Chapter 17
Adaptation and Mitigation of Climate Change by Improving Agriculture in India

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Abstract Between 1800 and 2050, the population of India would increase from 255 million to 1.71 billion, by a factor of 7, with a strong environmental impact. Rapid urbanization and its encroachment on agricultural land is a consequence of increase in population. Between 1950 and 2025, the population (106) would increase from 1.4 to 28.6 (20.4 times) of New Delhi, 4.5 to 20.1 (4.5 times) of Kolkata, 2.9 to 25.8 (8.9 times) of Mumbai, 0.6 to 6.6 (11.0 times) of Pune, 1.1 to 8.9 (8.1 times) of Hyderabad, 0.7 to 9.5 (13.6 times) of Bengaluru, and 1.5 to 9.6 (6.4 times) of Chennai. The city of Mumbai generates 11 thousand Mg of waste per day or 4 million Mg per year, which if recycled effectively, can improve urban and peri-urban agriculture. It takes about 40,000 ha of land to provide accommodation and infrastructure to 1 million people. An annual increase of 11.5 million people in India encroaches upon 0.5 million hectare (Mha) of agricultural land. Thus, there is a strong need to protect prime agricultural land against other uses. By 2025, India will have 7 cities of >10 million people, and a city of 10 million consumes 6000 Mg of food per day. Thus, nutrients brought into the city must be returned to the land by recycling waste as compost and for producing energy. Climate change, with increase in frequency of extreme events, is exacerbating vulnerability of agricultural soils to degradation processes. Land area (Mha) in India already affected by degradation includes 93.7 by water erosion, 9.5 by wind erosion, 14.3 by waterlogging, 5.9 by salinity/alkalinity, 16.0 by soil acidity and 7.4 by complex problems. In addition to the impacts of changing and uncertain climate, soil degradation is exacerbated by burning of crop residues, use of cow dung for household cooking rather than as manure, uncontrolled grazing, unbalanced use of fertilizers, and other extractive farming practices. The drought-flood syndrome, caused by water misuse and mismanagement, adversely affects agronomic productivity and wellbeing of millions of people despite the fact that India receives 4000 km^3 of annual precipitation.

A systematic understanding is needed of the coupled cycling of water, carbon, nitrogen, phosphorus and sulfur at ecoregions and watershed scale to enhance provisioning of essential ecosystem services from agroecosystem (e.g., food feed, fiber,

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fuel, water, biodiversity). In addition to the drought-flood syndrome, other ramifications of the mismanagement of coupled cycling include emission of greenhouse gases from agroecosytems, especially of CH_4 and N_2O with global warming potential of 21 and 310, respectively. Adaptation and mitigation of agroecosystems to climate change necessitate adoption of the strategies of sustainable intensification. The latter implies "producing more from less": more agronomic yield per unit of land area, and input of water, energy, fertilizers, pesticides and gaseous emissions. The large yield gap, difference in agronomic yield of research plots and the national average yield, can be abridged by adoption of the best management practices (BMPs). Thus, soil health must be restored by increasing soil organic carbon (SOC) concentration to the threshold level of ~1.5–2.0% in the root zone (0–40 cm depth). Soils of agroecosystems in India, similar to those of other countries in South Asia and Sub-Saharan Africa, are severely depleted of their SOC stocks. The magnitude of depletion is high in soils prone to accelerated erosion by water and wind, and other degradation processes. The SOC stock can be restored by adaptation of BMPs which control erosion and create a positive soil/ecosystem C budget. Important among these are afforestation of degraded and marginal soils, restoration and management of wetlands, use of conservation agriculture in conjunction with mulch farming/cover cropping, integrated nutrient management, and establishment of biofuel plantations on degraded lands. The SOC restored must also be stabilized/ protected to prolong its mean residence time to centennial/millennial scale. There is no one-size-fit-all BMP, and site-specific adaptation/fine-tuning is essential with due consideration of the biophysical, socio-economic and cultural (the human dimensions) factors. In addition to adaptation and mitigation of climate change, restoration of degraded soils is also essential to local, national, regional and global peace and harmony. Fertile soils of good health, rich in SOC stock, and teaming with biodiversity of intense activity are essential to advancing food and nutritional security, improving water quality and renewability and adapting and mitigating climate change. Healthy soils are the engine of economic development especially under changing and uncertain climate.

Keywords Climate change · Soil carbon · Carbon sequestration and soil health

17.1 Introduction

The population of India has and is growing at a fast rate, which (million) was 255 in 1800, 295 in 1900, and 1014 in 2000. It increased by only 40 million during the nineteenth century but by 719 million during the twentieth century. It is projected to increase by another 645 million to a total of 1.66 billion by 2050. The present population of India is 1.34 billion, and will increase to 1.51 billion by 2030, 1.66 billion by 2050, but decreases to 1.52 billion by 2100 (UN, 2017). The present population of India of 1.34 billion is 17.7% of the world population of 7.55 billion or one in 6 persons is living in India on merely 2.4% of the world's total land area.

Population of major cities (in million) of India is projected to increase between 1950 and 2025 by a factor of 20.4 for New Delhi (1.4 to 28.6), 4.5 for Kolkata (4.5 to 20.1), 8.9 for Mumbai (2.9 to 25.8), 11.0 for Pune (0.6 to 6.6), 8.1 for Hyderabad (1.1 to 8.9), 13.6 for Bangleru (0.7 to 9.5), and 6.4 for Chenai (1.5 to 9.6). An annual increase of India's population by 11.5 million, equivalent to adding the entire population of Cuba or Tunisia to that of India, may require an additional land area of 0.5 Mha to provide for infrastructure and accommodation. Therefore, the net land area available for agricultural production is shrinking because of the competing non-agricultural uses.

Agricultural land area in India is also shrinking because of soil degradation. Vulnerability to degradation is caused by land misuse and soil mismanagement. The widespread use of extractive farming practices, based on plowing and residues removal along with uncontrolled grazing, leads to the severe problems of soil degradation. Land area affected by a range of soil degradation processes in India is estimated at 146.8 Mha (Bhattacharyya et al. 2015), or 44% of the total land surface of 329 Mha. Severe problems of soil and environmental degradation, driven by anthropogenic factors, are also intricately interconnected to the changing and uncertain climate characterized by extreme events, drought-flood syndrome, and heat waves. Accelerated erosion and other degradation processes aggravate the emission of greenhouse gases (GHGs) from soils.

Notable among these gases are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Degraded soils are a major source of these gases because of the nitrification/de-nitrification, methanogenesis and mineralization processes. The objective of this article is to deliberate the importance of adopting best management practices (BMPs) to restore soil health, create a positive soil/ecosystem carbon (C) budget, sequester atmospheric CO_2 in soils of agro ecosystems as soil organic matter (SOM), enhance soil resilience to climate change, and improve agronomic productivity and use efficiency of inputs.

17.2 Extractive Farming Practices

The downward spiral of soil and environmental degradation is set-in-motion by the widespread use of extractive farming practices (Table 17.1). Notable among these, with adverse impacts on soil health, are excessive ploughing, residue removal and in-field burning, uncontrolled and free grazing, flood and excessive irrigation, unbalanced use of fertilizers (more N and less P and K), using animal dung for cooking rather than as manure, and scalping topsoil for brick making. Total number of bricks produced in India is 250 billion per annum, which decapitates a large area of agricultural land.

As a consequence of extractive farming, there is a severe problem of soil degradation or decline in soil health and its functionality. Notable among soil degradation processes are: (i) physical degradation such as accelerated erosion by water and wind, structural decline causing crusting and compaction, and waterlogging, (ii)

Table 17.1 Extractive farming practices which degrade soil and environment quality

Traditional practice		Degradation processes
1.	Excessive ploughing	Erosion by water and wind, decline of SOM content, reduction in aggregation.
2.	Removal of crop residues for competing uses (e.g., fodder, fuel, construction)	Reduction in SOM content, decline in soil biodiversity, decrease in aggregation, vulnerability to crusting and compaction, nutrient mining.
3.	In-field burning of crop residues	Emission of GHGs (CO_2, N_2O, CH_4) and other compounds (CO_2, NO_x, SO_2, SO_x, NH_3, particulate matter, soot of black C (BC), reduction in SOM.
4.	Uncontrolled and free grazing	Compaction, crusting, decline in SOM.
5.	Flood irrigation with brackish water	Secondary salinization, decline in water table, solublization of arsenic in alluvial soils
6.	Using animal dung for household fuel rather than manure	Decline in SOM content, depletion of soil fertility, emission of obnoxious gases (CO_2, SO_2, NH_4, PM, soot BC), pulmonary diseases.
7.	Scalping topsoil for brick making	Depletion of soil fertility, deficiency of micronutrients in soil, food of poor nutritional quality, low use efficiency of inputs.
8.	Imbalanced use of fertilizer (more N but less P and K)	Elemental imbalance in soil, low crop yield, nutrient depletion.

chemical degradation including salinity, alkalinity, acidification, nutrient depletion, and elemental imbalance (toxicity, deficiency), (iii) biological degradation characterized by loss of soil biodiversity, decrease in microbial biomass C, depletion of SOM content to below the critical level in the root zone, and (iv) ecological degradation comprising of disruption in biogeochemical and bio geophysical cycling, and perturbation of water and energy balance etc. (Fig. 17.1) Although estimates of soil degradation in India are tentative and incomplete, as much as 146.8 Mha of land area (45% of the total area of the country) is affected by soil degradation (Bhattacharyya et al. 2015).

The biophysical processes of soil degradation are driven by social, economic and cultural factors. These interactive effects (biophysical × socioeconomic) are exacerbated by causes related to land misuse and soil mismanagement (Fig. 17.2). Therefore, risks of soil degradation by diverse processes can be minimized by judicious management of factors and causes through adoption of BMPs.

17.3 Depletion of Soil Organic Carbon and Environmental Pollution by Soil Degradation

Soils of agroecosystems of India are strongly depleted of their soil organic carbon (SOC) concentration and stocks. Whereas the threshold level of SOC concentration in the root zone ranges from 1.1 to 1.5%, the actual levels in soils of the Indo-Gangetic Plains (IGPs) may be as low as 0.1% or less. Consequently, crop yields are

Fig. 17.1 Processes of soil degradation driven by biophysical, social, economic and cultural factors

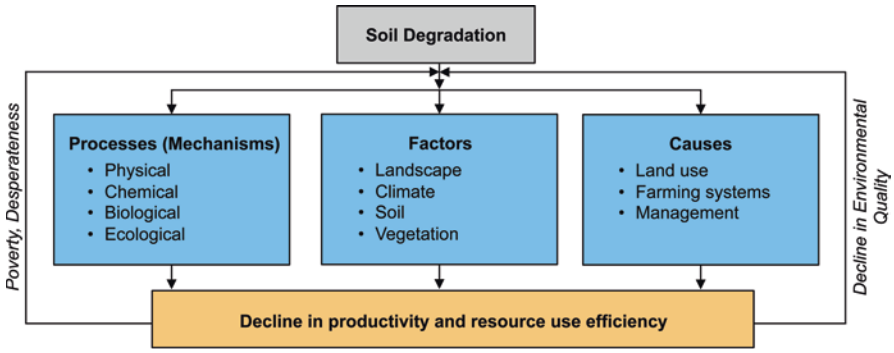

Fig. 17.2 Processes, factors and causes of soil degradation

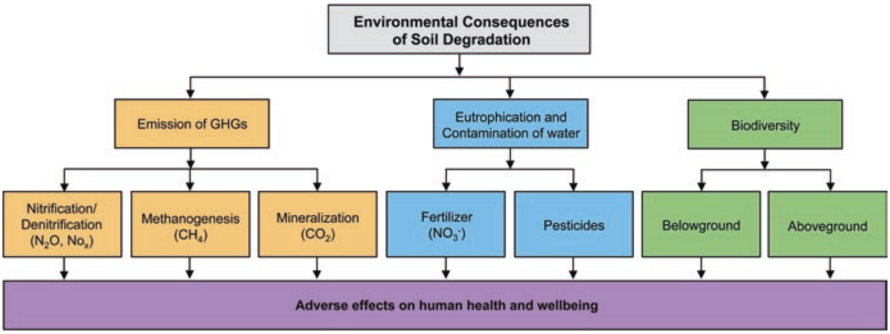

Fig. 17.3 Degradation of soil exacerbate emission of greenhouse gases from soil into the atmosphere, pollutes and contaminates water resources, reduces above and below-ground biodiversity, and adversely affects human health and wellbeing

low and stagnating and use efficiency of inputs (e.g., fertilizers, irrigation, energy) is low and losses (by erosion, decomposition, volatilization and leaching) are high. Furthermore, soil degradation (e.g., accelerated erosion) increases the emission of GHGs from soil especially that of N_2O by nitrification/de-nitrification and CH_4 by methanogenesis. Soil degradation also leads to pollution and contamination of water and decline of biodiversity (Fig.17.3). In addition to the decline in quantity and quality of food produced, soil and the associated environmental degradation also adversely impacts human health and wellbeing. Indeed, the health of soils, plants, animals, human and ecosystem is one and indivisible. Everything is connected to everything else (Commoner 1971), because when we try to pick one thing in nature, we find that it is hitched to everything else (Muir 1911). Soil degradation has severe and long lasting consequences. Landscape is a mirror image of people who live on it. Landscape with degraded and depleted soils supports meager living and impoverished lifestyle. Some options of BMPs in to minimize risks of soil degradation and restore degraded soils of India are outlined in Table 17.2 and briefly discussed below.

17.4 Crop Residue Management for Sequestration of Soil Organic Carbon and Restoration of Soil Health

India produces a large amount of crop residues estimated to range between 510 and 836 million Mg per year (Hiloidhari et al. 2014; Cardoen et al. 2015a; Ravindranath et al., 2005). However, most of the crop residues are either burnt in-field (~100 million Mg/yr), taken away for other competing uses (e.g., fodder, fuel, construction) or grazed. Consequently, the SOC budget is negative and SOC concentration and stocks are perpetually depleting. Hilodhari et al. (2014) estimated that 234 million Mg of crop residues are surplus, after the fodder and other needs are met. Other

Table 17.2 Basic principals of soil management and the associated best management practices

Basic principle		Associated Best Management Practices
1.	Creating a positive soil C budget and managing soil organic matter	Mulch farming, forages/cover cropping, conservation agriculture, agroforestry, and increasing input of biomass-C.
2.	Soil fertility improvement	Integrated nutrient management (INM), biological nitrogen fixation (BNF), mycorrhizal inoculation, balanced application of fertilizers, replacing whatever nutrients are removed, soil-test based fertilizer use, yield-based fertilizer input.
3.	Soil water management	Increasing soils available water capacity by increasing infiltration and reducing run-off and evaporation, increasing SOM content, improving root growth in the sub-soil, using drip sub-irrigation (rather than flood irrigation), direct-seeded aerobic rice.
4.	Improving soil structure and tilth	Conservation agriculture, mulch farming, manuring, use of gypsum in acidic soils.
5.	Managing soil compaction	Controlled grazing, minimizing vehicular traffic, growing deep-rooted crops (pigeon pea) in the rotation cycle, increasing activity of soil biota (earthworms), adopting conservation agriculture.
6.	Creating disease-suppressive soils	Improving soil biodiversity by increasing input of biomass-C, using compost and manure, enhancing microbial biomass-C.
7.	Integrated farming systems	Adopting complex cop rotations, growing pulses and cover crops, forages, agroforestry.

Table 17.3 Land use in South Asia and India

	Land area (10^6 ha)	
Parameter	South Asia	India
Total land area	688.0	358.7
Land area	640.0	297.3
Agricultural area	316.2	179.6
Arable land	22.4	156.4
Permanent crops	17.8	13.0
Permanent meadows and pastures	78.0	10.2
Forest	94.0	70.5
Other land	229.9	47.2
Inland water	48.0	31.4
Area equipped for irrigation	110.9	70.4

estimates of surplus amounts of residues include 279 million Mg and 383 million Mg. Assuming average surplus of crop residues of ~300 Mg/yr. and with C concentration of 40%, 120 Mg of biomass-C can be recycled back to the soil. With humification efficiency of 20%, 24 TgC can be sequestered through recycling of the surplus amount of crop residues. With arable land area of 156 Mha (Table 17.3), this would be equivalent to SOC sequestration rate of 150 kg/ha yr. With societal value of SOC of $120/Mg C (Lal 2014), farmers can be compensated at an average rate of $18/ha yr. through payments for ecosystem services.

Table 17.4 Nutrient Concentration of crop residues and animal dung (Recalculated from Cardoen et al. 2015a)

Residues	Concentration (%)		
	C	N	P
Cereals	41.1	0.49	0.08
Legumes	38.5	0.87	0.21
Dung	39.1	0.21	–

Table 17.5 Grain production in India (2014–2015)

Crop	Production (10^6 Mg)
Rice	104.8
Wheat	88.9
Maize	23.7
Millet	9.7
Sorghum	5.7
Coarse cereals	41.7
Barely	1.6
Small millets	0.4

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In addition to crop residues, application of cattle dung as manure can also lead to improvements in soil health though SOC sequestration. There are 500 million livestock in India (FAO 2017), which produce 500 to 700 million Mg of fresh dung (average of 562 million Mg/yr). The present use of dung involves 60% as manure, 37% for fuel and 3% for other uses (Dikshit and Birthal 2010; Lohan et al. 2015). With availability of clean cooking fuel, 40% of the dung (225 million Mg/yr) can be used as manure. With 40% C and 20% humification efficiency, additional soil application of 225 million Mg of dung as manure would also lead to SOC sequestration of (225×10^6 Mg × 0.4 × 0.2) of 18 Tg C/yr., at an average annual rate of 115 kg/ha yr. over 156 M ha of cropland. Inputs of crop residues and manure also add to plant nutrients (Table 17.4), especially N.P and S. Thus, recycling of nutrients can reduce the input of chemical fertilizers and enhance use efficiency of inputs. Recycling of biomass canalso improve the nutrient budget in agriculture (Pathak et al. 2010).

17.5 Agronomic Productivity

Food grain production in India is second only to that of China (Tables 17.5 and 17.6). Total food grain production in 2016–17 is estimated at 274.4 million Mg (Ray 2017), which is 8.7% more than that of the last year. Food grain production in India has increased from merely 50 million Mg in 1947 when the population of India was

Table 17.6 Pulse production in India (2014–2015)

Pulse	Production (10^6 Mg)
Pigeon pea	2.8
Chickpea	7.2
Black gram (urd)	1.9
Green gram (moong)	4.5
Other pulses	3.9
Groundnut	6.6
Soybean	10.5

FAO STATS 2017

344 million (105 kg/person) to 274.4million Mg in 2017 when the population is 1342 million (203 kg/person). Thus, the rate of food production has outpaced that of population growth. Nonetheless, there is no cause for complacency and even the bigger challenges lie ahead.

While food production must be increased from the soil and water resources already appropriated, the rate of population growth (1.18%/yr) must also be decreased to the replacement level or lower. Thus, a double-prong strategy is essential.

17.6 Management of Water Resources

Similar to soil, India is also endowed with a large amount of renewable water resources. However, the large water footprint of agriculture must be reduced. This would require use of drip sub-irrigation rather than flood irrigation, and use of conservation-effective measures to reduce losses of water by runoff and evaporation, and storage of water in the soil. Soil water storage can also be enhanced by increasing SOC concentration through retention of crop residue mulch and application of animal manure. India's water footprint can be reduced by conversion of blue water (runoff, deep seepage) into green water (plant-available water) (Hoekstra and Mekonnen 2012). In this regard, the importance of the judicious use of gray/black water (urban wastewater) cannot be over-emphasized. Following proper treatment to reduce the risks of pathogens, gray/black water can be used for irrigation and for recycling water and nutrients. Mega cities (>10 million population) consume ~6000 Mg of food per day. Thus, through prudent management, city waste, a rich source of nutrients, can be an asset rather than a liability. Nutrient contained in the municipal solid waste must also be recycled (Fiksel and Lal 2017).

17.7 Sustainable Intensification of Agroecosystems

India is endowed with vast amounts of soil and water resources distributed over a wide range of biomes (climates) and eco-regions. Yet, increase in population at 1.18% with annual addition of 11.5 million new mouths to feed and accommodate is a major challenge which must be critically addressed. In addition to restoring degraded soils (146.8 Mha), urban encroachment and brick making must also be controlled through appropriate policy interventions. The prime agricultural land must be protected from other competing non-agricultural uses (e.g., urbanization, infrastructure development, recreational facilities).

Agronomic yields in India are lower than the potential attainable yields. This is true both for irrigated and rainfed agro ecosystems. The yield gap can be abridged through adoption of BMPs (Table 18.2) and adopting the principles of sustainable intensification (SI). The latter implies producing more per unit of land area and input of fertilizers, pesticides, irrigation and energy. The goal is to reduce losses and increase the use efficiency of inputs. Thus, India can meet the needs of present and the future population from lesser land and water resources than those allocated at present. The land and water thus saved can be used for nature conservancy. With the average per capita food grain need of 250 kg/yr., India's population of 1.7 billion will need a total production of 425 million Mg year. With production of 273 million Mg in 2017, the annual rate of growth between 2017 and 2050 (33 yr) must be 4.6 million Mg/yr. This rate of growth is achievable, especially with increase in productivity with increase in SOC stock in the root zone (Lal 2006), and with adoption of system-based CA system (Lal 1995, 2015).

17.8 Conclusion

India's population of 1342 million in 2017 is projected to increase to 1513 million by 2030, 1659 million by 2050 and decrease to 1517 million by 2100. Rate of increase of food grain production of 4.6 million Mg/yr. between 2017 and 2050 (from 274 million Mg in 2016–17 to 425 million Mg by 2050) must be obtained from lesser land and water resources than those being appropriated at present. The strategy is to abridge the yield gap through SI of agroecosystems by "producing more from less" through:

1. Restoring degraded soils (146.8 M ha),
2. Preventing any new soil degradation,
3. Banning use of topsoil for brick making,
4. Prohibiting in-field burning of crop residues, and using conservation agriculture,
5. Using dung as compost and providing clean cooking fuel to rural communities,

6. Sequestering SOC by recycling of surplus crop residues and animal dung into agroecosystems,
7. Enhancing water use efficiency by using drip sub-irrigation, prohibiting flood irrigation and reducing losses by runoff and evaporation,
8. Increasing use efficiency of nutrients by restoring soil health and using improved formulations of fertilizers,
9. Incentivizing farmers through payments for ecosystem services (C and water credits), and
10. Promoting soil-centric technologies.

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