve their contents. With improved soil health, residual benefits are also documented in such studies (Chander et al. 2014b, 2013a) indicating resilience-building of production system.

TABLE 1.3
Postharvest Soil Fertility Status in Rainy Season Groundnut in Farmers' Fields in Nalgonda, 2010

Available Nutrients and Soil Organic Carbon	Farmers' Practice (N+P+K)	Balanced Nutrition (FP+S+B+Zn)
Soil organic carbon (%)	0.27	0.29
Phosphorus (mg kg^{-1})	1.42	2.97
Potassium (mg kg^{-1})	57.0	60.5
Sulphur (mg kg^{-1})	3.20	3.77
Boron (mg kg^{-1})	0.18	0.24
Zinc (mg kg^{-1})	0.69	1.31

Results of a long-term experiment at ICRISAT headquarter showed that soil test-based balanced fertilization along with improved crop varieties and landform management in Vertisols can sequester 335 kg C ha^{-1} yr^{-1} (Wani et al. 2003). It was found that C inputs increased with continuous cropping, particularly where soil test-based fertilizers were applied and when legumes were included in the system. Results showed that soil microbial biomass C responds more rapidly to the changes in management than soil organic C as such, and it serves as a surrogate for soil quality. Improved management of soils also resulted in higher (10.3 vs. 6.4%) biomass C as a proportion of soil organic C up to 120 cm soil depth.

In a study on monitoring changes in soil carbon between 1980 and 2005 (Bhattacharya et al. 2005), 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 (BSR; Andhra Pradesh, Madhya Pradesh, Karnataka, Gujarat and Maharashtra) soils, soil organic C stock of both the soils was found to increase during 1980 to 2005. However, the increase was more in the IGP than the BSR. This is due to the turnover of more biomass to the soils (both as above-ground and below-ground biomass) as IGP contributed largely to high levels of crop production compared to the BSR soils. During the post-green revolution era, the cropping intensity in the IGP increased from 137% to 158%, while the BSR remained less intensively cultivated, with an increase in cropping intensity from 111% to 123%. Adoption of the management intervention (that included balanced fertilization) recommended by the National Agricultural Research System for agricultural land use, during the post-green revolution, helped maintain the health of soils in the IGP and BSR areas, without causing a decline in soil organic C since 1980.

Scaling-up improved management is the need of the day as the SOC stocks of Indian soils demonstrate enough potential to sequester organic C (Pal et al. 2015). It is observed that vast areas of lands in arid, semi-arid and drier parts 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 m ha, of which arid areas cover 4.9, semi-arid 116.4 and dry sub-humid 34.5 m 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).

1.5 ORGANIC AMENDMENTS FOR REGULATING SOIL ORGANIC C POOLS

Soil organic matter has long been suggested as the single most important indicator of soil productivity. Even small changes in total C content can have a disproportionately large impact on key soil physical properties (Powlson et al. 2011). An increase of one ton of soil carbon pool of degraded cropland soils may increase crop yield by 5 to 400 kg ha^{-1} (Lal 2011). Low soil C levels (Table 1.1a–d) poses challenges for sustainability and external amendments for improving and maintaining soil C are needed. However, due to cheaper chemical fertilizers, farmers have moved away from using organic manure (ICRISAT 2016). Recycling large quantities of carbon (C) and nutrients contained in agricultural and domestic wastes (~700 million t organic wastes are generated annually in India) (Bhiday 1994) are needed to rejuvenate soil health for enhancing productivity (Chander et al. 2013a; Wani et al. 2014; Nagavallemma et al. 2004).

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1.5.1 Composts

Vermicomposting is a simple process of composting with the help of earthworms to produce a better enriched end product. It is one of the easiest methods to recycle wastes to produce quality compost tailored to individual farm requirements (Wani et al. 2014). Vermicompost, however, is in general richer in nutrients than other compost due to better decomposition of it. Earthworms consume various organic wastes and reduce the volume by 40–60%. The moisture content of castings ranges between 32 and 66%, and the pH is around 7.0. A mature vermicompost contains 9.8 to 13.4%

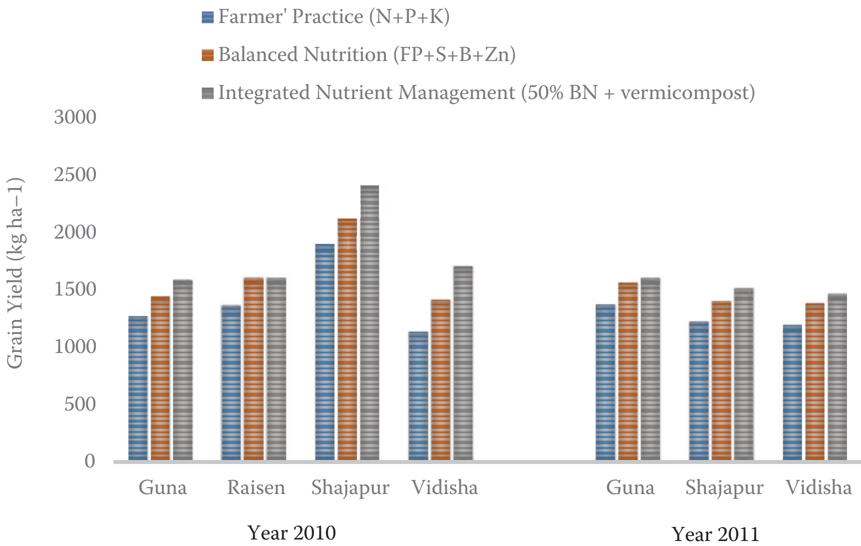

FIGURE 1.2 Effects of nutrient managements on soybean (*Glycine max*) grain yield under rain fed conditions in Madhya Pradesh, India.

organic carbon, 0.51 to 1.61% nitrogen, 0.19 to 1.20% phosphorus and 0.15 to 0.73% potassium, and other plant nutrients like sulphur, calcium, magnesium, boron, zinc, copper, iron, manganese, molybdenum chlorine and nickel (Nagavallemma et al. 2004).

Pilot studies have shown the benefits of the integrated approach of using composts along with chemical fertilizers in higher yields even over the balanced nutrition solely through chemical fertilizers, while saving chemical fertilizers up to 25–50% (Figure 1.2; Chander et al. 2013a). In the pilot studies with soybean crop in Madhya Pradesh, the rainwater use efficiency (RWUE) was 0.97 to 4.38 kg mm^{-1} ha^{-1} under integrated use of chemical fertilizers and composts, followed by 0.95 to 3.85 kg mm^{-1} ha^{-1} with balanced fertilizers as compared with the FP having lowest RWUE of 0.83 to 3.45 kg mm^{-1} ha^{-1}. The impacts of organic composts on improving water productivity are implied through positively affecting the physical properties of soil that increase the extent to which it can absorb rainfall and hold water, making it available for later crop use. Soil organic C also influences the ability of soils to retain nutrients, microbial biomass activity and its role as a major source of nutrients, which altogether exert a positive effect on crop growth to effectively use available water. Similarly the nutrient management also records profuse root biomass that could effectively utilize scarce water from far-off places and convert otherwise unproductive evaporation loss into productive transpiration under the integrated approach treatment followed by balanced fertilizers.

Soil test-based amendments of nutrients with or without organic composts also tend to increase grain nutrient contents over the farmers practice (Figure 1.3; Chander et al. 2013a), with more benefits under an integrated approach. Conjoint application of nutrients along with vermicompost apparently reduces fixation and leaching losses of nutrients and thereby enhances their availability in soil and uptake by plants. Benefits of application of B in maintaining membrane integrity are also well known and hence may account for enhancing the ability of membranes to transport available nutrients.

1.5.2 Conservation Agriculture and Residue Addition

Conservation agriculture (CA) refers to raising crops with minimal soil disturbance while retaining crop residues on the soil surface. In CA, the benefits of enhanced soil fertility are considered more a function of increased inputs of organic matter as mulch (Giller et al. 2009). CA is a suitable

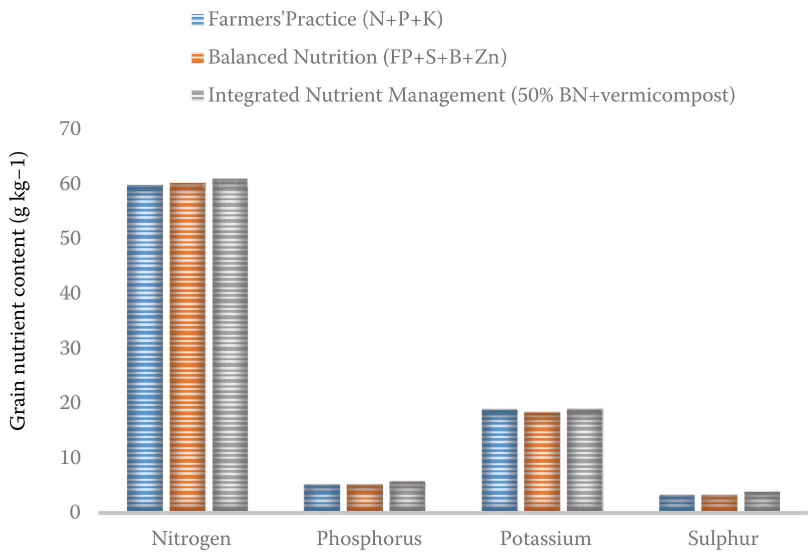

FIGURE 1.3 Effects of nutrient managements on soybean (*Glycine max*) grain nutrient contents in Raisen district, Madhya Pradesh, India during rainy season 2010.

technique for soil erosion control and economic productivity enhancement, by avoiding soil erosion losses through reducing the impact of raindrops and avoiding the detachment of soil particles, which accounts for 95% of erosion (FAO 2000). Retained crop residues promote more stable soil aggregates as a result of increased microbial activity and prevent any aggregate breakdown by direct raindrop impact as well as by the rapid wetting and drying of soils (LeBissonnais 1996), which is critical in water retention and infiltration. Due to enhanced rainwater infiltration under CA, soil erosion may be reduced to a level below the regeneration rate of the soil. Experimental results show that runoff decreases exponentially with the proportion of soil surface effectively covered by residues, a 30% cover of soil surface usually implying a reduction of runoff by >50% (Scopel et al. 2004). Soil cover not only protects soil against the impact of raindrops and gusty winds, but from the heating effect of the sun (FAO 2000; Bot and Benites 2005). CA helps to improve nutrient use efficiency as it reduces soil erosion, thereby preventing nutrient loss from the field and through appropriate use of deep-rooting cover crops that recycle nutrients leached from the topsoil (FAO 2001). CA has been found to positively affect the water balance of soils by improving rainwater infiltration (Govaerts et al. 2007; Shaxson et al. 2008), water holding capacity (Acharya et al. 1998; Govaerts et al. 2007; Mousques and Friedrich 2007; Govaerts et al. 2009) and reducing evaporative loss (Scopel et al. 2004). With these benefits of water availability and soil quality, CA apparently brings in resilience of crops to adapt to changes in local climate and may emerge as an important climate change adaptation strategy and also climate change mitigation through possible C sequestration.

As regards the effects of CA on crop productivity, some studies claim that CA results in higher and more stable crop yields, while on the other hand there are also numerous examples of no yield benefits and even yield reductions, especially during the initial years of CA adoption. Short-term yield effects have been found to be variable (positive, neutral or negative yield response) (Mbagwu 1990; Gill and Aulakh 1990; Lumpkin and Sayre 2009).

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 normal as well as minimum tillage practices (Jat et al. 2015). These results imply that under CA higher rainwater filters into the soil to add to the green water. Similarly, the peak rate of runoff, which indicates the erosive capacity of runoff water, is also decreased with residue addition. No significant benefit is observed by 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.

1.6 AMENDMENTS FOR PROBLEM SOILS

One of the challenges of harnessing higher productivity levels and sustainability of agriculture is in expanding soil salinity/alkalinity, which has in recent times become a serious issue of concern. India's total salt affected area is 6.74 m ha, out of which 3.79 m ha is affected with sodicity and the other 2.95 m ha with salinity (including 1.25 m ha coastal saline soils) (CSSRI 2017). Salt affected soils exist across the length and breadth of India covering 16 states/union territories; the maximum salt affected soils are in Gujarat (2.22 m ha) followed by Uttar Pradesh (1.37 m ha). With a scarcity of good quality irrigation water and rising pressure to produce more from every hectare of available arable land, the brackish groundwater is being increasingly used for irrigation (Dagar 2005), which is adding to the problem. The irrigation potential during the post-independence period has increased from 22.6 million ha in 1951 to about 92 million ha by the end of eighth plan, of which about 42 million ha was from ground waters and the surveys indicated that poor quality waters being utilized in different states are 32 to 84% of the total ground water development (Dagar 2005). The increase in irrigated area as envisaged would lead to secondary salinization, consequentially leading to an estimated 16.2 million ha of salt affected area by 2050 (CSSRI 2015). Thus, salt affected soils and poor quality waters including wastewaters represent an opportunity that can be exploited to increase agricultural production and productivity to ensure national food and nutritional security.

Chemical amendments in alkaline soils, and drainage and leaching of saline soils, are well documented technologies. Studies using different amendments like gypsum, pyrite, sulphuric acid, nitric acid, press mud, aluminium sulphate, ferrous sulphate and farmyard manure proved that gypsum followed by pyrites are the most useful because of their easy availability and cost consideration (Tyagi and Minhas 1998). The dose of an amendment required for reclamation of alkali soil is governed by its initial exchangeable sodium percentage (ESP), tolerance of crops to be grown, texture and minerology of soil and depth to be reclaimed. For the initiation of the reclamation of alkali soils for cultivation of shallow rooted crops, an application of 50% of the gypsum requirement, which amounts to 10–15 Mg ha^{-1} in 0–15 cm soil, is sufficient (Dagar 2005). The cost of alkali soil reclamation at constant prices is rising. Overdependence on finite and non-renewable resources as amendments (gypsum, pyrites) for reclamation is not sustainable in the long run. Organic materials together with inorganic amendments quicken the reclamation of alkali soils and also reduce the gypsum requirement (Dagar 2005). Taking into account the high costs, other alternate technologies like biological reclamation by exploiting the use of microbes, application of organic materials, diversification into silvi-pastoral systems, cultivation of salt-tolerant crop varieties and halophytes and grasses with no or reduced doses also needs to be considered and promoted.

1.7 CONCLUSIONS

Food and nutrition security of rising population can be achieved by increasing the sustainability of agriculture through the adoption of science-led developments. Maintaining proper soil health is one essential element of sustainable agriculture and safeguarding ecosystem services. Hungry soils produce unhealthy food in insufficient quantities. The swiftly rising population has put pressures on soil resources and altered equilibriums for the various soil functions due to mismanagement leading to soil degradation. This has threatened the sustainability and food security and livelihoods. Depletion of soil organic C is one of the major threat taking into account its multifarious effect on soil chemical, physical and biological properties. Nutrient imbalances and mining of N, P, S, B and Zn have reached alarming levels across different regions, and need-based nutrient amendments have shown a productivity benefit of 20 to 50% along with benefits in resource use efficiency and

C-sequestration. Organic compost amendments along with nutrients not only enhance or maintain yield levels, but also cut costs of chemical fertilizers by 25 to 50%. The scope and trade-offs of conservation agriculture, especially residue incorporations, need to be studied thoroughly for any further scaling-up. Current salt-affected soils of 6.74 m ha and increase in its area due to secondary salinization as a result of overexploitation of water resources up to 16.2 m ha by 2050 is another challenge. Taking into account no scope for expansion of cultivated area, soil amendments like gypsum or pyrites along with other management options in integrated ways for reclamation of alkali/saline soils needs desired attention. In this challenging scenario, policies to promote macro and micro nutrient amendments in soil and the addition of organic composts by recycling organic wastes generated both in urban and rural areas and amendments for problem soils are desired. In order to achieve sustainable development without degrading lands there is an urgent need to adopt science-led management of agriculture through diagnostic assays, specific and appropriate recommendations of the needed amendments, awareness building along with enabling policies and institutional mechanisms to make the needed amendments available to the farmers at the right time, at the right price and in the right quantities. Integrated nutrient management harnessing the full potential of biological, organic resources and filling the gap with the right chemical sources must be promoted.

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