Sustainable Soil Management

Sustainable Soil Management:

Beyond Food Production

Edited by

Somasundaram Jayaraman,
Ram C Dalal and Rattan Lal

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FOREWORD

M.S. SWAMINATHAN RESEARCH FOUNDATION

Soil is the foundation of farming and food production. It performs several ecosystem functions including ensuring physical stability and support, nutrient cycling, water storage and release, biodiversity and habitat protection, pesticide retention and degradation, filtering and buffering, and cleaning of the environment. Many civilizations started where fertile soils existed, giving credence to the adage, "healthy soil for healthy life". The famous saying of Franklin D Roosevelt, Former U S President, "the nation that destroys its soil destroys itself" emphatically indicated the importance of soils to the very survival of nations. Sustaining soil health is therefore of paramount importance in meeting the zero hunger challenge.

Land is a shrinking resource for agriculture and we have to produce more and more from less and less land. Adopting the right combination of crop (variety), agronomic practices, and soil (nutrient/water/other inputs) management is essential for crop productivity in perpetuity. We therefore need to ensure sustainable soils by protecting and monitoring soil health in partnership with farmers.

I believe this book will be widely used and read and help in reversing soil degradation, improving soil organic carbon, sustainable soil health, and mitigating climate change. If we do not attend to soil health, we will be unable to meet our goals of achieving food and nutrition security. I congratulate the editors/ authors for the timely publication of this book.

M S Swaminathan

Founder Chairman

Ex-Member of Parliament (Rajya Sabha)

PREFACE

World population will reach ~10 billion by 2050 and major rise in population will occur in developing nations in general and South Asian and African countries in particular. Achieving food and nutritional security for the growing population is a daunting task amidst the challenges such as soil degradation by accelerated erosion, loss of soil organic carbon, decline of biodiversity, and climate change. Soil degradation is a major threat as 33% of global soils are moderately or highly degraded owing to unsustainable approach/practices. Soil produces 98% of our food requirement and it is directly or indirectly connected with more than 7 out of 17 Sustainable Development Goals (SDGs) of the United Nations (U.N, 2015). Therefore, sustaining soil health/sustainable soil management (SSM) is essential to addressing food security and socio-economic, environmental, and ecosystem issues. This book on "*Sustainable Soil Management-Beyond Food Production*" not only addresses soil health/soil management but also deliberates issues such as reversing soil degradation, improving soil carbon stock and biodiversity, mitigating climate change, and enhancing ecosystem services/functions. *Soil system is often compared with a bank account: as more you invest in sustaining soil health more you receive higher returns in perpetuity*.

This book comprises of 12 chapters dealing with various issues, prospects, and importance *of "Sustainable Soil Management"* under different agro-climatic conditions, particularly India, but also covers other regions such as Australia and the Pacific, North America, South America, Africa and South Asia and South-east Asia. We place our sincere thanks on record to all the authors for their fine contribution and support in this assignment.

We express our gratitude to Professor M.S. Swaminathan, World Food Prize Laureate, Founder Chairman (MSSRF, Chennai) & Ex-Member of Parliament (Rajya Sabha) for writing Foreword for this book.

First Editor expresses sincere thanks to Hon'ble Dr. Himanshu Pathak, Secretary (DARE) and DG (ICAR), Dr. Alok K Sikka, Former DDG (NRM), Dr. S.K. Chaudhari, DDG (NRM), ICAR, New Delhi, and Dr Ashok K Patra, Director (Formerly), ICAR-IISS, Bhopal; and also thanks all the teachers and professors who have inspired them with their great knowledge and wisdom that has advanced their understandings of Soil Science vis-à-vis Sustainable Soil Management/Natural Resource Management.

We believe this book on "*Sustainable Soil Management-Beyond Food Production"* will be extremely useful to researchers, scientists, students, farmers and land managers for efficient as well as sustainable management of natural resources with the *theme of one-health* i.e. *soil-plant-animal-human-planetary health*.

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ABBREVIATION / ACRONYMS

4PT–Four Per Thousand (4PT)- 4 per mille

ACIAR– Australian Centre for International Agricultural Research

AMF– Arbuscular mycorrhizal fungi

BD– Bulk Density

BMPs–Best Management Practices

C:N ratio– Carbon: Nitrogen

CA–Conservation Agriculture

CA-CoP- CA community of practice

C–Carbon

CC–Cover Crops

CEC–Cation exchange capacity

CH_4– Methane

CLF–Crop-Livestock-Forest

CO_2–Carbon dioxide

COP21– Conference of Parties 21

COP23– Conference of Parties 23

CSA– Climate-Smart Agriculture

CSIRO–Commonwealth Scientific Research Organization

CT–Conventional Tillage

DAP–Diammonium Phosphate

EU–European Union

FAO– Food and Agriculture Organization

FCC– Fertility Capability Classification

GDP– Gross Domestic Product

GHG– Greenhouse Gas

GHGB–Greenhouse gas balance

GSP–Global Soil Partnership

HI–Harvest Index

IDOAM– The International Federation of Organic Agriculture Movements

IFS–Integrated Farming System

INM– Integrated Nutrient Management

IPCC– Intergovernmental Panel on Climate Change

IPM– Integrated Pest Management

IPNS– Integrated Plant Nutrient System

ISFM–Integrated Soil Fertility Management

ITPS– Intergovernmental Technical Panel on Soils

kg ha^{-1}– kilogram per hectare

K–Potassium

LCC–Land Capability Classification

LDN–Land Degradation Neutrality

LULUCF– Land Use, Land-Use Change and Forestry

MEA- Millennium Ecosystem Assessment

MHO–Mycorrhiza Helper Organisms

N_2O– Nitrous Oxide

NECB–Net Ecosystem Carbon Balance

N–Nitrogen

NPP– Net Primary Productivity

NT–No-Tillage

OECD–Organisation for Economic Co-operation and Development

OF– Organic Farming

P– Phosphorus

Pg–Peta gram

PGPR– Plant Growth Promoting Rhizobacteria

PSM –Phosphorus Solubilizing Microorganisms

R&D– Research and Development

RA–Regenerative Agriculture

RT– Reduced Tillage

SDG– Sustainable Developmental Goals

SEGH– The Society for Environmental Geochemistry and Health

SOC– Soil Organic Carbon

SOM–Soil Organic Matter

SRI–System of Rice Intensification

SSM–Sustainable Soil Management

SSP–Single Superphosphate

TAFE–Technical and Further Education

TSN–Total Soil Nitrogen

t–tonne

UN– United Nations

UNCCD– United Nations Convention to Combat Desertification

UNESCO–United Nations Educational, Scientific and Cultural Organisation

USLE– Universal Soil Loss Equation

VGSSM–Voluntary Guidelines for Sustainable Soil Management

WCED– World Commission on Environment and Development

WFPS– Water Filled Pore Space

WUE–Water Use Efficiency

WWII– World War II

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CHAPTER ONE

SUSTAINABLE SOIL MANAGEMENT: *CHALLENGES, PROSPECTS AND BENEFITS*

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Abstract

Soil not only provides food and nutritional support but also performs many ecosystem functions and services. *Soil* is considered as a non-renewable resource, but it takes centuries to form one millimeter of soil. In the pursuit of higher food production, urbanization and development, the soil resource has been taken for granted and jeopardized in an unprecedented manner. *'Soil health'* has been threatened by various challenges such as soil fertility depletion/degradation, loss of soil organic carbon/ biodiversity, salinization, acidification, contamination, soil erosion & degradation. These land degradation processes severely constrain not only food production but also critical soil functions and ecosystem services. Thus, sustainable soil management (SSM) is essential to safeguard this precious resource. According to FAO "*Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by* *soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity*". This chapter deliberates on the *SSM* definition, importance, challenges, various strategies, and approaches to enhance soil health and soil organic carbon, reduce soil erosion and degradation, and thus improve soil functions.

Keywords: Sustainable soil management, SOC, 4PT, conservation agriculture, regenerative agriculture, organic farming, land degradation neutrality

1. Introduction

Soils are used, misused, exploited and over-exploited for the pursuit of higher food production and economic growth/development (UN 2015; FAO 2017). Soil resource is viewed as fundamental material for food production and thereby fulfils food and nutritional security (Amudson et al. 2015). Soil is often closely associated with farming and produced 98% food either directly or indirectly (FAO 2020). Besides, it also performs many ecosystems function and services (food, fibre, water regulation, carbon sequestration, biodiversity gene bank, filtering of contaminants, cultural heritage and aesthetic provisioning, climate change mitigation etc). Globally, widespread land degradation (~33% area) is a major problem, which jeopardises soil resource and food production (Lal 2009a, 2015a). Therefore, conserving soil resource and also sustaining its health is of paramount significance in the present-day context (Dalal et al. 2021). Sustainable Soil Management (SSM) deals with sustaining soil health and management strategies to protect soil health and food production without adversely affecting the environment. Moreover, feeding a world of 10 billion population requires innovations ahead, such as those in 1960's revolutionised by the noble laureate Borlaug (2002). Then the world witnessed the 'Green revolution' and tripled the food grain production. Yet, malnutrition and undernourished population is still the cause of concern. Therefore, sustainable development via sustainable farming approach is urgently required. Soil health is vital for sustaining agricultural production, biodiversity, ecosystem services, and providing safe and nutritious food for growing population. Thus, in this book, the authors critically consider various aspects of SSM such as soil health, net primary productivity, carbon sequestration, soil security & protection, reversing land degradation, and food and nutritional security (Figure 1).

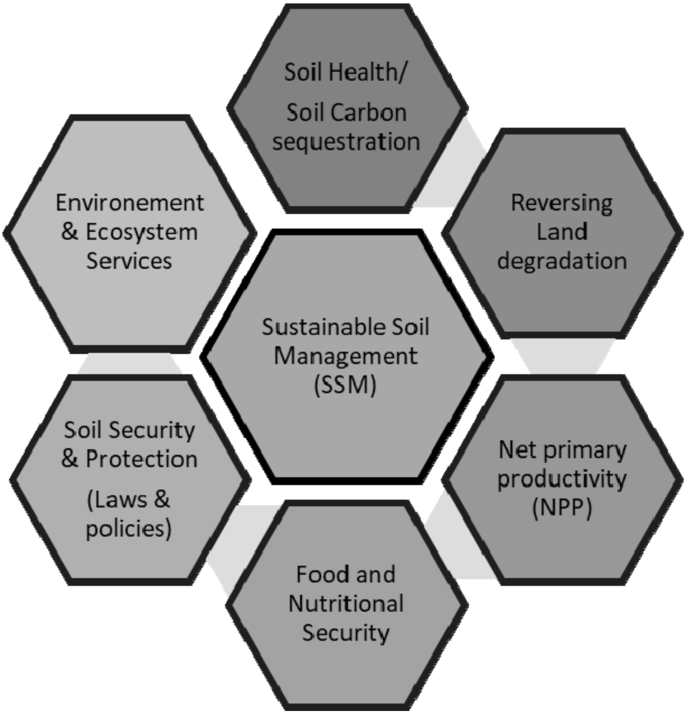

Figure 1. Sustainable Soil Management in close nexus with Soil functions and ecosystem services (Source: Authors developed from many literature sources).

Definition of Sustainable Soil Management

There are many definitions for sustainable soil management (SSM). According to WCED (1987), sustainable development "*meets the needs of the present without compromising the ability of the future generations to meet their own needs from the land*". The aforesaid definition has been modified/ adapted for SSM by Smith and Powlson (2007). They defined SSM as "*soil management that meets the needs of the present without compromising the ability of the future generations to meet their own needs from that soil*". Of late, the Intergovernmental Technical Panel on Soils (ITPS) defines soil health as "*the ability of the soil to sustain the productivity, diversity, and environmental services of terrestrial ecosystems*". In the ITPS Soil Letters, (it is stated that "*In managed systems, soil health can be maintained, promoted or recovered through the implementation of sustainable soil management practices*" (UN 2015;

FAO/ITPS 2020). According to FAO (2020), "*Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity*". Similarly, Lal (2009b) proposed # 10 laws of sustainable management practices for reverting soil degradation and restoration processes and also have minimal C and water footprint. Yachi and Loreau (1999) defined "*management practices that threaten the soil biological community may also threaten soil sustainability by reducing the capacity of the soils to adapt in future"*. Soil sustainability is jeopardized by many management practices such as conversion of natural vegetation to arable cropping using inappropriate management practices, over-cultivation/-fertilization/use of chemicals, crop residue burning, low addition of organic inputs (manures and crop residue), which lead to the decline in soil organic matter. (Smith and Powlson, 2007; Powlson et al. 2010, 2011). Therefore, SSM is essential for attaining food and nutritional security and ecosystem services (Figures 1, 2).

Why is Sustainable Soil Management needed?

Soil is essential for all the terrestrial living organisms, as it directly or indirectly provides about 98% of the food consumed by humans (Kopittke et al. 2019, 2021). This shows that soil is important for the survival of human being/living organisms. Moreover, Lal opines that "*soil is a living thing, as it houses about 25 percent of all biodiversity. And like any living thing, soil should also have right to be protected, restored, and managed properly.*" (http://www.fao.org/fao-stories/article/en/c/1330050/). Soil resource performs the many functions and services (Figure 2). Among them, five essential soil functions include nutrient cycling, water storage and release, biodiversity and habitat, filtering and buffering, and physical stability and support. However, by adopting SSM there are benefits, challenges, and opportunities, which occur simultaneously. Worldwide, land degradation is one of the major threats to the sustainability and food production. Soil erosion is also viewed in terms acceptable or tolerable rate (i.e. this should be in the range of 0.2 to 2.2 t ha^{-1} with respect to soil production rate), which should not affect the crop production adversely (permissible limit of 1–11 t ha^{-1}) (FAO, 2019). Thus, to safeguard soil resources from threats such as soil fertility depletion/ degradation, loss of soil organic carbon/ biodiversity, soil erosion, and other soil degradation processes need to be addressed through site-specific SSM for crop production, and food and nutritional security. According to the Food and Agriculture Organization of the United Nations, about a third of the planet's soil is classified as "moderately to highly degraded." Moreover, soil nutrients are depleted, crops that are grown are less healthy and yields are lower. Thus, FAO (2017, 2019) has suggested four broader groups of measure that revert/control soil erosion namely *Group 1*: measures to minimize land use change, *Groups 2 &3*: measures to reduce soil erosion and runoff velocity and *Group 4:* measure to minimize export of soil particles and associated nutrients and other contaminants from the soil. Appropriately adopting these management practices help in achieving land degradation neutrality (*it aims to maintain or increase the amount and quality of land resources by reversing degraded lands that support ecosystem functions and services, indeed life itself*).

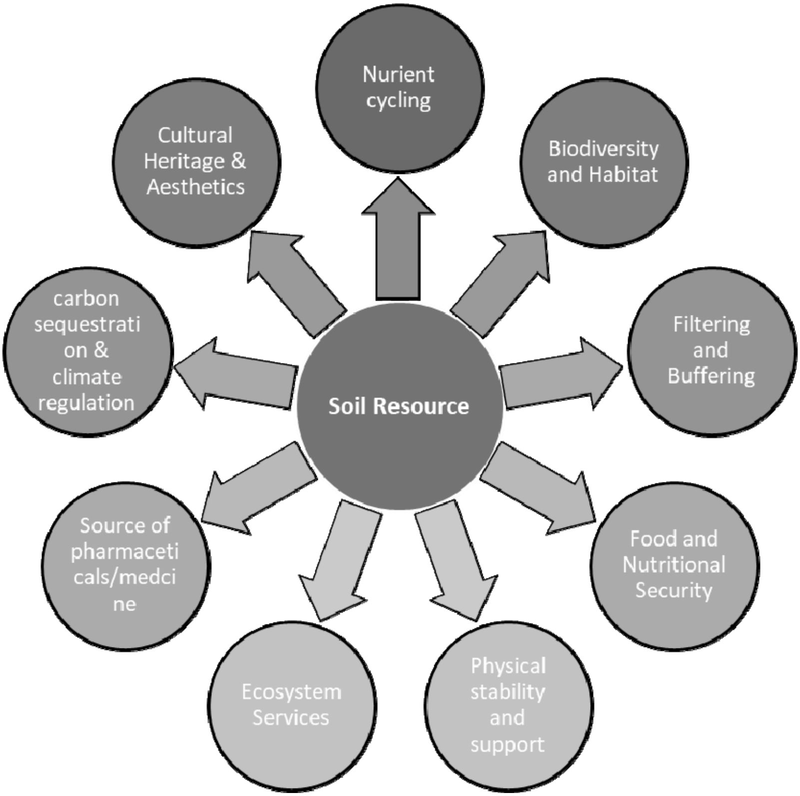

Figure 2. Different functions performed by soil (Source: Developed by Authors)

2. Importance of SSM

It is evident that agriculture contribution in gross domestic product (GDP) is large in developing countries and partially in developed countries. Globally, agriculture contributes 4% GDP (average). Globally, agricultural land area is 4.80 billion ha (2021) which is down by 0.13 billion ha compared to 2000 (4.93 billion ha). Out of this area, 3.2 billion ha area is under pasture and meadows and 1.6 billion ha area under agriculture (FAO 2021). Farming is entirely dependent on soil resource coupled with sustainable soil management and optimum agronomic practices. Therefore, soil resource needs to be conserved and preserved for the posterity for food and nutritional security vis-à-vis Sustainable Developmental Goals (SDGs).

3. Sustainable Soil Management: *Challenges, Prospects and Benefits*

SSM is *'One Stop Solution'* to address soil, plant, carbon sequestration, greenhouse emission (GHG), climate change and environmental issues. SSM focusses on soil as it addresses different landscapes [agriculture, agri-horticulture, pasture, integrated crop livestock system (ICLS)] for bringing more benefits in each land use systems.

a. Soils

Soil plays a significant role in farming and food production. World has witnessed calamity, pandemic, climatic extremes such as drought, floods, water logging, etc. Whenever, we think of food grain production and sustaining life on earth, the soil comes first to fulfilling food and nutrition. This also requires fertilizer inputs since organic nutrients source is insufficient for optimum food production and nutritional security. Worldwide, about 190 million tonnes of fertilizer was used for food production during 2019 (FAO 2021), out of which 57% is nitrogen-based fertilizer. Due to the increase in fertilizer costs, the per capita of crop land decreased across all regions (2000 and 2019); the largest decrease was observed in Africa followed by America, and Asia. In addition, soils are threatened by many problems such as soil erosion by water and wind, soil organic carbon loss, soil nutrient imbalance, soil salinization, soil contamination, acidification, loss of soil biodiversity, soil sealing, soil compaction and waterlogging (FAO 2017).

b. Crops

Sustainable soil management cannot be achieved by managing soil *per se*, but it should be complemented with agronomic and other management practices (White et al. 2012; Lal 2014; Stagnari et al. 2019). Choosing appropriate cropping system/rotations and crop cultivars, which can provide livelihood security to growers/farmers and simultaneously taking care of soil system. We need to grow soil nourishing crops such as leguminous crops, which are able to fix atmospheric nitrogen (by establishing symbiotic relationship with bacterial groups, eg *Rhizobium, Bradyrhizobium*) and return nitrogen to the soil by roots and nutrient residue recycling via leaf fall. These crops not only provide carbon storage but also provide soil cover. Similarly, selection of crops having contrast rooting patterns so that different crops take nutrient and water from different layers (e,g Soybean intercrop with maize, Pigeon pea intercropped with maize or sorghum or legume-cereal rotations) (Davies et al. 2010). Water scarce region or rainfed areas suffer from various biophysical and socio-economic constraints affecting the productivity of crops and livestock. In addition, selection of climate resilient cropping system/conservation agriculture (minimum soil disturbance with residue retention) in rainfed region provides livelihood source to farmers and helps in maintaining live mulch on the soil surface and fodder to animals.

c. Fertilizer use/ Manures/amendments use

In earlier days, farming is generally practiced as *'subsistence farming'* where minimal use of inorganic fertilizers and higher use of organic manure (e.g. farm yard manure, crop residue, farm wastes, lime) was practiced, which eventually resulted in lower crop yields. During early 1960s in the era of Green revolution, '*intensive farming'* or high input based farming (higher fertilizer nutrient application and nutrient responsive cultivars) is widely used to feed the growing population (Figure 3) (Sanchez and Swaminathan 2015; Davies et al. 2010). Since then, application of fertilizers and manures/amendments are largely practiced to sustain crop productivity, reduce hunger and malnutrition and increase economic prosperity. High input-based farming sustained food and nutritional security (Borlaugh 2000), however, led to secondary problems such as yield stagnation, contamination of water bodies (eutrophication, hypoxia) and groundwater pollution by fertilizer nutrients. Therefore, there is an urgent need to develop guidelines and code of conduct for fertilizer use. Recently, FAO (2019a) developed an "*International Code of Conduct* *for the Sustainable Use and Management of Fertilizers"*. It is a voluntary guideline ('fertilizer code'), with special regard to avoid/reduce nutrient imbalances and soil pollution for achieving SSM. This 'Fertilizer Code' was finally endorsed by the 41st session of the FAO Conference in June 2019. Therefore, considering the importance of soil biodiversity, food, and environmental safety, we need to be very cautious while using fertilizers, pesticides, and manures at different scales. Adoption of 4Rs (right rate, right source, right placement, right timing) nutrient stewardship/integrated soil fertility management (ISFM) consists of balanced/integrated nutrient management (INM) coupled with biofertilizers for higher fertilizer use efficiency and crop yields and also maintains nutrient levels in safe range. Soil test-based fertilizer application (using sensors and tools/equipment) across different major cropping systems (site-specific nutrient management), recycling of nutrient (farm waste/crop residues), sewage water and sludge with utmost care and attention (circular nutrient management).

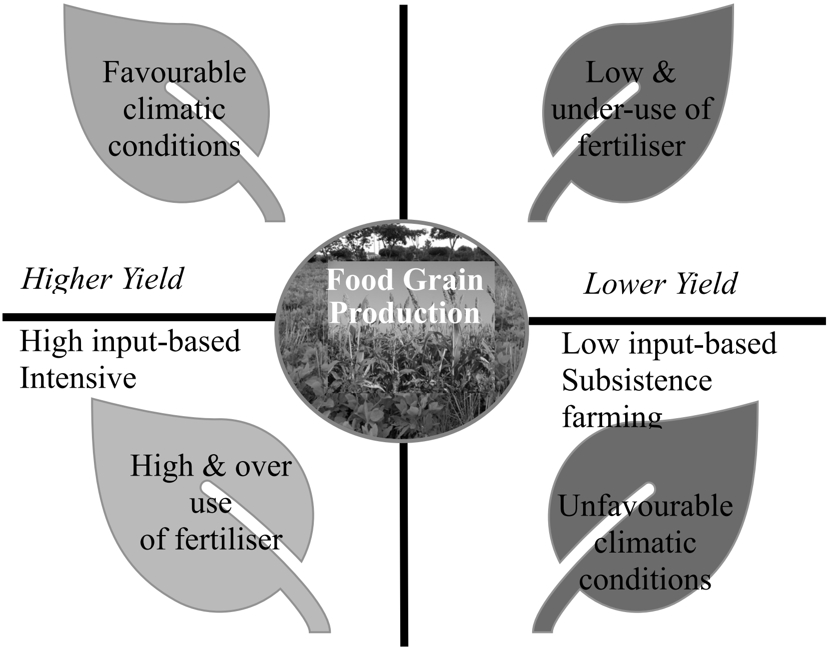

Figure 3. Comparison of intensive and subsistence farming (Source: Developed by the Authors)

d. Weeds and soil-borne disease management

Weeds (monocots and dicots) and soil-borne diseases (caused by pathogens such as *Fusarium, Pythium* and *Rhizoctonia* species) always pose serious problems in crop management. Sometimes, if not managed properly it may lead to yield penalty. Therefore, proper agronomic and soil management practices such as use of appropriate chemicals to control weeds and soil-borne diseases, mulching (organic/inorganic material, artificial material such as plastic films, introduction/maintenance of appropriate microbiomes to induce soil disease suppressiveness), crop rotation/intercropping, conservation tillage practices, soil solarisation and summer ploughing (where appropriate) to suppress weeds and soil-borne fungal diseases (Jayaraman et al. 2021).

4. Strategies and approaches for Sustainable Soil Management

a. Conservation Agriculture

Worldwide, no-till farming and conservation agriculture (CA) are is practiced on more than 200 million ha (Kassam et al. 2019). CA is a "*set of management practices involving minimum soil disturbance (conservation tillage/NT), maximum soil cover through residue cover or organic mulch and diversified cropping system/rotations"* (Figure 3) (FAO 2022). Generation of residue through growing of cover crops, is an important component of CA, which not only reduces soil erosion, supresses weeds, moderates soil temperature (Davies et al. 2010) but also improves soil organic carbon/soil health via residue recycling/addition (Figure 3) (Dalal and Bridge 1996; Lal 2015a, Dalal et al. 2011, 2018). Soil cover is a principle of CA, which can be created in many ways. Even in the semi-arid climates, soil cover is necessary to reduce soil evaporation and build soil health, water infiltration and water retention. In semi-arid region/ environment, including cover cropping in the rotation brings multiple benefits in these areas such as in the Mediterranean environments in Central Asia, Europe, Australia, and South Africa. In perennial systems, ground cover with dead or live mulch has been shown to be necessary part of the CA system (personal communication from Amir Kassam; Davies et al. 2010; Lal 2015a,b; Jayaraman et al. 2020, 2021a, b, c,d; Jayaraman and Dalal 2022). CA is a sustainable intensification approach, which is able to increase crop yield (5.6%), water use efficiency (12.6%), and net economic return (25.9%) and reduce global warming (12-33%) (Jat et al. 2021).

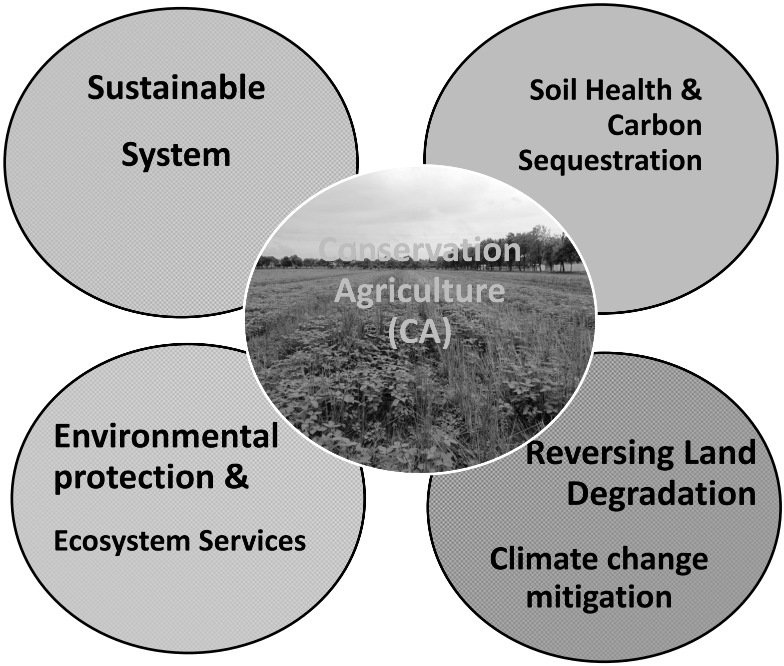

Figure 3. Conservation agriculture provides multiple benefits (Source: Developed by the Authors)

b. Regenerative Agriculture

Land (soil) degradation through soil erosion and loss of fertile topsoil is known as the most significant factor impacting productivity, livelihood of local communities and soil health. Thus, we need to protect our natural resources through SSM practices, which consist of resource conservation technologies, sustainable intensification, and CA/precision farming. Moreover, there is an urgent need to modify current farming/management practices to minimize the input use efficiency and soil disturbance via appropriate SSM practices/techniques. Thus, Regenerative Agriculture (RA), has been advocated for higher productivity, returns, sustainable production, and soil health (Lal 2021; TAAS 2021). RA is defined as practices aimed at promoting soil health by restoring soil's organic carbon (SOC). *It is a holistic principal-based approach to farming that helps to build/strengthen ecosystem and community services. RA Practices are instrumental in restoring the land to a holistic farming system".*

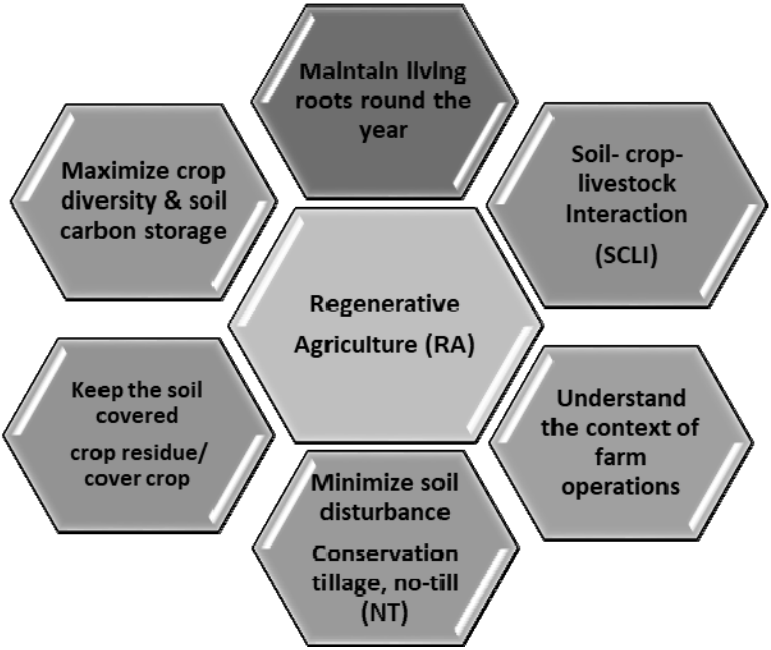

Figure 4. Components of Regenerative Agriculture (Source: Developed by the Authors)

In addition, the RA concept aids in reversing land degradation; maximizing crop productivity per unit area, enhancing C storage-soil biodiversity, soil health, and eventually enhances soil functions and ecosystem services. RA is a system-based approach, it includes a wide range of farming practices aimed at restoration and sustainable management of soil health through sequestration of SOC. It is a method of farming that improves the resources it uses, rather than destroying or deteriorating them. In RA concept, various practices/ strategies including conservation agriculture/no-till farming with residue retention, cover cropping, integrated farming system (IFS), integrated nutrient management (INM)/integrated plant nutrition system (IPNS) and pest-management, and agri-horticulture/agroforestry-systems have been promoted and advocated (Newton et al. 2020). For managed (arable) soils, it should be managed by mimicking nature's way to protect and improve soil biodiversity, soil health and sustainability and to protect them from degradation via unscientific land conversion. Thus, there is a need for policy application for incentives and rewards to farmers for carbon credits/ecosystem services for adoption of RA.

c. Organic Farming

The sustainable developing goals (SDGs) aimed to identify and restore the degraded soils and improve soil health by SSM practices/technologies (FAO 2017). One of the promising options and technology is organic farming, which can sustainably increase agricultural yield/sustainability without harming the environment or degrading soil quality (Tully and McAskill 2020), provided abundant organic amendments are available. Organic farming (OF) is recognized as a holistic production management approach that promotes and enhances overall agroecosystem health including biodiversity, biological cycles, and soil biological activity (Didawat et al. 2022). It is one of the options available to farmers for implementing SSM technologies while reducing use of chemical-based inputs but increasing organic amendments including composts.

Albert Howard (1940) is called the '*father of modern composting'*, for his refinement of a traditional Indian composting system into what is now known as the '*Indore method'*. Howard has noticed one of the important and interesting aspects was that '*the connection between healthy soil and the villages' healthy populations, livestock and crop*. He documented his experience in a book on '*An Agricultural Testament'*, and highlighted the importance of maintaining humus, keeping water in the soil, and the role of mycorrhizae and developed composting and organic farming techniques (Howard 2006). About 44 million ha (Mha) of agricultural land are managed organically worldwide, according to the most recent global survey conducted in more than 130 countries by the Research Institute of Organic Agriculture (FiBL, Switzerland) and The International Federation of Organic Agriculture Movements (IFOAM, Germany) (IFOAM 2016). Organic farming has many of potential benefits as compared to conventional farming e.g. improvement of soil aggregation, porous structure, soil microbial biodiversity, environment protection, and soil quality improvement, food safety and quality and premium rate of crop output (Stinner et al. 2007). As a result, organic farming has the potential to ensure the long-term viability of agricultural systems where sufficient organic inputs are used. Addition of large quantity of biomass/organic manure via organic farming not only improves produce quality but also improves SOC, soil health and agricultural sustainability (Sharma et al. 2011; Schweizer et al. 2021). However, it is more suitable in niche areas such as agri-horticulture, fruit trees, vegetable, etc. For annual crops such as wheat and rice, N, and other nutrients supplementation through addition of huge quantity of biomass/manure is quite challenging task. Of late, natural farming or zero budget natural farming (ZBNF) is gaining momentum to reduce inputs of fertilizers and pesticides as well as address emerging the poor biodiversity problems in agriculture.

d. Four Per Thousand (4PT) Programme vis-à-vis soil carbon

The '4 per thousand' programme has been ambitiously launched to increase soil organic carbon (SOC) by 0.4% per year globally at COP21 held in Paris, 2015 (Lal 2015b; https://4p1000.org/) within the framework of the Lima-Paris Action Plan (LPAP). This international "4 per 1000 (4PT)" initiative aims to exhibit that agricultural soils, can play a vital role in carbon storage vis-a-vis food security and climate change mitigation (van Groenigen 2018; Soussana et al. 2019; Rumpel et al. 2020). Despite the significance of soil-carbon as well as these societal imperatives, SOC sequestration is still not on the international political agenda, and it was not deliberated at the Bonn COP23 in Germany (2017) (Rumpel et al. 2018; Chenu et al. 2019). Lal (2016) has clearly indicated various strategies to promote SOC sequestration through adoption of best (recommended) management practices of carbon farming including conservation agriculture (CA), no-till farming, crop residue mulching/ retention (Figure 5), cover cropping, agroforestry, biochar application, improved grazing, and reversing degraded soils through sustainable soil management (Dalal et al. 2021a, b). Similarly, Minasny et al. (2017) conducted meta-analysis of 4PT initiative and discussed various strategies and approach of enhancing SOC (i.e. 2-3 Gt C yr^{-1} soil carbon can be increased in the upper 1 m of soil, this translates to reduce 20–35% of global anthropogenic greenhouse gas emissions) (Soussana et al. 2019; Henry et al. 2022). By adopting appropriate SOC practices, we can sequester carbon up to 5 Gt CO_2 yr^{-1} soil carbon, however, its effectiveness varies across agro-ecological regions and the level of adoption SOC practices by different land holders (Fuss et al. 2018), that is, it is region-site-socioeconomic context specific. In fact, increasing C by capturing atmospheric CO_2 by changing the management practices (by higher addition of nitrogen fertilizer) may lead to increase of other greenhouse gases such N_2O. Therefore, a suitable and appropriate SSM (involving nitrogen management) is advocated and recommended to curtail CO_2 emission into atmosphere across major cropping systems representing different agro-ecological regions of a country (Dalal et al.

2021a, b; Henry et al. 2022), while reducing N_2O emissions into the atmosphere.

Figure 5. Crop residue retention under maize-chickpea system
(Photo Source: Authors)

e. Other areas: Appropriate Soil and Water Conservation measures, site-specific nutrient management

Agricultural sustainability is threatened by soil erosion and degradation (Lal et al. 2007, Lal 2015b; Borrelli et al. 2017). On the other hand, water scarcity due to low rainfall or non-adoption of appropriate soil and water conservation measures impacts agricultural production. For example, farmers in South Asia (for example, India and Pakistan) (Wani et al. 2011) and African countries (Vohland and Barry 2009) in the rainfed regions receive entire rainfall in less than 100 days for the entire year. The amount of rainfall received during this period needs to be conserved for the whole year by adopting soil and water conservation measures (i.e. agronomic measures coupled with levelling and bunding, conservation ditches/ trenches) and bioengineering measures (farm pond/check dam) and water harvesting techniques to capture rainwater for improving crop productivity and livelihood security in the region (Wani et al. 2011; Delgado et al. 2020). In addition to soil and water conservation, site-specific nutrient management is another component of SSM, which needs to be sensibly used to sustain crop yield. Moreover, resource poor farmers often do not have too many choices to apply all fertilizer nutrients required in addition to nitrogen-based (N) fertilizer. Therefore, integrating N based fertilizer with organic input (crop residues, farm wastes, farmyard manure, composts) with biofertilizer is required for enhancing crop yield and also sustaining soil health. In addition, *in-situ* recycling of crop residue by application of microbial consortia will be helpful in reducing the residue burning and also increasing SOC stock. Thus, soil-centric based stewardship is required for reversing soil degradation, enhancing crop productivity and soil health for achieving food and nutritional security (Soussana et al. 2019; Dalal et al. 2021a, b).

f. Land degradation neutrality (LDN): Reducing Soil erosion and reversing land degradation

Worldwide, unprecedented soil erosion and land degradation due to inappropriate management or unscientific management. Accelerated soil erosion and terrain deformation in agricultural lands coupled with loss of top-fertile soils via erosion is a series concern across many countries. Large areas have been already degraded by one or other land degradation processes in many countries particularly in USA (32% area) (Lal 2003), China (30.7% area) (Guo et al. 2015), Africa (16%), Europe (17%) (Bai et al. 2008; Borrelli et al. 2017; Tamene et al. 2017), Australia (2/3rd area) and India (45%) (NAAS 2010; FAO 2019b)). Reducing soil erosion and reversing land degradation through appropriate conservation measures are urgently required. Thus, the land degradation neutrality has been launched to counterbalance the degradation. LDN is defined by Parties of Convention (UNCCD 2015; https://www.unccd.int/land-and-life/land-degradation-neutrality/overview) as "*a state whereby the amount and quality of land resources necessary to support ecosystem functions and services to enhance food security remain stable, or increase, within specified temporal and spatial scales and ecosystems*." LDN represents a paradigm shift in land management policies and practices, in which already 128 countries have signed out of 196 countries (https://www2.unccd.int/actions/achieving-land-degradation-neutrality). The LDN works in close alignment with SDG especially SDG 15.3 to revert degraded land, combat desertification, and ensure food security by 2030. The LDN revolves under three concurrent actions, namely *i) "avoiding new degradation of land by maintaining existing healthy land; ii) reducing existing degradation by adopting sustainable land management practices that can slow degradation while increasing biodiversity, soil health, and food production; and iii) ramping up efforts to restore and return degraded lands to a natural or more productive state"*. Besides, there are 19 principles outlined by LDN which governs the implementation process (Source: https://www.unccd.int/land-and-life/land-degradation-neutrality/overview).

g. *Sustainable Soil Management for Climate Change Mitigation*

Sustainable soil management (SSM) practices consist of SOC centered approach, which is a promising option not only to improve soil health, enhance food security and farm incomes, but also to mitigate climate change (Lal 2004; Powlson et al. 2010, 2011; Paustian et al. 2016; FAO 2019a). The SSM impacts on soil health (by improving physical, chemical, and biological properties), carbon sequestration and reducing greenhouse gas emission (Lal 2015b). Organic C and N management plays a significant role in food grain production and soil health. Sometimes, increasing SOC by higher addition of N fertilizer results in increase of other greenhouse gas (GHG) emission such as N_2O and CH_4. Therefore, appropriate SSM across agroecological region and dominant cropping system is urgently required to curtail temperature increase not more than 1.5 to 2.0 ºC in alignment with Paris Agreement and the Global Agenda vis-a-vis Sustainable Development Goals (Söderström et al. 2014; Dalal et al. 2021a, b; Henry et al. 2022). A need for better framework consists of decarbonization programme with SSM would be potential option of cropped soils to mitigate climate change via carbon sequestration as well as reducing GHG emissions of N_2O and CH_4 into the atmosphere (Rumpel et al. 2022).

Conclusions

Feeding 8 billion people is always and remains a challenging task amidst of global challenges such as pandemic, land degradation, global warming, and climate change. Soil is a vital resource which not only provides food and nutritional security but also performs many ecosystem functions and services such as water purification, nutrient cycling, climate change mitigation/regulation, contaminants and pesticides retention and degradation, cleaning environment and flood prevention, and cultural heritage and aesthetic provisioning. Therefore, sustainable soil management is essential for all sectors such agriculture, forestry, fisheries, health, and allied-industrial sectors. Much has been said about the importance of soils vis-a-vis sustainable development goals (SDGs) (UN 2015). There are 7 SDGs directly linked with soil resource namely SDG1 (End poverty), SDG2 (Zero hunger) SDG3 (Good health and well-being), SDG 5 (Gender equality), SDG6 (Glean water and sanitation), SDG7 (Affordable and clean energy), SDG 9 (industry, innovation, and infrastructure), SDG 11 (Sustainable cities and communities), SDG 13 (Climate Action) and SDG 15 (Life on Land). Therefore, protecting soil