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Editors

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Managing Soil Health For Sustainable Agriculture

Bhumi Publishing

First Edition: 2022

MANAGING SOIL HEALTH FOR SUSTAINABLE AGRICULTURE

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PREFACE

A summary of how to improve soil health can be found in the new book "Managing Soil Health for Sustainable Agriculture" by Dr. Prem Kumar Bharteey, Mr. Ayush Bahuguna, Ms. Nidhi Luthra, and Dr. Shakti Om Pathak. This book is a compilation of prestigious articles written by renowned experts in the field of managing soil health and Sustainable agriculture.

People need food to survive which is dependent on nature. In this era, comprehensive thinking is needed to meet the increased consumer demands. Today the population of the world is increasing rapidly and resources are being consumed at the same rate, due to which the availability of land is also decreasing day by day and there is a need to create awareness about food. To transfer future generations to a more sustainable way, increasing the number of conscious producers and consumers, strengthening awareness for sustainable foods, respecting the natural balance and gaining a sense of responsibility, consumption habits will have to be saved. Our main goal. The greatest success in agriculture today will be achieving the desired increase in production while minimizing negative environmental conditions. This can be achieved only by implementing sustainable methods and sustainable solutions in agriculture. The fact that agricultural activities and practices are environmentally friendly and sustainable is very important in terms of contributing to the sustainability of the ecology. We hope that this book imparts basic and innovative knowledge of various of soil health and Sustainable agriculture.

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CONTENT

Managing Soil Health for Sustainable Agriculture
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Chapter

1

PRINCIPLES OF SUSTAINABLE AGRICULTURE

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INTRODUCTION

Sustainable Agriculture is the successful management of resources for agriculture to satisfy the changing human needs, while maintaining or enhancing the quality of environment and conserving natural resources. Sustainable agriculture defines to the capability of a farm to produce food indefinitely, without triggering severe or temporary damage to ecosystem health. Biophysical (the long-term consequences of diverse practises on soil qualities and processes crucial for agricultural productivity) and socio-economic issues (the long-term ability of farmers to obtain inputs and manage resources such as labour) are two major problems. The physical aspects of sustainability are partly understood. Excessive tillage (which promotes erosion) and irrigation without appropriate drainage (leading to accumulation of salt in the soil) are two practises that can harm soil over the long term. The best information on how different methods affect soil qualities important to sustainability comes from long-term research.

Agroecology, regenerative agriculture, organic farming, natural farming, and sustainable farming are a few of the term most commonly used to represent diverse sustainable agriculture approaches. Sustainable agriculture is farming that is performed in a manner that doesn't compromise future generations' ability to fulfil their own requirements. It is founded on an understanding of ecosystem services, which is the study of interactions between organisms and their environment. It is a long-term methodical structure that takes into consideration family, business, health, fairness, and ecological sustainability in a farming community.

In order to achieve sustainable development, the requirements of the present generation must be satisfied without affecting the ability of future generations to satisfy their own needs. To prevent or reduce the effect of environmental challenges, sustainability is essential. Agriculture sustainability refers to the process of ensuring that present approaches of interacting with agriculture are continued with the goal of maintaining the environment as magnificent as naturally possible based on ideal-seeking behaviours. Plants, animals, microbes, and their environment interact dynamically to form ecosystems that function as a single, cohesive system. Ecosystems that lose their balance will deteriorate.

It is defined by three essential characteristics, namely:

1. Economic benefit
2. Environmental responsibility
3. Being socially responsible.

For agriculture to be sustainable, it must be profitable, environmentally friendly, and promote social and economic equality for both the present and future generations. The environmental, social, and economic aspects of sustainable food and agriculture (SFA) have an impact on sustainability dimensions as well as availability, access, utilisation, and stability, which are the four pillars of food security. A sustainable food and agriculture vision is one in which everyone has access to good quality food and where natural resources are utilised effectively to meet both present-day needs and future.

BASIC PRINCIPLES OF SUSTAINABLE AGRICULTURE

The basis of agricultural sustainability is the principle that we must satisfy our needs to enforce without affecting the ability of future generations to satisfy their own demands. Therefore, short-term economic gain is just as important as long-term conservation of both natural and human resources. Conservation of human resources includes taking into consideration social duties such as living and working conditions of farmers, the needs of rural populations, and the current and long-term health and safety of consumers. Land and natural resource stewardship entails preserving or improving the quality of these resources and utilising them in ways that enable future regeneration. Stewardship considerations must also address concerns about animal welfare in farm enterprises that include livestock.

1. The application of biological and ecological principles used into agriculture and food production. These procedures might consist of nitrogen fixation, soil regeneration, and nutrient cycling,
2. Using decreased amounts of non-renewable and unsustainable inputs, particularly the ones that are environmentally harmful.
3. Using the expertise of farmers to both productively work the land as well as to promote the self-reliance and self-sufficiency of farmers.
4. Solving agricultural and natural resource problems through the cooperation and collaboration of people with different skills. The problems tackled include pest management and irrigation.

Although there is air and sunlight everywhere on Earth, crops also need nourishment in the soil and a source of water. Some of these nutrients are taken out of the soil when farmers cultivate and harvest their crops. The land would become nutrient-depleted and unfit for further farming without replenishment. In order to be sustainable, agriculture must restore the soil while using these kinds of non-renewable resources as possible, such as mineral ores or natural gas (used to transform atmospheric nitrogen into synthetic fertiliser) (e.g., phosphate). Potential nitrogen sources that would, in theory, always be accessible include:

1. Recycling animal or human waste and agricultural waste
2. Growing forages and legume crops like groundnut or alfalfa that symbiotically fix nitrogen with bacteria called rhizobia.

3. The Haber Process, which produces nitrogen industrially, depends on hydrogen, which is currently obtained from natural gas. However, hydrogen might instead be produced by electrolyzing water with electricity (perhaps generated by solar or wind energy), or

4. Using genetic engineering to generate nitrogen-fixing symbioses or nitrogen fixations without the use of microbial symbionts in non-legume crops.

The three basic objectives of sustainable agriculture are social and economic fairness, economic profitability, and environmental health. To achieve these objectives, various ideologies, rules, and procedures have been used.

ACCORDING TO FAO FIVE KEY PRINCIPLES OF SUSTAINABILITY FOR FOOD AND AGRICULTURE

1. Increase productivity, employment and value addition in food systems.
2. Protect and enhance natural resources.
3. Improve livelihoods and foster inclusive economic growth.
4. Enhance the resilience of people, communities and ecosystems.
5. Adapt governance to new challenges.

CURRENT CONCEPT OF SUSTAINABLE AGRICULTURE

The fundamental objective or the outcomes of sustainable agriculture is to develop agroecosystem systems that are productive and profitable, conserve the natural resource, environmental protection, and enhance health and safety, and to do so over the long-term. Low input techniques and skilled management are the means of achieving the above; people seek to maximize the management and use of internal production inputs (i.e., on-farm resources) in cases which provide acceptable levels of sustainable crop yields and livestock production and lead to financially rewarding returns. In order to prevent soil erosion, reduce nutrient losses, and maintain or improve soil productivity, this strategy stresses cultural and management methods such crop rotation, recycling of animal manures, and conservation tillage**.**

In order to reduce production costs, prevent surface and groundwater pollution, reduce pesticide residues in food, lower a farmer's overall risk, and increase both short- and long-term farm profitability, low-input farming system actually works to minimise the use of external production inputs (i.e., off-farm resources), such as purchased fertilisers and pesticides. The majority of high input farming systems will likely fail sooner or later since they are neither long-term economically or environmentally viable, which is another reason for the focus on low-input farming systems.

GOALS OF SUSTAINABLE AGRICULTURE

1. A more extensive integration of natural processes including nutrient cycling, nitrogen fixation, and interactions between pests and predators into agricultural production systems.

2. Reducing the use of off-farm, external, and non - renewable sources that have the greatest potential to harm the environment or the health of producers and consumers, and using the remaining resources more effectively in order to reduce variable costs.

3. The complete participation of farmers and rural populations in all process of technology development, adoption, and extension as well as problem analysis.

4. A more sustainable livelihood to predictive resources and assistance, and improvement towards more socially just forms of Agriculture.

5. Constantly making the greater use of the genetic and biological potential of various plant and animal species.

6. A more effective use of local knowledge and practises, including novel techniques that scientists and farmers have not yet completely grasped.make productive use of the knowledge and skills of farmers, thus improving their self-reliance and substituting human capital for costly external inputs.

7. A development in people in rural areas' and farmers' independence. To make productive use of people's collective capacities to work together to solve common agricultural and natural resource problems, such as for pest, watershed, irrigation, forest and credit management.

8. An improvement in the compatibility between cropping patterns and the environmental restrictions of climate, as well as potential for production and landscape to assure the long-term sustainability of current output level.

9. Profitable and efficient production with an emphasis on integrated farm management and the conservation of soil, water, energy and biological resources.

PRINCIPLES OF SUSTAINABLE AGRICULTURE

1. Social & Environmental Management System
2. Ecosystem Conservation
3. Wild life protection
4. Water conservation
5. Occupational Health & Safety
6. Community Relations
7. Integrated crop management
8. Soil management and conservation
9. Integrated waste management

SOCIAL AND ENVIRONMENTAL MANAGEMENT SYSTEM

An organization can decrease negative effects on the environment and improve operational effectiveness by implementing an Environmental Management System (EMS), which is a collection of procedures and methods. For small enterprises, the corporate sector, as well as local, state, and federal authorities, this site gives resources and information about EMS. An EMS is a framework that enables an organization to continuously examine, assess, and enhance its environmental performance in order to accomplish its sustainability goals. The idea is that by regularly reviewing and evaluating the organization's environmental performance, possibilities for improvement and implementation will become apparent. Each organization's EMS is customized to meet its own goals and objectives. the EMS itself does not specify a level of environmental performance that must be achieved.

Ecosystem Conservation:

The key to our safe future is the conservation of natural resources through sustainable ecosystem management and development. Inventorying and monitoring an ecosystem as well as using integrated technologies, practices, and interdisciplinary approaches are all part of ecosystem sustainability. Therefore, having an understanding of the environment is more important now than ever. Ecological and environmental education must be ingrained in the educational system at all levels of education if this vision is to be realized. The imperative for humankind as a whole to comprehend environmental issues and adhere to sustainable development principles is now more important than ever. Our environment is degrading as a result of ongoing pollution, forest loss, solid waste management, and other challenges.

Wildlife protection:

Conservation agriculture practices on farms, forests, and ranches benefit wildlife by enhancing soil health, water quality, and plant diversity. Additionally, they produce profitable, productive agricultural land that is more resistant to fire, drought, and other natural calamities.

Wildlife-friendly farming practices include**:**

(i) planting plants or shrubs along streams and rivers to control erosion.

(ii) To protect wildlife and water quality due to integrated pest control.

(ii) Crop "stubble" should be left on the fields to serve as a shelter for nesting birds.

Water Conservation:

In the world's 90% of groundwater and 70% of its freshwater are used by agriculture, which also contributes to several environmental issues such pollution, groundwater depletion, and river drought. In order to support sustainable agriculture and feed the expanding world population, water conservation is therefore considered to be a must. The primary methods for addressing the shortage of water resources in agriculture are to increase water supply (e.g., interbasin water transfer, artificial precipitation) and improve water use efficiency through water-saving technologies (e.g., dripping irrigation, mulching, deficit irrigation, and water-saving cultivars). In actuality, several scales of water use efficiency are measured to the help of people to understand the significance of the process of water consumption and to increase water productivity.

Occupational Health and Safety:

The problem facing the agricultural and forestry industries is ensuring a more sustainable future in terms of striking an appropriate balance between environmental protection and agricultural growth in order to provide safe and healthy food for a growing population. Occupational safety and health (OSH) play a significant role in boosting production and profitability, but they also significantly influence the improvement of environmental and social issues. However, in principle, the sustainability viewpoint has frequently placed a greater emphasis on problems related to the environment and the economy, leaving major global and workplace concerns, including OSH, underemphasized or altogether ignored.

Community Relations:

In order to make agriculture more profitable by introducing more technical and scientific methods and increasing the utility of bio-fertilizers and bio-pesticides against fertilisers, which not only present a threat serious health risks but also destroy the fertility of agricultural lands.

Objectives:

(i) To save cultivation costs by eliminating chemical pest management

(ii) To increase net incomes and withstand lives dependent on agriculture

(iii) To increase women's capacities and skills to support agricultural and farm-related activities

(iv) To increase farmland's natural resource base

Integrated Crop Management:

Crop can be managed using the Integrated Management approach in urban, agricultural, or natural ecosystems. The strategy's main objective is to put into practises a wide range of management approaches chosen to control the rate of environmental deterioration and minimize the impact of chemical inputs on people and non-target species. The sustainability of many agro-ecological systems depends heavily on the sustainability of many agro-ecological systems depends heavily on integrated crop management.

Integrated management Program, is "an ecosystem-based strategy that focuses on long-term prevention of crops or their damage through a combination of techniques like biological control, habitat modification, modification of cultural practises, and use of resistant varieties. Pesticides are only used when monitoring suggests they are required in accordance with prescribed norms, and treatments are performed with the intention of eliminating only the target organism. Materials for pest control are chosen and used in a way that poses the fewest dangers to the environment, beneficial and nontarget species, and human health.

Soil management and conservation:

The majority of living things are sustained by the soil since it provides all of their mineral requirements. A healthy soil management system provides that the appropriate nutrients enter the food chain and that they don't become toxic or insufficient for plants. Soil management is significance affects crop yield and environmental sustainability, Both directly and indirectly and human health. The management of soils will be more essential than ever in the upcoming years due to the expected increase in the global population and the resulting need to enhance food production. The difficulty will be managing soils in a sustainable way through correct nutrient management and appropriate soil conservation methods in order to attain future food security. Research will be needed to produce enough safe and nutrient-rich food for healthy diets and to prevent excessive soil degradation due to erosion or contamination.

Integrated waste management:

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Waste management the process of collection, transport, disposal, recycling, and monitoring of wastes. The waste control is performed to recycle the wastes so as to reduce the negative effects of wastes on environment, health, and aesthetics. Wastes are manufactured in many different categories, including industrial, mining, municipal, and agricultural wastes. Medical and nuclear wastes are two examples of wastes that are more dangerous. Waste management methods include landfilling, incineration, anaerobic digestion, pyrolysis, plasma gasification, recycling, and composting, among others. Biogas, the end product of anaerobic digestion, is used as a biofuel. By using plasma gasification, wastes are converted into power. Recycling of wastes involves the collection, sorting, and reprocessing of wastes into new products.

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Chapter

2

SOIL PRODUCTIVITY IMPROVEMENT AND MAINTENANCE

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INTRODUCTION:

Soil productivity is essential for agricultural development, food production, and agricultural sustainability. Agriculture is the principal source of economic growth in the majority of developing countries (Karlen, 2005). Soil provides ecological services that allow life to survive and thrive. So, maintaining and improving soil health is essential for the ecosystem's long-term viability. Healthy soils produce healthy crops, which in turn feed people and animals (FAO, 2015). In most cases, soil productivity is determined by comparing inputs and outputs. In agriculture, "input" usually refers to plant nutrients, water, genetic resources, pest control, or work, and "output" usually refers to crop yield; thus, productivity is usually calculated as efficiency, i.e. water use efficiency or nutrient use efficiency (Karlen, 2005). Nowadays indiscriminate use of inorganic fertilizers, pesticides, fungicides, and weedicides has harmful effects on soil health, human health, groundwater health, and the environment (Singh *et al.*, 2020). Enhancement of soil productivity and increase in crop yields are obtained with the addition of manure, compost, farm yard manure, and green leaf manure (Srinivasa Rao *et al.*, 2011). The soil productivity can be enhanced by the use of biochar which gives the total soil organic carbon (SOC)sequestered inside the soil as compared to the natural process (Yeboah *et al.*, 2009). Biochar is an organic carbon- intensive which facilitates the water retention capacity, structure, carbon sequestration, and fertility of degraded soils. For boosting soil productivity, Integrated Soil Fertility Management (ISFM) has been adopted nowadays with the combination of organic and inorganic fertilizers for the production of the crop (Vanlauwe *et al.*, 2004). Soil fertility is not only one component of soil productivity, but it is also an important one. For example, the soil can be more fertile, yet there is less vegetation as a result of a lack of water or a temperate climate. Even in optimal climatic conditions, the soil's capability to create a suitable environment for root hairs varies. For sustainable agriculture, good natural fertility or soil fertility is essential. This chapter is mainly concerned with the preservation and improvement of soil productivity.

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WHAT IS SOIL?

Soil is a biologically porous and active substance that developed in the earth's crust's uppermost layer. Soil is a recipe of soil organic matter, gas, minerals, living organisms, and water. Soils are the host of minute to large living organisms which include insects, bacteria, fungi, protozoa, birds, and archaea. The soil microorganisms help to provide organic matter decomposition, transfer of essential nutrients from one place to another, nitrogen fixation, good drainage and aeration, and good soil structure through soil aggregation. Good physical characteristics of soil make a good soil condition which includes soil texture, soil color, soil structure, soil depth, soil porosity, and soil stone content. It serves as a storehouse for nutrients, air, and water. It is also a means of purifying and breaking down hazardous material. It also helps the carbon cycle, nitrogen cycle, and the movement of other components throughout the global environment. It has evolved as a result of weathering processes influenced by biological, climatic, geologic, and topographic factors. The soil color indicates the organic content inside the soil in which dark brown soil indicates high organic matter content, black soil indicates the presence of humus, red soil indicates the presence of iron and free draining, green/grey/blue soil indicates water logging and poor drainage while the yellow soil indicates less weathering and moist conditions (Leeper and Uren, 1993). A good soil structure influences plant health and soil by allowing air and water movement inside the soil profile. The number of soil pores also influences the capacity of soil drainage inside the soil profile. The higher clay content in the soil increases the strength of the structure but decreases the drainage capacity. The excessive compaction and declining space for macrospores between the aggregates reduced the amount of air and water inside the soil (Leeper and Uren, 1993). Some important soil function is shown in Fig.1

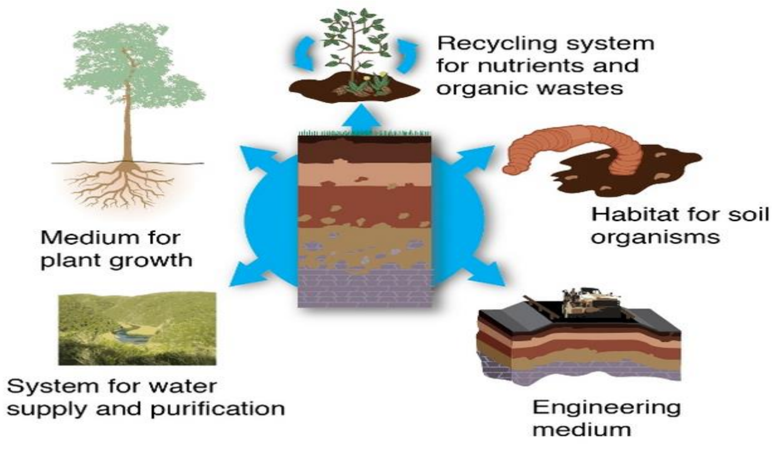

Figure 1: Functions of soil (Source: Adopted from Needelman, 2013)

Soils provide support for roots, allowing them to hold water and nutrients. Soil is home to a myriad of microbes that fix nitrogen and decompose organic materials, as well as armies of small animals, earthworms, and termites, are important aspects of soil are:

- The function of soil provided that plant growth factors
- Environmental Interaction: storage, filtering, and transformation

- Physical and cultural heritage
- Development and dissemination of roots in the soil
- Carrying nutrients, water, and air to the root surface for plants absorption
- Habitat for soil organism

SOIL ENVIRONMENT?

The soil environment consists of a variety of physical, chemical, and biological factors that affect the abundance and diversity of microbes found in soil (Sylvia, 2005). The nutrients uptake by the plants and minerals available to the plant is related to the soil environment. So, the abundance, growth, and distribution determine the soil environment. The soil environment consists of a solid and porous fraction, and in these fractions, a variety of physical and chemical factors interact and are influenced by microbes. These consist of temperature, texture, pH, oxygen, exchange properties, and redox reactions. It is divided into three types: such as the physical, chemical, and biological environment.

a) **Physical environment:** The physical environment is related to morphology, thermal properties, temperature, water, structure, texture, color, aeration, stress, and resistance.

b) **Chemical environment:** The chemical environment is related to nutrient availability, organic matter, pH, acidity, salinity, and sodicity.

c) **Biological environment:** The biological environment is related to microorganisms and microbial activity in the soil.

WHAT IS SOIL PRODUCTIVITY?

Soil productivity is the capacity of soil to produce a certain yield of crops or other plants by following a set of management methods (Karlen, 2005). Soil, climate, pests and diseases, plant genetic potential, and human management are key factors in soil productivity measured by crop yield. The total amount of nutrients is not only sufficient but must also be obtained in an easily available form and a balanced ratio. In addition to fertility, other factors also determine productivity.

"All productive soils are fertile, but all fertile soils are not productive"

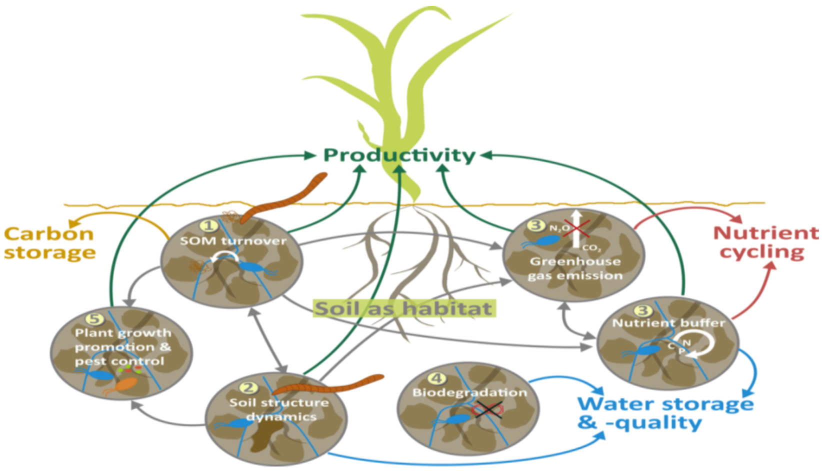

Figure 2: Soil productivity-related component (Source: Bonkowski, 2004)

Soil productivity is the capacity of soil to support plant growth under normal conditions. It provides nutrients and water for plant growth, a medium for plant root growth, and sustainable land management is required to maintain soil productivity. The improvement in soil productivity is shown in Fig. 2.

MOST PRODUCTIVE SOIL

There are twelvekinds of soil order in the world. Among all soils order, the Mollisols soil order has high productivity and fertility because it is rich in organic substances added for a long time from plant roots. Due to its high organic content, it is considered to be the most productive land in the world. In India, Alluvial soil is the most productive soil, located in parts of Uttar Pradesh, Some parts of Punjab and Haryana, Bihar, West Bengal, and North East India.

FACTORS AFFECTING SOIL PRODUCTIVITY

Soil productivity factors include all factors that affect the physical, chemical and biological properties of the soil environment in which plants flourish. All practices that affect fertility, water, and air interactions, and biological agent activity such as bacteria, disease insects, and pests are covered.

a) **Genetic (Internal factors):** termed as hereditary factors which cannot be manipulated such as soil texture etc.
b) **Environmental (External factors):** Aggregate all the exterior conditions and influences affecting the life and development of an organism.
c) **Climatic factors:** precipitation, solar radiation, atmospheric gases, wind speed, etc
d) **Edaphic factors:** soil mineral matter, soil inorganic and organic components, soil air, soil temperature, soil moisture, and microorganisms
e) **Growth restricting substance**
f) **Biotic factors:** Plants, Bacteria of symbionts, and free living
g) **Animals**: rats, crabs, mole cricket, termite, and earthworms
h) **Physiographic factors:** geological strata
i) **Anthropogenic factors:** Human factors such as cultivation skills and efficiency

SOIL FERTILITY

Soil fertility is the soil's capacity to support plant growth and maximize crop yield. Soil productivity can be increased by improving soil fertility. To improve soil fertility, organic and inorganic fertilizers can be added. This is the most effective maternal management system and a low-cost method of increasing fertility. Soil productivity increases as soil fertility improve. Soil fertility is defined as the soil's ability to produce economically valuable plants to maintain soil health. Recent studies show that the efficacy of city waste compost in the sodic and saline soil reclamation improves the soil quality in the wheat-rice, pearl millet crop in the Indo-Gangetic plains of India (Sudha *et al.*, 2020; Singh *et al.* 2018). Soil productivity improvement is shown in Fig. 3

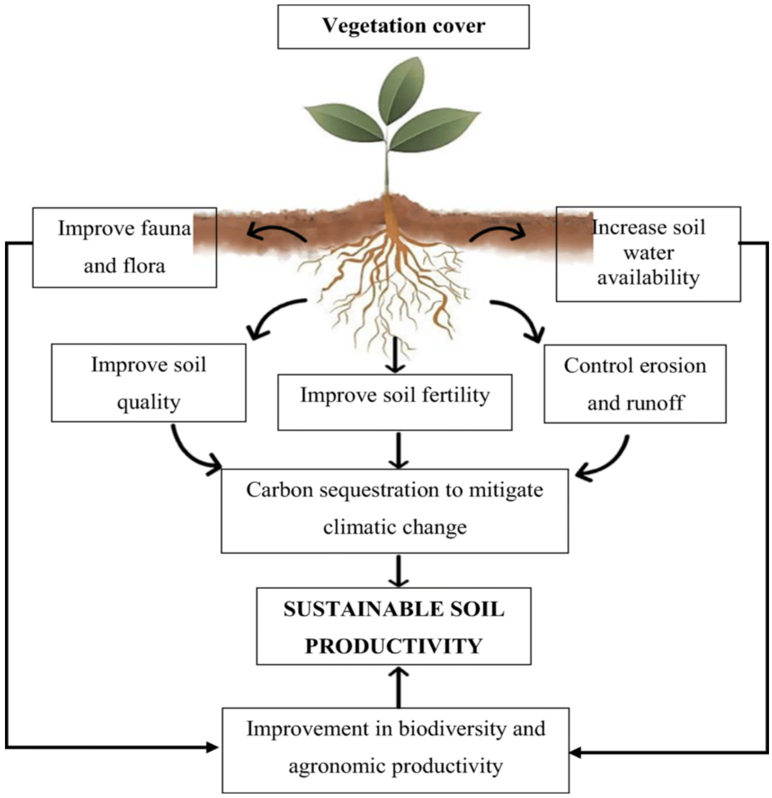

Figure 3: Soil productivity improvement through soil fertility enhancement (Source: Adopted from Khadija *et al.*, 2021)

Difference between soil fertility and soil productivity

S.No.	Soil fertility	Soil productivity
1.	The capacity of the soil to supply all essential plant nutrients in useful forms and a suitable balance is known as soil fertility	The capacity of soil to produce a specified crop yield under well-defined and specified input and environmental conservation systems.
2.	One of the crop production factors; also includes water supply, etc.	It is viable that all of the factors will interact.
3.	It can be analyzed in the lab.	It can be assessed in the field under particular climate conditions.
4.	It is the soil's potential to produce crops.	a result of several factors that have an impact on soil management
5.	It is determined by the soil's physical, chemical, and biological factors.	Depending on factors like geography, fertility, health, etc.
6.	It is a natural property of soil.	It is not a natural property of soil.
7.	Not all fertile soils are productive.	All productive soils are certainly fertile.

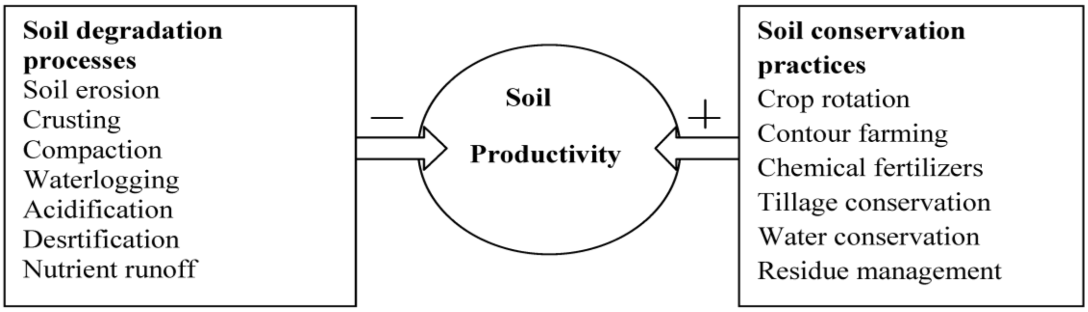

Figure 4: Relationship of soil productivity to soil degradation and soil conservation

SOIL DEGRADATION PROCESSES

Soil degradation is the deterioration of soil conditions caused by improper use or poor management, most commonly for agricultural, industrial, or urban purposes. It is a major environmental problem. Soil erosion, excessive salts, chemical degradation, physical degradation, and biodegradation are all part of the land-degradation process.

Impact of soil degradation on soil productivity

Soil degradation endangers future production potential by causing soil severity and biodiversity loss, salinization of irrigated areas, excessive use of groundwater, pollutant accumulation, and pest resistance. Rapid increases in agricultural production and productivity have a negative impact on agricultural natural resources in general.

SOIL EROSION

Soil erosion has been occurring since the ancient period, but it has become more severe as human populations have increased. Because of the deterioration of physical land qualities and land degradation caused by soil erosion, agricultural production and productivity are reduced. Soil erosion reduces the diversity of plants, animals, and microbes, ultimately jeopardizing the stability of entire ecosystems (Bharteey *et al*., 2019).

Soil erosion is defined as the separation of soil particles from the parent body, transportation from one location to another, and deposition in other locations as a result of causing agents such as water, wind, gravity, and other forces. Soil erosion occurs in three stages, which are as follows:

a) Detachment of soil particles
b) Spraying, floating, rolling, and pulling are all methods of transporting soil particles.
c) Soil particle deposition elsewhere.

The most productive portion of the soil profile used for agriculture is the most valuable soil, which is removed by soil erosion. This loss of soil diminishes production and increases production expenses. The soil erosion effect is shown in the following Fig. 5

Figure 5: Soil Erosion (Source: Frederick J. Weyerhaeuser / WWF-Canon)

The effects of erosion on farmland and crops are:

a) Reduced capacity of soil to store moisture and nutrients
b) Destroy soil infrastructure
c) Reduces physical, chemical, and biological properties
d) Loss of newly planted plants
e) Low-grade mud deposits.
f) Loss of plant nutrients
g) Reduce soil productivity

OVERGRAZING

The initial damage caused by turning natural ecosystems into pasture land is less than that caused by growing crops, but this change in land use can result in high rates of erosion and loss of topsoil and nutrients. Overgrazing is caused by the intensive grazing of plants for a long period. It can be caused due to lack of animal management in which the owner does not provide them proper food and leads them to feed on any land, improper use of the land, and finally overstocking. One of the contributing factors is desertification, land degradation, loss of beneficial species, and erosion due to overgrazing, which decreases soil productivity and biodiversity. It can be controlled by early grazing avoidance and the use of a grazing chart.

Figure 6: Land affected by overgrazing (Source: Agbenyuie, 2017)

Overgrazing is believed to be the cause of the spread of invasive foreign plants and weed species. Walking while grazing cows can cause major and related changes in soil surface properties such as:

- Increase in soil strength and bulk density
- Reduction in soil Aeration
- Reduction of hydraulic permeability.

DESERTIFICATION

Arid regions of the world (dry, semi-arid, and sub-humid with potential evaporation exceeding precipitation) account for about 40% of the earth's surface. The range and intensity of desertification have increased in some dryland areas over the past several decades. Land degradation in arid, semi-arid, and dry sub-humid environments brought on by several factors, such as weather changes and human activity, is known as desertification (United Nations Convention to Combat Desertification 1994). The effects of desertification are shown in Fig. 7.

Figure 7: Land affected by desertification (Source: Adopted from Priyam, 2020)

SALINIZATION

Soils affected by salinity and sodicity are not confined to just arid and semi-arid regions, where rainfall is insufficient to leach salts from the soil (Shahid *et al*. 2018). Salinity is the buildup of salt content on or near the surface as a result of a total lack of soil productivity, and it is eventually brought on by practices like irrigation and groundwater evaporation. Saline medium has a very high concentration of soluble salts, which will have an impact on plant production and growth. There are three ways that salt in the water and soil can affect plant growth. By raising the osmotic potential, it can reduce the water consumption rate

a) Several ionic effects can be created by enhancing the ion concentration and inhibiting cellular metabolism.
b) By adversely impacting the soil structure, it might decrease soil aeration and moisture permeability. The type of crop being grown determines how negatively soil salinity affects plant growth and output.

Figure 8: Impact of soil salinization on crop and soil

WATERLOGGED SOIL

Soils that have been saturated with water for a significant amount of time in a year are said to be waterlogged. Waterlogging has been a big constraint to cereal crops across the globe (Manik *et al.,* 2019). It affects the soil chemically, physically, biologically and electro-chemical characteristics (Ferronato *et al.,* 2019).It also affects the growth of plants by minimizing the oxygen dispersal through the pore space inside the soil and the root zone area (Christianson *etal.*, 2010). The waterlogged soil contains the toxic metabolite ethylene which affects root growth (Shabala, 2011). Due to waterlogging, the productivity of the land is impacted and the carbohydrate production is reduced as also the photosynthetic rate (Perez-Jimenez *et al.,* 2018) Fig. 9 shows numerous changes to soil characteristics carried on by waterlogging

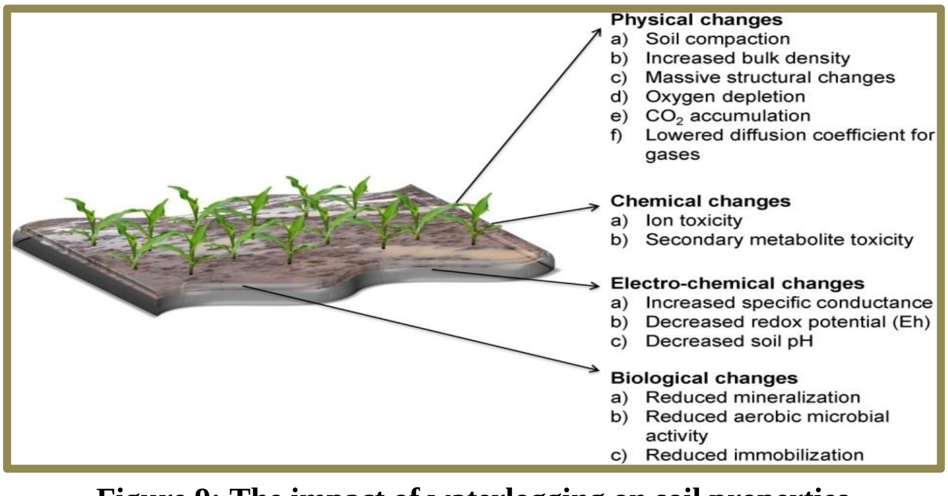

Figure 9: The impact of waterlogging on soil properties
(Source: Adopted from Manik *et al.,* 2019)

ACIDIFICATION

Lowering the pH of the soil results in soil acidification, which is the creation of hydrogen cations. When a proton donor is added to the medium, this happens chemically. Acids like nitric acid, sulfuric acid, or carbonic acid are examples of donors. It could also be a substance that reacts in the soil and releases protons, like aluminium sulfate. The soil pH in the soil affects the clay minerals in the soil which contain aluminum (Carol, 2015). This aluminium is toxic to the plants and lowers the pH value of the soil causing the yellowing of leaves, stunting plants, and hampering the crop vigor during the early stages (Carol, 2015). When this aluminium is released into the soil they will bind with the magnesium and calcium causing leaching out to the root zone areas (Carol, 2015). When a fertilizer based on aluminum is applied to the soil surface it converts quickly to nitrate and a nitrification process occurs which releases a large number of hydrogen ions and makes the soil acidic. Fig. 10 shows a few effects of acidity on plant growth and health. Due to various soil changes caused by the acidification process, such as:

- The nutrient shortage for plants
- Toxicity of elements in soil
- Problems in weed control
- Effect on aquatic biota
- Decrease in the microbial populations in the soil
- Reductions the activity of nitrifying bacteria
- Limit the development of nodules on leguminous roots
- Decrease in soil productivity
- Decrease in soil fertility
- Increase in soil salinity and erosion

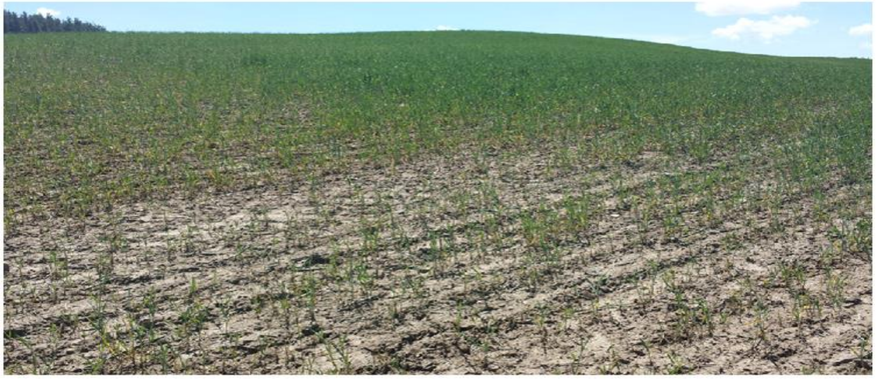

Figure 10: Death of plant due to low pH (Source: Adopted from Carol, 2015)

HOW TO IMPROVE SOIL PRODUCTIVITY?

There are several ways to ensure that your soil is fertile enough to support a high yield. By incorporating organic resources such as manure, compost, and mulching. Introducing a few vital animals that are part of soil life, as well as providing appropriate air and water to the soil

Soil Conservation practices

Farmers can utilize soil conservation to minimize soil erosion, increase organic matter, and hence crop production. Soil conservation strategies of various forms ensure long-term land use and maintain it fruitful for future generations.

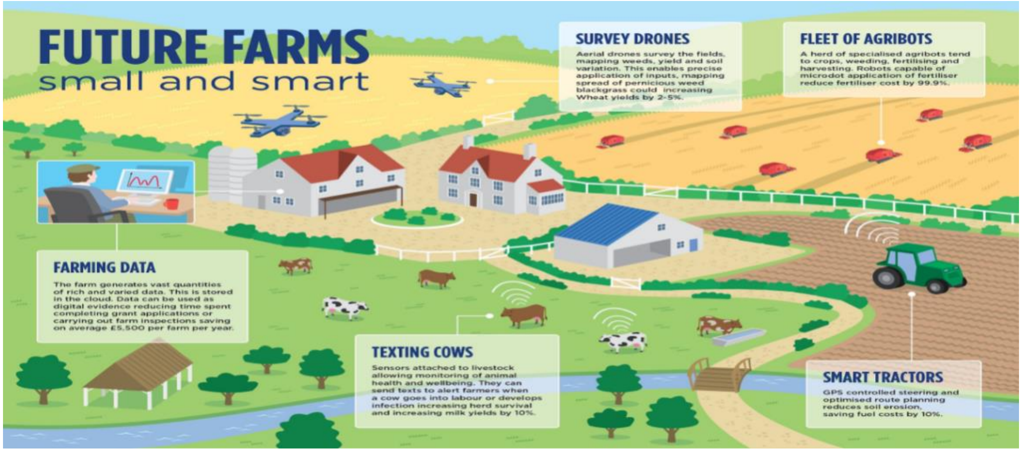

Figure 11: Future farming system (Source: Adopted from Liz, 2020)

Crop rotation

Crop rotation is the process of planting various crops on the same piece of land to maintain soil health, optimize nutrients in the soil, and resist insect and weed pressure. The idea of crop rotation is to rotate the crops so that insect pests, weeds, and diseases will not hamper the crop as a single crop can be a potential home for them as their preferred crop is available all the time (Liz, 2020). During normal growth periods, crop rotation yields are generally 10% higher than in single cultures, and up to 25% during dry growth periods. When growing grains or vegetables after soybeans, an additional supply of nitrogen will increase production. However, both crops provide enough nitrogen, but the yield of alternative crops is usually higher than that of a single crop. Assume a farmer has planted a field of maize. After the corn harvest, planting bean crops such as maize consumes a lot of nitrogen while beans restore nitrogen to the soil. Figure 12 shows effective crop rotation.

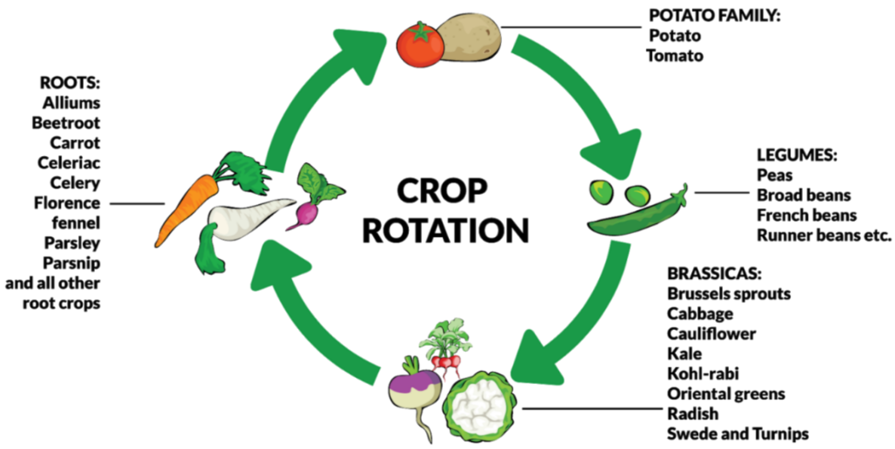

Figure 12: Crop Rotation (Source: Adopted from Liz, 2020)

Conservation tillage

Conservation tillage, particularly no-tillage and zero-tillage, along with N fertilizer management, provides farmers with one of the best opportunities to save energy in crop production. Where soil disruption is minimal and wastes cover around 30% of the soil surface. It can protect previously cultivated soil aggregates, organic materials, and surface residues. It helps to lower the use of fertilizer, and labor costs, lower energy, good crop productivity, reduce fuel, time savers, and higher yields (Singh, 2021). The following changes may be made as part of conservation tillage:

- Timing of tillage
- Use less destructive tillage tools
- Minimum tillage practices

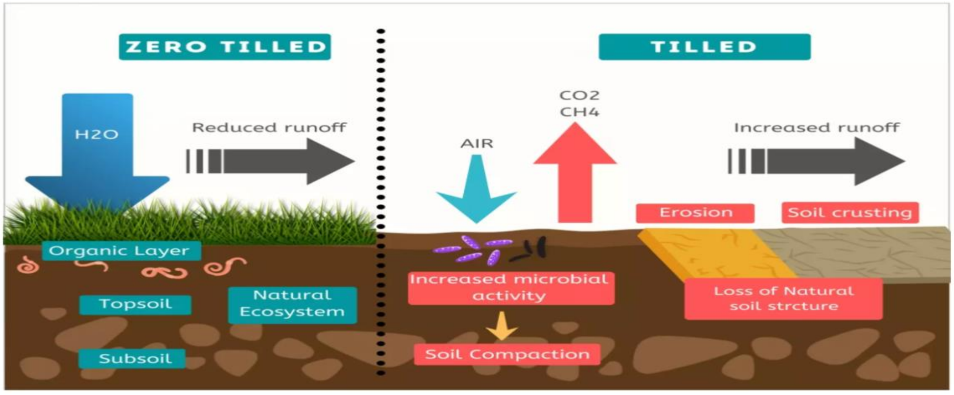

Figure 13: Comparison between zero-tilled and tilled soil structure (Source: Adopted from Singh, 2021)

Contour farming

Tilling sloppy land along lines of uniform height to preserve rainwater and prevent soil losses due to surface erosion. These goals include lowering fertilizer loss, power and time consumption, and machine wear, as well as enhancing crop yields and decreasing erosion. Contour farming can help absorb the impact of strong rainfall, which can wash away topsoil in straight-line planting. It can reduce 50% of erosion in hill farming. It helps to improve water irrigation, booting the nutrients and increasing the yield (Sasha, 2019)

Figure 14: Contour farming (Source: Adopted from Sasha, 2019)

Cover crop

Cover crops are used to promote soil health, increase organic matter, increase water infiltration, minimize erosion, reduced nutrient deficiencies, increase fertilizer efficiency, and increase available pasture for livestock. Cover crops improve the physical and chemical properties of the soil. They are planted to suppress insect pests, weeds, and diseases and to improve soil health. They are referred to as "living mulch" or "green manure" as they add nitrogen to the soil by boosting soil fertility (Lauren, 2022). Some examples of cover crops are winter rye which can withstand frost and are tall enough to act as a cover crop; common buckwheat which can prevent weeds, and erosion and attract pollinators; hairy vetch which acts as a good nitrogen fixer and can withstand both in spring and winter; mustard can be used as a cover crop as it contains compounds called glucosinolates which acts as biofumigant and helps to repel the insect pests (Lauren, 2022). Cover crops help to prevent soil erosion and nutrient erosion, and improve soil health, fertility, and productivity. The cover crop is depicted in fig. 15.

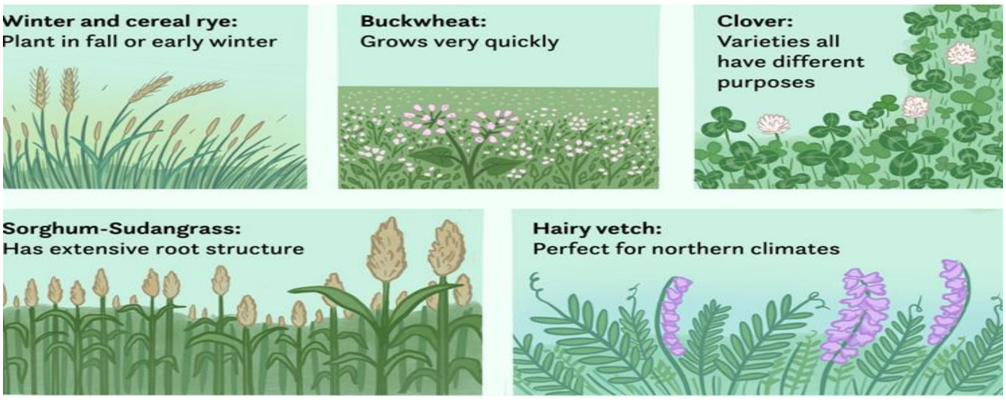

Figure 15: Cover Crops (Source: Adopted from Lauren, 2022)

Mulching

Mulching material is any organic or inorganic covering material applied to the soil surface to reduce evaporation losses. This material may be grown on-site, any material that has been grown and modified before placement, or any material that has been processed or produced and transported before placement (Irshad *et al*., 2016). Plastic mulch can be replaced with biodegradable grass clippings, compost, leaves, cardboard, wood chips, and hay for achieving sustainable agriculture (Barbara, 2021). Fig. 15 shows the crop residue used for covering the surface.

Figure 16: The irrigation channels are covered with crop residues (Source: Adopted from Barbara, 2021)

Soil Organic matter

Soil organic matter is the proportion of the soil that consists of decomposing plant or animal tissue. The majority of our productive agricultural soils contain 3 to 6% organic matter. The use of organic matter increases soil fertility, organic content inside the soil, and soil health (Neemishaa and Neeraj, 2022). Also, the use of organic matter in the soil gives a good platform to achieve sustainable agriculture and gives a good soil environment for keeping the productivity of an ecosystem. Organic matter is composed of several components that can be classified into three major categories:

a) Plant waste and alive microbial biomass
b) Organic matter in active soil
c) Stable soil organic matter (Humus)

Figure 17: Impact of organic matter on plant growth
(Source: Adopted from Neemishaa and Neeraj, 2022)

CONCLUSION

The chapter in this publication is about soil productivity, management and identifying and assessing soil variables that limit crop output. Soil variables such as topography/relief, texture, structure, porosity, permeability, drainage, and intrinsic nutrients all have an impact on plant roots. They necessitate interactive management approaches to accomplish the core goal of crop yield and soil fertility improvement while being ecologically friendly. Soil fertility management, soil conservation management, soil acidity management, and soil moisture management are examples of soil management approaches. In most cases, it is measured in terms of input and output. Agronomic circumstances often refer to water and/or the relationship between fertilizer input and crop output; our issue is to manage soils in such a way that they will meet human requirements in the future.

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Chapter

3

SUSTAINABLE SOIL MANAGEMENT AND CLIMATE CHANGE

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INTRODUCTION

Humankind is facing tremendous challenges in Agriculture. The climate is changing, the Global Population is growing quickly, Cities are expanding, Diets are undergoing major shifts - and soil are becoming increasingly degraded. In this fast-changing world, and given urgent need to eliminate hunger and ensure food security and Nutrition, and attaining Sustainable Soil Indeed, the sustainable soil management identify the need to restore degraded soil and improve soil health. There is widespread agreement that we must Nature and unlock the full potential of soils, so as to be able to not only support food production but also to store and supply more clean water, maintain biodiversity, sequester carbon and increase resilience in a changing climate. This is the requires the universal implementation of sustainable soil management. Soil are the foundation of food production and many essential ecosystem services. It has been shown that sustainable soil management contributes to increasing food production, enhancing the nutrient content of food, and adapting to and mitigating climate change.

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. The balance between the supporting and provisioning services for plant production and the regulating services the soil provides for water quality and availability and for atmospheric greenhouse gas composition is a particular concern. Soils 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”. Thus, sustainable soil management (SSM) is crucial to effective soil functioning, strongly contributing also to climate change adaptation and mitigation, combating desertification, and promoting biodiversity. SSM is an integral part of sustainable land management, thus a territorial perspective is important in such studies.

Figure 1: Sustainable soil management and the factors of soil quality (Source: Stephen Meredith)

CHARACTERISTICS OF SUSTAINABLE SOIL MANAGEMENT

- Minimal rates of soil erosion by water and wind;
- The soil structure is not degraded (e.g. soil compaction) and provides a stable physical context for movement of air, water, and heat, as well as root growth;
- Sufficient surface cover (e.g. from growing plants, plant residues, etc.) is present to protect the soil;
- The store of soil organic matter is stable or increasing and ideally close to the optimal level for the local environment;
- Availability and flows of nutrients are appropriate to maintain or improve soil fertility and productivity, and to reduce their losses to the environment;
- Soil salinization, acidification and alkalinization are minimal;
- Water (e.g. from precipitation and supplementary water sources such as irrigation) is efficiently infiltrated and stored to meet the requirements of plants and ensure the drainage of any excess;
- Contaminants are below toxic levels, i.e. those which would cause harm to plants, animals, humans and the environment;
- Soil biodiversity provides a full range of biological functions;
- The soil management systems for producing food, feed, fuel, timber, and fibre rely on optimized and safe use of inputs; and
- Soil sealing is minimized through responsible land use planning.

GUIDELINES FOR SUSTAINABLE SOIL MANAGEMENT

The following constitutes technical guidelines to address soil threats that hamper SSM (Sustainable Soil Management). They should not be viewed as a full list of good practices, but rather a technical reference to be applied on a context specific basis. Specific technical manuals may be developed later to provide complementary tools.

Minimize soil erosion

The SWSR (Status of the World's Soil Resources) report identified soil erosion by water and wind as the most significant threat to global soils and the ecosystem services they provide. Soil erosion causes the loss of surface soil layers containing organic and mineral nutrient pools, partial or complete loss of soil horizons and possible exposure of growth-limiting subsoil, as well as of-site impacts such as damage to private and public infrastructure, reduced water quality and sedimentation. Soil erosion is accelerated by human activities through, amongst others, reduced plant or residue cover, tillage and other field operations, and reduced soil stability leading to soil creep and landslides.

Figure 2: Erosion in an unprotected Tennessee cornfield following a brief storm (Tim McCabe/USDA NRCS)

- Land-use changes such as deforestation or improper grassland-to-cropland conversion that cause removal of surface cover and loss of soil carbon should be avoided or carefully planned and appropriately implemented if unavoidable;
- A cover of growing plants or other organic and non-organic residues that protects the soil surface from erosion should be maintained through implementation of appropriate measures such as mulching, minimum tillage, no-till by direct seeding with attention to reduced herbicide use, cover crops, agro-ecological approaches, controlled vehicle traffic, continuous plant cover and crop rotation, strip cropping, agroforestry, shelterbelts, and appropriate stocking rates and grazing intensities
- Erosion by water on sloping and relatively steep lands should be minimized by measures that reduce runoff rates and velocity such as strip cropping, contour planting, crop rotation, intercropping, agroforestry, cross slope barriers (e.g. grass strips, contour bunds and stone lines), terrace construction and maintenance, and grassed waterways or vegetated buffer strips;
- Where appropriate, riparian buffers, buffer strips, wetlands, water harvesting and cover crops should be used/installed tominimize export of soil particles and associated nutrients and contaminants from the soil system and protect the downstream areas from damaging

impacts; and Erosion by wind, including dust storms, should be minimized and mitigated through vegetative (trees and shrubs) or artificial (stone walls) windbreaks to reduce wind velocity.

Enhance soil organic matter content

Soil organic matter (SOM) plays a central role in maintaining soil functions and preventing soil degradation. Soils constitute the largest organic carbon pool on the Earth and play a critical role in regulating climate and mitigating climate change through trade-offs between greenhouse gas emission and carbon sequestration. For this reason, SOM is strategic for climate change adaptation and mitigation, and global stores of SOM should be stabilized or increased. A loss of soil organic carbon (SOC) due to inappropriate land use or the use of poor soil management or cropping practices can cause a decline in soil quality and soil structure, and increase soil erosion, potentially leading to emissions of carbon into the atmosphere. On the other hand, appropriate land use and soil management can lead to increased SOC and improved soil quality that can partially mitigate the rise of atmospheric CO_2.

- Increase biomass production by increasing water availability for plants using methods (e.g., irrigation with drippers or micro sprinklers; irrigation scheduling; monitoring of soil moisture or loss of water via evapotranspiration) that maximize water-use efficiency and minimize soil erosion and nutrient leaching, using cover crops, balancing fertilizer applications and effective use of organic amendments, improving vegetative stands, promoting agroforestry and alley cropping, and implementing reforestation and afforestation
- Protect organic carbon-rich soils in peatlands, forests, pasturelands, etc.
- Increase organic matter content through practices such as: managing crop residues, using forage by grazing rather than harvesting, practicing organic farming, applying integrated soil fertility management and integrated pest management, applying animal manure or other carbon-rich wastes, using compost, and applying mulches or providing the soil with a permanent cover
- Fire should preferably be avoided, except where fire is integral to land management, in which case the timing and intensity of burning should aim to limit losses of soil functions. Where fire is a naturally occurring event, steps to minimize erosion and encourage revegetation after fire should be considered, where practical.
- Make optimum use of all sources of organic inputs, such as animal manure and properly processed human wastes
- Management practices such as cover crops, improved fallow plant species, reduced- or no-tillage practices, or live fences should be adopted to ensure the soil has a sufficient organic cover
- Decrease decomposition rates of soil organic matter by practicing minimum or no-tillage without increasing the use of herbicides

- Implementing crop rotations, planting legumes (including pulses) or improving the crop mix.

Foster soil nutrient balance and cycles

The concepts of sufficiency and utilization efficiency apply especially to nutrient dynamics in the soil- water-nutrients-plant root continuum. Plant nutrition should be based on crop needs, local soil characteristics and conditions, and weather patterns. Plant nutrition can be enhanced through nutrient recycling or additions including mineral (chemical) fertilizers, organic fertilizers and other soil amendments including primary sources (e.g. rock phosphate) and secondary sources (e.g. phosphorus from sewage sludge). It is crucial to select an appropriate plant nutrient management system and approach alongside assessing the suitability of the land for a given land use. The benefits of sufficient and balanced nutrient supply for plant needs are well-established and include: production of food, feed, fibre, timber, and fuel at levels at, or close to, the optimum potential in the specific geographical context; reduced need for pest control measures, external application of organic and inorganic amendments, and mineral fertilizers; less pollution resulting from inappropriate use of agro-chemicals; and enhanced soil carbon sequestration through biomass production and restitution to the soil.

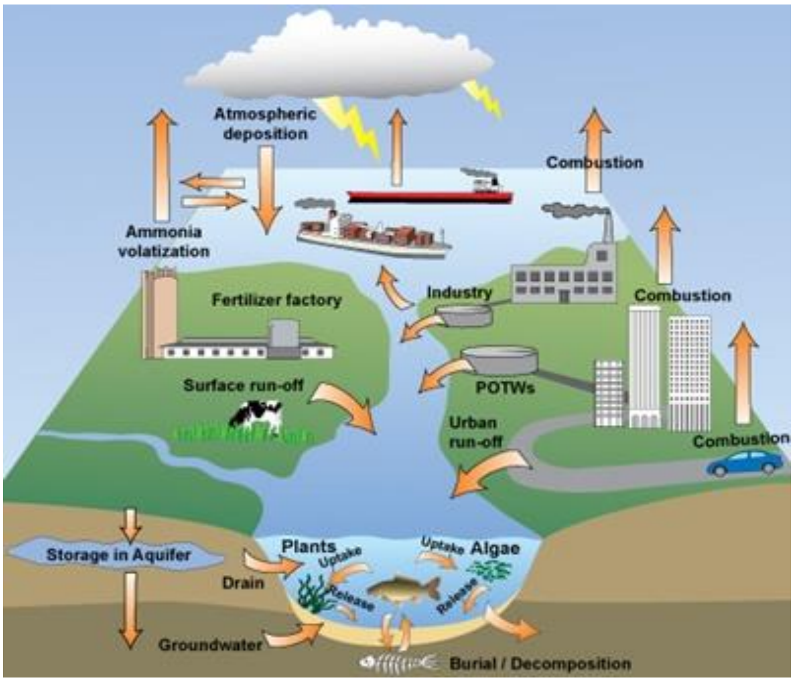

Figure 4: Nutrient Cycling

The lack of basic nutrients leads to the underdevelopment of plants and decrease in yields and crop nutritional value. The consequences of excess nutrients in soils are

a) the loss of excess nutrients (especially nitrogen and phosphorus) from agricultural fields, causing eutrophication and deterioration of water quality and terrestrial and aquatic ecosystems
b) increased release of the greenhouse gas nitrous oxide from soils to the atmosphere

c) leaching of mobile forms of nitrogen to water used for human consumption, with potential human health impacts

d) crop failure.

- Natural soil fertility and natural nutrient cycles should be improved and maintained through the preservation or enhancement of soil organic matter. Improved soil fertility can be attained through soil conservation practices such as the use of crop rotations with legumes, green- and animal manures, and cover crops in combination with reduced- or no-tillage with attention to reduced herbicide use, as well as agroforestry. Nutrient cycles are best managed in integrated systems such as crop-livestock systems or crop-livestock forestry systems
- Nutrient use efficiency should be optimized by adopting measures such as applying balanced and context adapted soil organic and inorganic amendments (e.g. compost and liming agents, respectively) and/or innovative products (e.g. slow and controlled release fertilizers), as well as the recycling and reuse of nutrients
- Fertilizer application methods, types, rates and timing should be appropriate to limit losses and promote balanced crop nutrient uptake. This should be based on soil and plant analyses and be a long-term endeavor rather than short term action
- The addition of soil micronutrients should be considered when planning soil fertilization
- Practical sources of plant nutrients should be used, including the precise and judicious use of organic and mineral amendments, inorganic fertilizers, and agricultural bioproducts. These amendments and bio-products include liquid, semi-solid or solid manures, crop residues, composts, green manures, household refuse, clean ash generated during bioenergy production, soil amendments and inoculants. In order to increase their efficiency, such measures should be combined with the mitigation of other limiting factors (such as water deficiency). Safe use (including tolerable levels of contaminants and pollutants, and worker health) of the amendments should be ensured
- Soil and plant-tissue testing and field assessments should be adopted and used. This provides valuable guidance in diagnosing and correcting limiting factors in crop production related to plant nutrients, salinity, sodicity, and extreme pH conditions. Such guidance is key for making informed decisions and monitor progress
- Where appropriate, livestock movement and grazing should be managed to optimize manure and urine deposition
- Application of liming agents in acid soils is a prerequisite for optimal nutrient use efficiency in such soils, while application of organic amendments such as compost, as well as appropriate soil-crop management should be considered for alkaline and other soils.
- Naturally occurring mineral fertilizer resources like rock phosphate or potash should be allocated efficiently and strategically to ensure the continued availability of adequate amounts of mineral inputs for future generations.

Prevent, minimize and mitigate soil salinization and alkalinization

Soil may filter, fix and neutralize, but also release pollutants when conditions change (e.g., heavy metal release with lowering pH). Therefore, prevention of soil contamination remains the best way to maintain healthy soils and food safety in accordance to the Sustainable Development Goals.Contaminants can enter soils from a variety of sources including agricultural inputs, land application of by-products, atmospheric deposition, flood and irrigation water, accidental spills, inappropriate urban waste and wastewater management, and other means. Accumulation and contamination occur if the rate of addition of a given contaminant exceeds its rate of removal from the soil system. Negative consequences may include plant toxicities and subsequent productivity declines, contamination of water and of-site areas through sediment transport, and increased human and animal health risks through accumulation in the food-chain.

Figure 5: Saline Soil

- Governments are encouraged to establish and implement regulations to limit the accumulation of contaminants below established levels to safeguard human health and well-being, and facilitate remediation of contaminated soils that exceed these levels
- Management of local soil contamination requires establishing background levels, followed by testing, monitoring and assessing contaminant levels to identify sites that are likely to be contaminated. Risk assessment, including total cost assessment, and remediation should be applied to reduce risks to humans and ecological systems;
- Identification of soils that are the most susceptible to the harmful effects of diffuse pollutants is needed. Appropriate attention should be given to reduce contaminant loads in these soils;
- Information on contaminated soil sites should be available to the public;
- Contaminated soils should not be used for food and feed production;
- Recycled nutrients originating from treated waste water or other waste materials that are used as soil amendments should be properly processed and tested to ensure they

- contain safe levels of contaminants and plant available nutrients. For instance, organic xenobiotics can pose a serious, incalculable and irreversible threat to soil fertility and human health; and
- Outflows of flood water from paddy rice cultivation after applying fertilizers and
- pesticides should be minimized to avoid off-site effects.

Prevent and minimize soil acidification

- Human-induced acidification of agricultural and forest soils is primarily associated with removal of base cations and loss of soil buffering capacity or increases in nitrogen and sulfur inputs (e.g., legume pastures fertilizer inputs, atmospheric deposition). Soils with low pH buffering capacity and/or high aluminium content are most prevalent when they have a low content of weatherable minerals (e.g. ancient, strongly weathered soils, and soils developed from quartz-rich parent materials).
- Monitoring soil acidity and minimizing surface and subsurface soil acidity by using proper amendments (such as lime, gypsum and clean ash);
- Balanced fertilizer and organic amendment applications
- Appropriate use of acidifying fertilizer types.

Preserve and enhance soil biodiversity

- Soil provide one of the largest reservoirs of biodiversity on earth, and soil organisms play key roles in the delivery of many ecosystems' services. Little is known about the degree of biodiversity required to maintain core soil functions, but new tools for biochemical techniques and Monitoring programs for soil biodiversity, including biological indicators (e.g. community ecotoxicology) and in-situ early warning signals, should be undertaken
- Soil organic matter levels supporting soil biodiversity should be maintained or enhanced through the provision of sufficient vegetative cover (e.g. cover crops, multiple crops), optimal nutrient additions, addition of diverse organic amendments, minimizing soil disturbance, avoiding salinization, and maintaining or restoring vegetation such as hedgerows and shelterbelts
- The authorization and use of pesticides in agricultural systems should be based on the recommendations included in the International Code of Conduct on Pesticide Management and relevant national regulations. Integrated or organic pest management should be encouraged
- The use of nitrogen fixing leguminous species, microbial inoculants, mycorrhizas (spores, hyphae, and root fragments), earthworms and other beneficial micro-, meso- and macro-soil organisms (e.g. beetle banks) should be encouraged where appropriate, with attention to limiting the risk of invasive processes by promoting the use of local biodiversity and avoiding the risk of disturbance in soil services
- Restoring plant biodiversity in ecosystems, thereby favoring soil biodiversity

- In-field crop rotation, inter-cropping, and preservation of field margins, hedges and biodiversity refugees should be encouraged
- Any land use change in areas with high biodiversity should be subject to land use planning and in line with the UNCBD, UNCCD and other relevant international instruments and with national law.

Minimize soil sealing

- Land conversion and subsequent soil sealing for settlements and infrastructure affect all soils, but are of particular concern on productive, arable soils because of their importance for food production and food security and nutrition, and circular economy targets. In many places, Urban sprawl affects the most productive soils adjacent to the cities and settlements. Soil sealing and land conversion causes a largely irreversible loss of some or all soil functions and the ecosystem services they provide.
- Considering the total value of soils and to ensure the preservation of productive, arable soils, existing policies, relevant laws and land use planning procedures for the development of settlements and infrastructure should be reviewed as appropriate
- Where policy and legislation aim to minimize land conversion, measures should be implemented to encourage densification and re-use of existing urban or industrial areas such as abandoned areas and brownfields, and restoring degraded neighbourhoods after appropriate reclamation measures have been implemented. Ecological restoration of quarries and mining sites should be encouraged
- Soils with significant ecosystem services including high soil carbon stocks, high biological diversity or high agricultural suitability should be protected from land conversion for settlements and infrastructure by special legislation.

Prevent and mitigate soil compaction

- Soil compaction is related to the degradation of soil structure due to imposed stresses by machinery and livestock trampling. Soil compaction (reduced or disrupted pore continuity) reduces soil aeration by destroying soil aggregates and collapsing macropore density, and reduces water drainage and infiltration, generating higher runoff. Compaction limits root growth and seed germination by high mechanical impedance, affecting soil biodiversity and causing surface soil crusting.
- Deterioration of soil structure due to inappropriate or excessive tillage should be prevented
- Vehicular traffic should be minimized to the absolutely essential, particularly on bare soils, by reducing the number and frequency of operations, creating controlled traffic systems, and by performing agriculture/forestry operations only when the soil moisture content is suitable down to deeper depth
- Machines and vehicles used in the field should be adjusted to soil strength and should be equipped with tyre pressure control systems or other means to reduce surface pressure (e.g. contact area), and use of heavy machinery should be avoided. During forestry operations,

machine traffic should be restricted (e.g. controlled traffic) and brush mats used to help protect exposed soils from physical damage; on agricultural soils, controlled traffic and drive rows should be established, where possible

- Cropping systems should be selected that include crops, pasture plants and, where appropriate, agroforestry plants with strong tap roots (dense and fibrous root systems) able to penetrate and break up compacted soils
- An adequate amount of soil organic matter should be maintained to improve and stabilize soil structure
- Macrofauna and microbial (especially fungal) activity should be promoted to improve soil porosity for soil aeration, water infiltration, heat transfer and root growth
- In grazing systems, a sufficient cover of growing plants should be maintained to protect the soil from trampling and erosion; livestock management should take into account grazing intensity and timing, animal types and stocking rates.

Improve soil water management

A sustainably managed soil has rapid water infiltration, optimal soil water storage of plant available water and efficient drainage when saturated. However, when these conditions are not met, waterlogging and water scarcity problems arise. On the one hand waterlogging, which is related to the saturation of soil with water, creates rooting problems for many plants, thereby reducing yields, and can cause contaminants such as arsenic and methylmercury to become mobile in the soil. On the other hand, water scarcity occurring in areas where water is lost by evaporation, surface runoff and percolation, can cause crop failure.

- In humid areas where precipitation exceeds evapotranspiration, additional drainage systems are needed to provide aeration for root functions like nutrient uptake. This is a concern especially in fine-textured soils which have high water retention capacity.
- Surface and sub-surface drainage systems should be installed and maintained to control rising groundwater tables in order to mitigate potential waterlogging.
- The efficiency of irrigation water use by plants should be increased through improved conveyance, distribution, and field application methods (e.g. scheduled drip or micro sprinkler irrigation) that reduce evaporation and percolation losses of irrigation water, as well as through better soil water reserve estimation, better species or variety choices, and better computing of water loading periods and amounts.
- In dryland cropping systems, measures should be implemented to optimize water-use efficiency such as the management of soil cover (e.g. previous crops, forage and fallow) and water harvesting to increase soil water availability at sowing; reduction of runoff and evaporative losses from the soil surface; and ensuring that there is adequate water available at each stage of crop development. These measures often involve trade-offs and risks that should be recognized and managed
- Optimal soil water extraction by the crop through the selection of appropriate cultivars and careful timing of agronomic operation should be promoted

- Regularly monitor irrigation water quality for nutrients and potential harmful substances.

CLIMATE CHANGE

It refers to the change in the environmental conditions of the earth. This happens due to many internal and external factors. Climate change has become a global concern over the last few decades. Besides, these climatic changes affect life on the earth in various ways. These climatic changes are having various impacts on the ecosystem and ecology. Due to these changes, a number of species of plants and animals have gone extinct.

When Did it Start?

- The climate started changing a long time ago due to human activities but we came to know about it in the last century. During the last century, we started noticing the climatic change and its effect on human life.
- We started researching on climate change and came to know that the earth temperature is rising due to a phenomenon called the greenhouse effect. The warming up of earth surface causes many ozone depletion, affect our agriculture, water supply, transportation, and several other problems.

Reason of Climate Change

Although there are hundreds of reasons for the climatic change, we are only going to discuss the natural and manmade (human) reasons.

1. **Natural Reasons**

- These include volcanic eruption, solar radiation, tectonic plate movement, orbital variations. Due to these activities, the geographical condition of an area become quite harmful for life to survive.
- Also, these activities raise the temperature of the earth to a great extent causing an imbalance in nature.

2. **Human Reasons**

- Man due to his need and greed has done many activities that not only harm the environment but himself too. Many plant and animal species go extinct due to human activity. Human activities that harm the climate include deforestation, using fossil fuel, industrial waste, a different type of pollution and many more. All these things damage the climate and ecosystem very badly. And many species of animals and birds got extinct or on a verge of extinction due to hunting.

Effects of Climatic Change

These climatic changes have a negative impact on the environment. The ocean level is rising, glaciers are melting, CO_2 in the air is increasing, forest and wildlife are declining, and water life is also getting disturbed due to climatic changes. Apart from that, it is calculated that if this change keeps on going then many species of plants and animals will get extinct. And there will be a heavy loss to the environment.

What will be the Future?

If we do not do anything and things continue to go on like right now then a day in future will come when humans will become extinct from the surface of the earth. But instead of neglecting these problems we start acting on then we can save the earth and our future.

- Although human mistake has caused great damage to the climate and ecosystem. But it is not late to start again and try to undo what we have done until now to damage the environment. And if every human start contributing to the environment then we can be sure of our existence in the future.

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Chapter

4

SUSTAINABLE SOIL MANAGEMENT-CONCEPTS, GOALS AND PRACTICES

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ABSTRACT:

Soil is the vital part of Earth and supports the life in it. In order to achieve the Sustainable Development Goals (SDGs) set forth by the United Nations, it provides vital services for food production, plant development, animal habitation, preserving biodiversity, sequestering carbon, and maintaining environmental quality. For achieving the SDGs by 2030, soils may need to be used and managed in a sustainable manner. The three main purposes of soil have been (1) medium for plant growth, (2) foundation for buildings and other civil structures, and (3) raw material for industry since the beginning of well-established agriculture. In light of the serious problems faced by the world, some additional soil functions include: (4) carbon sequestration to slow down climate change; (5) pollution filtering; (6) safe disposal of industrial and urban wastes; (7) repository for biodiversity and genetic material; (8) nutrient cycling and transformation; and (9) providing aesthetic and cultural value to the landscape. Of these soil functions, sustaining and enhancing net primary productivity (NPP) and agronomic yields to meet the demands (for food, feed, fiber, and fuel) of the growing world population is an urgent issue of global importance which can be achieved by sustainable soil management. Sustainable soil management not only take care of present soil health but also maintains long term quality of soil in a holistic manner.

KEYWORDS: Sustainable, Soil, Health, Functions, Sustainable development goals

INTRODUCTION:

Being a natural resource that is both necessary and non-renewable, soil provides commodities and services that are important to human life and the ecosystem. The best soils produce the best food, feed, fibre, and fuel. Additionally, they act as natural physical, chemical, and biological filters to clean thousands of cubic kilometres of water each year. In addition to acting as a carbon sink, soil has a role in regulating greenhouse gas emissions, which in turn helps to control climate change. Sustainable soil management is not only a vital aspect of sustainable land management but also a base for solving the challenges like poverty, food insecurity and malnutrition. Sustainable soil management can help with climate change adaptation and pave the road for preserving biodiversity and key ecosystem services. The widespread adoption of sustainable soil management practises generates numerous socio-economic benefits, particularly for smallholder farmers and large-scale agricultural producers around the world whose livelihoods directly depend on their soil resources. However, the soil's ability to store and cycle carbon, nutrients, and water is significantly reduced due to the indiscriminate use of fertilizers and intensive farming. The estimated annual losses in grain production from erosion are 7.6 million tonnes. The UN General Assembly declared 2015 the International Year of Soils, and the FAO Conference approved the updated World Soil Charter in response to the mounting worries about the condition of the world's soils. More broadly, the 2030 Agenda for Sustainable Development established other related goals in 2015, including those aimed at restoring degraded soil, striving to achieve a land degradation-neutral world and implementing resilient agricultural practices that progressively improve soil quality and minimize soil contamination.

Natural resource usage has always been fundamental to the history of humanity. The ability of people to sustainably manage natural resources like soil, water, and air, and ultimately how to prevent or reduce their loss or degradation, is a key factor in the development and fall of civilizations (Montgomery, 2012). Soils must also be safeguarded against deterioration from unfavourable human activities, much like water and air are. The use of soil (as a source of food, fibre, and fodder) from the beginning of agriculture, however, unavoidably includes an alteration of its basic qualities and functioning and might result in its intrinsic degradation. This is in contrast to the use of air and water. Hence, soil conservation entails both defending against threats and using multipurpose soils sustainably. The complex nature of soils which is due to their high number of components and the interactions and feedbacks between these components (Havlicek & Mitchell, 2014) requires also a complex and a multidisciplinary sustainable soil management approach (Fig 1.)

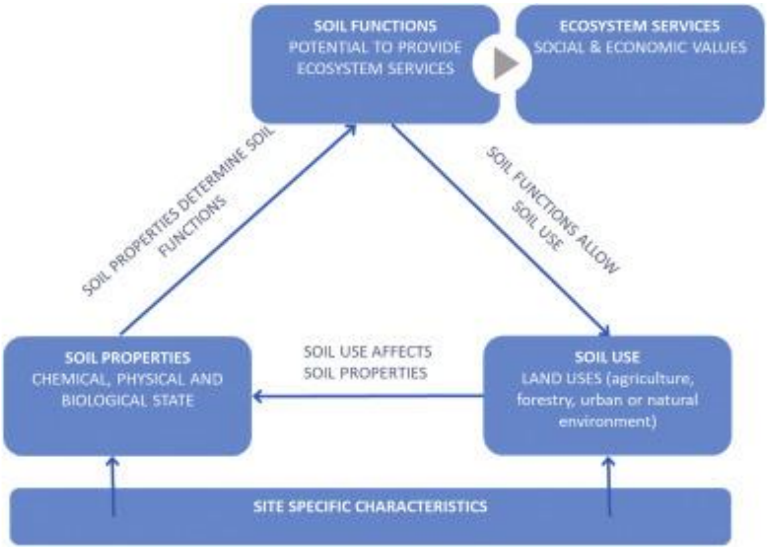

Figure 1: Interrelations between soil properties, soil functions and soil use (adapted from FOEN, 2020)

Various types of soil degradation, including erosion, compaction, pollution, a drop in soil organic matter, a loss of soil biodiversity, and others have been identified at regional, national, and international levels as being caused by the diverse and frequently unsustainable uses of soils. The urgent need for soil management has come to the forefront of the world's environmental and development agenda, and numerous articles about soils have recently been published, emphasising the value of soil as a crucial natural resource that performs a variety of functions and provides ecosystem services (Drobnik *et al.,* 2018).

DEFINITION OF SUSTAINABLE SOIL MANAGEMENT:

"Soil management is sustainable if the supporting, provisioning, regulating, and cultural services offered by soil are maintained or increased without severely compromising either the soil functions that provide those services or biodiversity. The balance between the supporting and provisioning services for plant production and the regulating services the soil offers fo rwater quality and availability and for atmospheric greenhouse gas composition is a special concern". The types of ecosystem services and the soil functions referred to in the definition can be elaborated as follows,

- Primary production, nitrogen cycling, and soil formation are examples of supporting services;
- Provisioning services include the provision of raw materials such as food, fibre, fuel, wood, and water. habitat, surface stability, genetic resources, and material.
- Regulating services implies governing elements like water supply and quality, carbon sequestration, climate regulation, prevention of floods and erosion; and

The term "cultural services" refers to the aesthetic and cultural advantages of using soil.

CHARACTERISTICS OF SUSTAINABLE SOIL MANAGEMENT:

Sustainable soil management is associated with the following characteristics:

1. minimal water and wind erosion rates of the soil.
2. The soil structure provides a strong physical foundation and is not degraded (e.g., by soil compaction) as it is a framework for root growth as well as for the circulation of heat, water, and air.
3. There is enough surface cover, such as through vegetative growth, plant remains, etc., to safeguard the soil.
4. The organic matter reserve in the soil is steady or growing and, ideally, not far from the ideal level for the neighbourhood.
5. To maintain or increase soil fertility and productivity and to lower their losses to the environment, nutrient availability and fluxes are appropriate.
6. There is little salinization, sodification, or alkalinization of the soil.
7. Water (e.g. from precipitation and supplemental water sources such as irrigation) (e.g. from precipitation and supplementary water sources such as irrigation) is effectively accessed and saved. Contaminants are below toxic levels, *i.e.* those which would cause harm to plants, animals, humans and the environment.
8. Soil biodiversity provides a full range of biological functions.

9. The soil management systems for producing food, feed, fuel, timber, and fibre rely on optimized and safe use of inputs.
10. Soil sealing is minimized through responsible land use planning (Baritz *et al.,* 2018)

OBJECTIVES OF SUSTAINABLE SOIL MANAGEMENT

- Sustainable land management is described as a blend of socio-economic concepts with environmentally conscious technologies, regulations, and activities in An International Framework for Evaluating Sustainable Land Management (FESLM). Efficiency, Security, Protection, Vitality, and Acceptability have been defined as the five objectives for realistic sustainable land management. Each of these objectives has unique features that can be explained as follows:
- ***Efficiency:*** This goal implies that there are other benefits to sustainable soil management in addition to financial ones. It focuses more on the advantages that will result from land use for protective, soil, human, and aesthetic reasons.
- ***Security:*** Reduced risk is the main focus of this goal. In contrast to techniques that prioritise commercial concerns, sustainable management models preserve the equilibrium between land usage and the current environmental conditions, hence reducing production risks.
- ***Protection***: Water and soil resources need to be strictly protected for upcoming generations. Additional objectives for protection could exist locally, such as the necessity to preserve genetic diversity or a particular plant, animal types.
- ***Vitality:*** If the applied land uses do not match the local conditions, the use cannot survive.
- ***Acceptability***: If land use practises have unfavourable societal repercussions, it is inevitable to eventually break. It's not always obvious what aspect of social and economic impact is directly affected. Given this context, it must be produced safely in the field, with a production plan that safeguards natural resources and is also both commercially and socially viable. This strategy demands, in theory, to conserve and increase soil fertility, to prevent and reduce land degradation, to stop environmental harm and rectify soil degradation, but it should also be acknowledged that the system cannot be sustainable with the practises where the agricultural structure is improperly managed and the land is constantly damaged.

SOIL MANAGEMENT AND SUSTAINABLE DEVELOPMENT GOALS

Soil conservation promotes sustainable and economic development to meet the U.N. Sustainable Development Goals (SDGs) :17 goals are there focusing on providing a “sustainable future for all.” According to the European Environment Agency, there are 7 sustainable development goals that directly correlate to soil conservation practice.

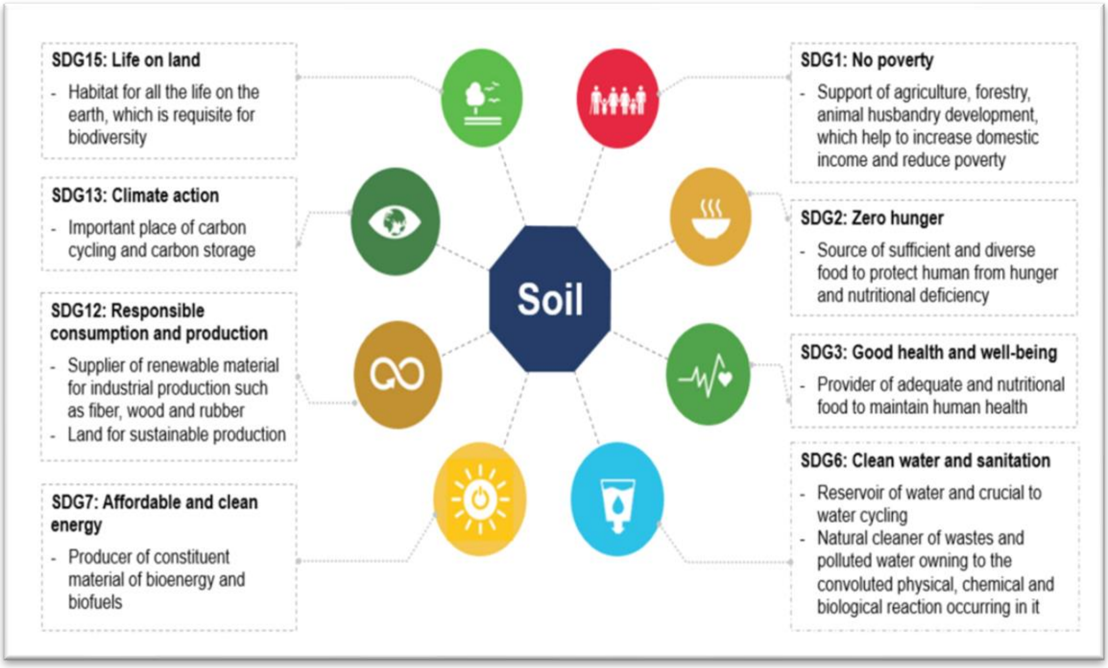

Figure 2: The relevance of soil to the United Nations' Sustainable Development Goals (SDGs). (Hou *et al.*, 2020)

Figure 3: Sustainable development goals and soil management

These are:

- **SDG 6 — Clean Water and Sanitation:** Through drainage and purification, soil helps to provide clean water for drinking and farming.
- **SDG 13 — Climate Action:** Through sequestration, soil can play a pivotal part in combating climate change by reducing atmospheric carbon.
- **SDG 15 — Life on Land:** Healthy soils are essential for sustainable management of forests, fighting desertification, and reversing land degradation.

Building the resilience of our ecosystems is critical to addressing the challenges of a changing climate. One key factor sits right under our feet: soil. Through soil conservation, we can work to minimize the impact of climate change and support the long-term needs of society.

Table 1: Examples of using soil science in realizing Sustainable Development Goals (Lal *et al.*, 2021)

SDG #	Focus	Principles of Soil Science to Realize SDGs: Examples
1	End Poverty	Micro-enterprise and micro-finance programs; conditional Cash Transfer Programs
2	Zero Hunger	130 countries have aligned with the Zero Hunger Challenge (ZHC) 23 U.N. agencies fund programs on ZHC
3	Good Health and Wellbeing	Books on the soil-human health nexus; improved understanding of transfer of nutrients from soil to plants to humans
4	Quality Education	Books on soil education; curricula changes at the school-level regarding sensitization about soils; teacher-supportive curricula; school kitchen gardens, etc.
5	Gender Equality	Enhanced enrollment of women in soil science education and professional jobs
6	Clean Water and Sanitation	Global population of using clean water increased from 61% in 2000 to 71% in 2017; eco-sanitation using tera preta principles costing ~US $50
9	Industry, Innovation, and Infra-Structure	Enhancing societal connections to soil and where our food comes from; organizations working with community groups, schools, etc.; best practice advice in how soils are handled, stored, and reused at construction projects
11	Sustainable Cities and Communities	Composting waste and recycling; strengthening local food production systems through urban agriculture and home gardens; use of Technosols in urban ecosystems; permaculture as agroecological farming in Australia; green infrastructure
12	Responsible Consumption and Production	Composting food waste; awareness-raising projects such as "My Food – My Future" on sustainable nutrition; reducing land consumption
13	Climate Action	Global initiatives (e.g., 4p1000, AAA, PLACA, Living Soils in the Americas); negative emission technologies (NETs); payments for ESs
15	Life on Land	Implementation of the concept of Land Degradation Neutrality by 2030; c-sequestration in land (soil, trees, wetlands)

PRINCIPLES OF SUSTAINABLE SOIL MANAGEMENT

Figure 4: Tenets of sustainable soil management (Lal, 2009)

Due to the fact that the world's soil resources are finite, unevenly distributed among ecoregions, vulnerable to abuse, poor management, and the threat of global warming, as well as nonrenewable throughout the course of a human generation (s). Thus, sustainable management of this precious resource must be based on following fundamental principles:

1. Causes of Soil Degradation. Economic, social, and political forces are what drive the biophysical process of soil degradation. To effectively manage biophysical processes in reducing degradation risks and enhancing restoration mechanisms, it is important to address the human factors that influence land misuse, soil mismanagement, and the prevalence of extractive farming practices.
2. Soil Stewardship and Human Suffering. People who are famished, helpless, and poor transfer their anguish to the earth. Only when the fundamental requirements are sufficiently addressed can the stewardship idea become significant. When there is no fuel available to cook the family dinner, a sermon extolling the merits of protecting a tree is met with blank stares.
3. Nutrient, Carbon, and Water Bank. Similar to a bank account, soil cannot be used for more than what is placed into it without losing some of its quality. Soil quality is influenced by the rate, timing, technique, and form of what is being removed or replaced in addition to the amount. Managed ecosystems are therefore long-term sustainable if the output of all components produced balances the input into the system.

4. Marginality Principle. Marginal soils cultivated with marginal inputs produce marginal yields and support marginal living. The sustainable soil management strategy is to cultivate the best soils by best management practices to produce the best yields so that surplus land can be saved for nature conservancy.
5. Organic Versus Inorganic Source of Nutrients. Plants cannot differentiate the nutrients supplied through inorganic fertilizers or organic amendments. Rather than an "either/or" question, itis a matter of logistics and practicality in making nutrients available in sufficient quantity, appropriate form, and at the critical time needed for optimum crop growth and desired yields.
6. Soil Carbon and Greenhouse Effect. Mining carbon has the same effect on global warming whether it is through mineralization of soil organic matterfor releasing nutrients through plowing and extractive farming or it is through burning fossil fuels (coal, gas,oil), using petrol-based products, or draining peat soils.
7. Soil as Sink for Atmospheric CO_2. The conversion of land use to one that is sustainable and the adoption of advised management techniques that result in positive carbon and nutrient budgets can make world soils a significant sink for atmospheric CO_2 and CH_4. The economic and ecological process of increasing the pedosphere's carbon sink capacity (3 Pg C y-1; 1 Pg C y-1 in soils of croplands, grazing fields, and degraded/desertified regions) has various additional advantages. Carbon sequestration in the pedosphere not only improves water quality and food security, but also slows global warming.
8. Soil versus Germplasm. Even the elitevarieties, developed through biotechnology and genetic engineering, cannot extract water and nutrients from anysoil where they do not exist. The yield potential of improved germplasm canbe realized only if grown under recommended management practices ofsoil, water, and crop husbandry.
9. Engine of Economic Development. Being the foundation of agrarian societies,sustainable management of soils is the engine of economic development, political stability, and transformation of rural communities in developing countries.
10. Traditional Knowledge and Modern Innovations. It is important to build upon the traditional knowledge and avail the benefits of modern innovations. It is not an "either/or" scenario. Modern science must synthesize the traditional knowledge and build upon it. Those who refuse to use modern science to address urgent global issues mustbe prepared to endure more suffering.

SUSTAINABLE SOIL MANAGEMENT PRACTICES

Sustainable soil management means using practices that build healthy soil, reduce erosion and the need for fertilizer, pesticides, and herbicides. They include:

- Planting cover crops, especially in the fall to prevent erosion and add nutrients and organic matter to the soil.
- Using mulch around plants whenever possible to prevent erosion, suppress weeds, hold moisture, and add nutrients and organic matter to the soil.

- Rotating crops to disrupt disease and pest life cycles and reduce excess nutrients.
- Reducing soil compaction which helps fungal and insect life in soil thrive. Whenever possible reduce tilling and using equipment.
- Providing habitat for beneficial insects like cover crops, mulch, wildflower patches (Komatsuzaki *et al.*, 2007)

IMPORTANCE OF SUSTAINABLE SOIL MANAGEMENT

The sustainable management not only protects the soil and the environment but also ensures the long-term production for future generation without compromising the need of the present generation. The benefits of sustainable soil management are as follows:

- More products in small areas with high efficiency.
- A positive impact on the ecosystem. Provides a habitat for animals and also contribute to agricultural production.
- Increase in productivity by judicial application of fertilizers.
- Creates new areas of employment (Tuğrul, 2019)

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Chapter

5

SOIL COMPACTION AND STRATEGIES FOR ITS AVOIDANCE

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INTRODUCTION:

When soil particles are compacted, less pore space availablity for air and water, which is an issue in the development of field crops. Particles make up around half of the soil volume, and soil pores make up the other half. These pores are generally evenly filled with air and water at field capacity. Roots develop, bacteria thrive, and water and nutrients pass through the soil in pores. Therefore, compaction can result in least water infiltration, incline water runoff and soil erosion, constrained root growth, decreased nutrient uptake, and ultimately stunted plant growth and yields. As an illustration, in the spring of last year, we went to a dry bean field where there was around an acre of beans along a road that were deformed. We discovered that the soil in the affected area was drastically compacted, and that root growth was constrained. There were no issues with soil compaction in the regions with strong plant growth. We heard from the farmer that the impacted region was where water accumulated during severe rains. This provided more proof that the soil in that area of the field was compacted and had poor drainage.

Both the soil surface and the subsoil are susceptible to soil compaction. Water striking tilled soil causes surface compaction by forming a crust. Ring rolling can be used to break up the crust and keeping the soil covered with plant debris or a winter cover crop throughout the rainy season can prevent this. The more difficult to control subsurface compaction will be the main topic of this paper. The subsoil may have deep compaction or a hardpan layer of compaction. When tillage equipment compacts the soil immediately beneath it, a hardpan is created. When too much weight is placed on the soil, especially when the soil is damp, deep compaction founds moving deeper down in the soil profile. After heavy compaction, breaking up the soil can be challenging.

Figure 1: Soil Compaction

CAUSES OF SOIL COMPACTION

1. **Soil Profile**

Dry soils are capable of supporting a lot of weight. Wet or clayey soils tend to have fewer voids and compact more readily than dry soils. Some soils, such sandy or loamy soils, are inherently more prone to compaction and denser soil volume than other soil types. Due to improper farming practises or drainage techniques, these soils are more likely to get compacted.

2. **Poor Drainage**

It is more common for soils to become highly compacted when they are overwatered, damp, have poor aeration, and have low porosity. Your plant roots will be able to absorb nutrients more efficiently when water is allowed to properly permeate the soil. Standing water on compacted topsoil, whether from raindrops or excessive watering, can cause the soil's moisture content to rise too high. This can create maladaptive soil conditions and potentially starve your crops.

3. **Thatch build up**

Around your grass, an accumulation of living and dead stems, roots, and rhizomes is called thatch. As a matter of fact, it can worsen topsoil compaction to accumulate thatch material on your lawn as opposed to mulching your soil with organic matter. Your grass may become choked by thatch accumulation. decreasing the soil's capacity to absorb air and water.

4. **Foot traffic**

Compacted topsoil can result from high human and livestock foot movement. Due to the reduced soil permeability and increased soil compaction, crop yield and plant growth may be hampered by nutrient and air penetration resistance.

5. **Field operations**

Wheel traffic from deep tillage and over-plow operations can increase soil compaction and decrease soil strength. Heavy machinery's tyres press against the ground as it travels across it, further compacting the soil. (You may have seen that crops hardly ever grow near heavily trafficked areas.) Aggregates that hold the soil particles together are also destroyed by repeated soil tillage operations, ploughing, and ground treatments. This may throw off the soil's natural equilibrium, which could result in serious subsoil compaction.

6. **Climate change**

Compaction of the soil can also be attributed to climate change and global warming. The soil becomes unbalanced as soil temperatures and/or nutrient availability vary, resulting in clumping, soil erosion, leaching, or other abnormalities that facilitate additional compacting.

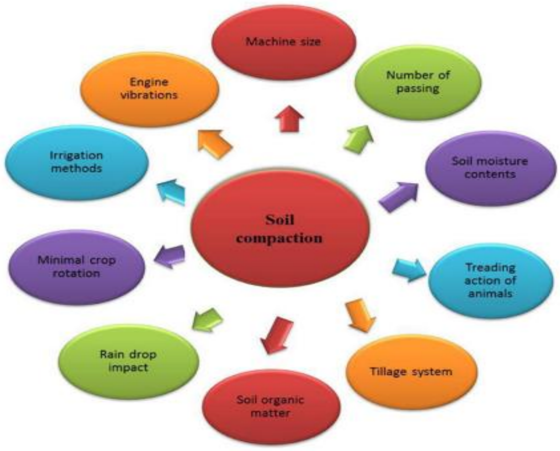

Figure 2: Summary of causes and effects of soil compaction

EFFECTS OF SOIL COMPACTION

1. **Poor aeration**

Lack of sufficient aeration leads to increased soil compaction, which can also lead to a lack of proper aeration. Watering any unaerated soil will raise soil density, which can lead to soil particles sticking together and starving the roots of your plant.

2. **Pests and Diseases**

Pests and illnesses thrive in soil that has been compacted. Compacted, waterlogged soil lacks the nutrients it needs to control some germs and organisms, which can lead to root rot and unhealthy plants.

3. **Poor crop yield**

Due to a lack of room between soil particles, plants in compacted soil may have persistently poor crop growth and yields from season to season. Poor root development also prevents plants from absorbing nutrients, which can result in underwhelming crop yields.

4. **Flooding**

Because the surplus water content can't effectively permeate the soil, areas with severely compacted soils are more likely to experience runoff or flooding. Due to soil erosion, this may result in further structural damage as well as agricultural harm.

SOIL COMPACTION EMPHASIZED AGRICULTURAL PRODUCTIVITY

For the purpose of understanding the impact of compaction, studies were carried out in the early 1940s and 1950s. These findings demonstrated that severe compaction significantly inhibited or reduced plant growth and development (Schafer *et al.*, 1992). The initial responses of environmentally stressed plants decrease crop growth, decreased stomatal conductance and functioning, photosynthesis, and exacerbation of membranous injury (Ripley *et al*., 2007). Soil compaction decline the crop development and yield because it stops crop root systems from entering the compacted soil and absorbing soil-bound water. (Hula *et al*., 2009). Compacted dirt caused by mechanical movement and vehicle tracks in a field of soybeans

HOW CAN SOIL COMPACTION BE AVOIDED?

Your soil can gain bulk density and beneficial microbial activity by adding organic materials. Your soil can also be given extra nutrients and have space between the soil particles by spreading manure or compost on it. The addition of earthworms to your soil can also aid in separating the particles of your soil.

One would anticipate that any activity that will increase "soil organic matter" (SOM), which is the only material that stabilises the structure in the majority of soils, would decrease soil compaction. A permanent grass ley (cover crop) in orchards (or vineyards) will reduce soil compaction because the wheels of tractors, spray carts, or loaded trailers moves in between the rows, according to E. L. Greacen in Australia published in the 1950s or early 1960s, according to the first author. Clean, cultivated intergrows with low organic matter contents experienced significant compaction. There is a dearth of South African data on the interactions between SOM concentration and soil compaction. When data are represents, especially for annual crops, the outcomes almost always appear to be unexpected. Agenbach and Stander (1988) discovered that minimal tillage and zero tillage (direct-drilling with a no-till drill) particularly in comparison to tillage with a tined tool or a standard mouldboard plough, produced considerably greater soil organic carbon and nitrogen concentrations. Their experiments with wheat in the Southern Cape supported their findings. Higher soil water contents at planting were also produced by zero tillage and minimal tillage. But throughout the course of the trial, conventional tillage produced a yield that was 62% higher than zero tillage. More yields were produced than with minimum tillage as well. This was due to soil compaction, which PR stated, especially in the top 150mm, was significantly greater in the zero-till plots than in the conventionally tilled plots down to a depth of 250 mm. According to Agenbach and Stander (1988), low yields under zero tillage were caused due to low plant densities and poor emergence since the seed drill was unable to adequately penetrate the compact soil. It is possible that this negative relationship between soil compactionandorganic matter content is made up because topsoil organic matter is higher under no-till or minimal tillage than under conventional tillage, but subsoil compaction is also higher due to wheel traffic and there is no reduction in it.

TRADITIONAL METHOD OF COMPACTION

Control By performing a laboratory compaction test, such as the traditional Proctor test or a modified version, and using the results to define limits for dry density and water content, compaction is often controlled. It is standard practise to set water content restrictions that are within a range of percentage on each side of the ideal water content and minimum dry densities that are 90 or 95 percent or greater of the maximum dry density. The following variables can be taken into account while deciding between the standard Proctor test method and the modified test:

1. *The objective of compaction of the soil*. A particularly high-quality products are unlikely to be needed for a relatively low embankment for a road, thus the ordinary Proctor test

would be adequate. A higher quality fill may be preferred if the goal is a high earth dam, in which case the modified test would be more suitable.

2. *The field compaction equipment that is accessible*. It would be unlikely to get the density required by the modified test if only light equipment was used.
3. *The site's local climate and the soil's inherent water content*. Whenever the natural water content exceeds the ideal water content if it is high in comparison to the optimum water content from the standard Proctor test and the climate is such that drying the soil may be challenging, it would beimpractically fair to adopt the modified optimum water content, which would require much higher drying than the standard Proctor optimum value.

Alternative Compaction Control Using Air Voids and Undrained Shear Strength When compacting soil, mainly the goals are to produce a fill with high strength and low compressibility, and, in the case of soilwater-retention, to increase the amount of low permeability fills. It is also preferred that the fill not become noticeably softer over time from exposure to rain. The classic control strategy is based on the idea of aiming the maximum density, the aforementioned goals will be accomplished. This is not always the case, and there is no reason why different parameters wouldn't work just as well to obtain the desired results. Air voids and undrained shear strength seem to be appropriate substitute variables that are more closely related to the fill's intended qualities.

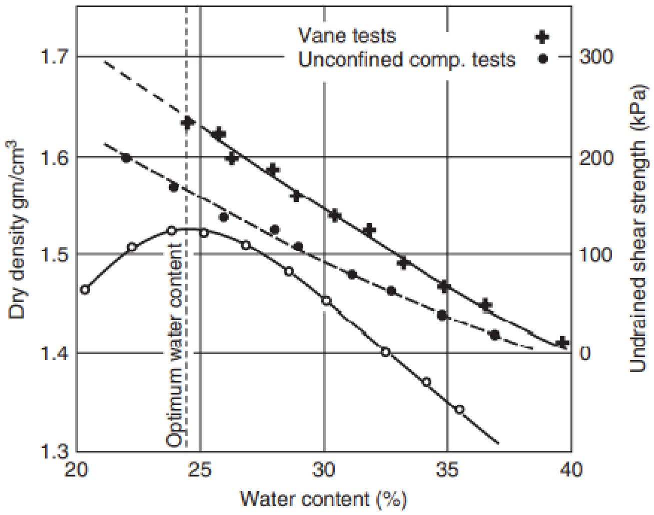

Figure 3: Measurements of undrained shear strength with standard Proctor compaction test on clay

Figure 3 depicts the purpose of using a conventional Proctor compaction test on clay is explained, along with measures of undrained strength, density, and water content. The compacted soilsamples measurements were taken using a hand shear vane and unconfined compressive testing. Results from the two strength assessments are noticeably different. According to the unconfined tests and the vane tests, the undrained shear strength is around 150 kPa and 230 kPa, respectively, at the ideal water content. In cases where conventional requirements permit water concentrations that are 2 or 3 percent above optimal levels, the corresponding shear strength values would be about 120 and 180 kPa. Thus, establishing a minimum undrained shear strength in the vicinity of 150–200 kPa would be appropriate in order to produce a fill with characteristics similar to those produced with current control methods. The amount of water at which the soil can be compressed would be capped as a result. Since the requisite shear strength might be formed by compacting the soil in a very dry state, which is normally desired since dry fills may soften and expand excessively when exposed to rainfall, since the undrained shear strength continuously increases with decreasing water content. The air spaces in the soil are a second characteristic that is defined to prevent the soil from becoming overly dry. According to Figure 3, the water content is optimal, the air vacuum in the in typically, 5% of something is dirt. If the soil is compacted 2-3% drier than the optimal water content corresponding to the compaction effort being applied, the air gaps may be as large as 8 or 10%. As a result, an upper limit on the air gaps is established, typically in the range of 8–10%, to avoid the soil being overly dried out and compacted. The comparison between this approach of preventing compaction and the conventional approach is shown in Figure 4. The highest limit of the dry density for any given water content is always the zero-air-voids line, which holds true for both techniques. The typical approach encloses the area by placing upper and lower limits on water content and a lower limit on dry density. depicted in the figure. The alternate method uses a line parallel to the zero-air-voids line to represent the upper limit of air voids and an upper limit on water content that corresponds to the lowest shear strength. Although there is no set minimum water content, the air gaps limit keeps the soil from becoming overly dry (Wesley, 2019).

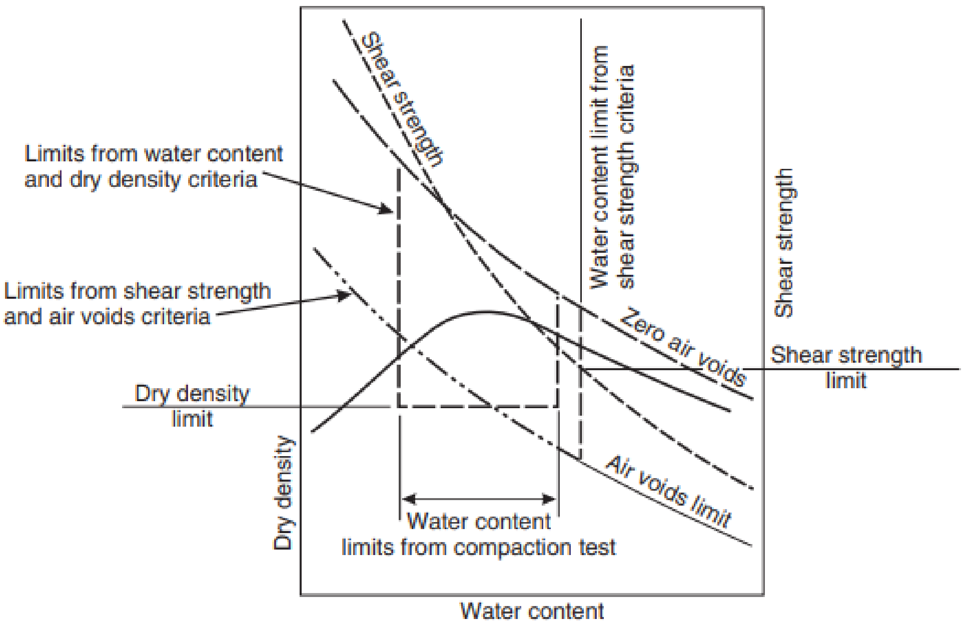

Figure 4: Specific alternative parameters to compaction control

CONSEQUENCES OF SOIL COMPACTION ON PHYSICAL PROPERTIES

1. **Total porosity**

The types of pores found in soil macropores, mesopores, and micropores are. Macropores, which are air-filled pores, provide soil flora and fauna with oxygen. A reduction in macropores led to the emergence of anoxic conditions, which impedes the growth and development of crops. As pore spaces are reduced by soil compaction, air and water mobility within the soil profile are impeded, as well as water retention properties. (Dexter 2004). Compaction changed the pore size distribution, which led to higher runoff, lower infiltration, and higher erosion losses. Due to heavy axle loads and ground pressure imposed by farm equipment, soil pores shrank, resulting in a reduction in the volume of pores. (Pagliai and Vignozzi 2002). As reviewed above, tillage system has noticeable effects on pore dispersion of sizes. According to the standard tillage system, considerable soil loosening results in the development of more macropores early in the growing season (Botta 2000), but later in the season, macropores are reduced as a result of soil compaction. Pore structural instability is highly reliant on timing, field traffic intensity, and rainfall pattern, and it tends to fluctuate as these parameters change (Mapa *et al*., 1986; Karunatilake and van 2002). According to Dexter (1988), soil compaction is a degrading process that modifies the position, size, and form of pores in the soil profile. Boizard *et al*. (2013) also reported that no discernible macropores were seen in the heavily compacted zone of their study on the impact of repeated wheeling on pore size distribution and pore volume. Additionally, extensive structural disruption and in this zone, smooth breaking surfaces have also evolved. Koch *et al.* (2008) found that the topsoil's macropore volume and air permeability are negatively impacted by the compacted zone. (0.05-0.1 and 0.18-0.23 m) and subsoil (0.4-0.45 m) layers. This is another report on the destructive effect of the compact zone.

2. **Hydraulic conductivity**

Hydraulic conductivity, in particular saturated conductivity, is highly susceptible to deformationof soil, particularly soil compaction (e.g., Whalley *et al*. 1995) and alteration in porosity (e.g., Green *et al*. 2003). (e.g., Matthews *et al*. 2010). Reduced soil hydraulic conductivity is caused by a loss in soil aggregate stability, an increase in soil bulk density, and a decrease in air voids (Nayak *et al*. 2007). Additionally, Radford *et al*. (2000) noted that compaction affects hydraulic conductivity in addition to increasing soil strength. Saturated hydraulic conductivity, which is more prone to decline than unsaturated hydraulic conductivity, is determined by the structural distribution of pores. Micropore image analysis demonstrated a linear relationship between saturated hydraulic conductivity and the prevalence of elongated soil pores under these circumstances. The longer the soil, the higher The greater the number of pores, the higher the conductivity, but overall porosity reduced bysoil compaction, resulting in a reduction in soil hydraulic conductivity (Pagliai *et al*., 2003). Even if the average porosity of a soil is the same, the size of its pores may vary because water is held in micropores rather than macropores (Kutlek and Nielsen 1994). Compared to soils with more macropores, soils with more micropores have higher saturated hydraulic conductivity.

3. Aggregate stability

The stability of the soil aggregate is a significant indicator of soil quality, and soil sustainability and productivity are influenced by soil physical characteristics. Due to cohesive forces between soil particles forms the interactions of organic matter, cations, and anions with soil particles cause groups of soil particles to adhere together to form soil aggregates. The ability of soil particles to resist dispersion and degeneration of soil peds/clods is measured by the aggregate stability index. Tillage reduced the soil's stability index by applying a number of disruptive forces that caused soil particles to dissolve. Higher crop yields are produced by soil with high soil stability index compared to soil with low stability index, which has higher soil erosion losses. The formation of soil aggregates is inhibited by soil compaction, which is exacerbated when the soil is attacked by both high axle loads and high moisture contents. The magnitude of the impacts of soil compaction are determined by the spatial composition of these aggregates within the soil profile (Dexter, 1988). The stability of the soil aggregate is influenced by factors such as extensive tillage, high axle loads, plenty of moisture, tyre rutting, and wheeling velocity and intensity. An early sign of soil quality decline or deterioration is a change in aggregate stability. Comparing tillage systems, the conservation tillage approach produced higher levels of structural regeneration and aggregate formation (Alakkuku *et al*., 2003). Furthermore, according to some other experts, conservation tillage enhances soil quality while conventional tillage degrades it by increasing soil aggregates, organic matter content, and porosity (Wiermann *et al*., 2000). In a different investigation by Pagliai and Vignozzi (2002), wetness and extensive tillage reduce the volume of soil aggregates are forced together because to pores, and as a result, their structures collapse and change into unfavourable shapes (Defossez and Richard, 2002). Reduced infiltration and increased runoff were the results of compacted soils with small pore spaces and low soil aggregate stability indices. Another sign of compacted soil is surface crusting, which is linked to small pore spaces and weak aggregates and causes significant soil erosion losses (Way *et al*., 2005). Sandier soils feature fewer stable aggregates and more widely scattered particles. Due to the greater binding of soil particles than sandy soils, clayey soils are more negatively impacted by soil compaction.

4. Penetration resistance

Resistance to penetration causes roots to work harder to penetrate the soil (Braim *et al*., 1992). Increased mechanical intrusion leads to increased compaction, increased resistance to penetration, and increased root labour. This soil characteristic is frequently used to determine how much soil porosity and aggregate stability will change (Dexter *et al.*, 2004). Increased penetration resistance was significantly attributed to compacted soil (Chaney *et al*., 1985). Penetration resistance rises as bulk density rises and water potential falls (Douglas, 1992). Root penetration resistance decreases as penetration resistance increases (Unger and Kaspar, 1994). Increase in water potential is closely connected with a reduction in penetration level. According to Lipiec *et al*. (2002), dry soils have greater penetration resistancein the presence of high soil water but lowsoil strength and penetration resistance (Horn *et al*., 1995)

5. **Bulk density**

The definition of bulk density is the oven-dry weight of soil per unit volume. The amount of porosity in a soil is determined by its bulk density. Increased soil macroaggregates and porosity are characteristics of soils with sound structural integrity. Increased soil compaction is associated with an increase in bulk density because the forces used to compact the soil reduce its volume by pore space elimination. External strain (high axle load) decreases the aggregate stability of the soil, increasing the soil's build density. Increases in bulk density have been well-documented to induce yield reductions, as was seen in Argentina. According to Ressia *et al*. (1998), bulk density more than 1.2 mg/m^3 caused a 30% reduction in maize production. High penetration resistance, less infiltration, and a rise in bulk density as a result of compaction are further effects elevated runoff, increased soil erosion, etc. The amount of bulk density is also influenced by the number of passing; according to Allen and Musick (1997), multiwheeling can enhance bulk density by up to 20%. Different tillage regimes result in different bulk densities. For example, conventional tillage initially produced high porosity and low bulk densities in the early seasons, but later due to agents that cause compaction, the number of pores decreased, and bulk density increased, which could prolong the growing season (Yavuzcan *et al*., 2000). The action of natural biological agents, such as worms and fungus, promotes soil productivity by increasing aggregate stability, porosity, and organic matter while decreasing bulk density. In contrast, under conventional tillage, bulk density and penetration resistance are initially more.

STRATEGIES

- As wet soils are much more susceptible to compaction and depth of compaction so do not work or drive over soil when wet. can increase with soil moisture.
- Tillage breaks up soil aggregates and disrupts soil microbial communities thus reduces tillage.
- To avoid a hardpan layer formation, vary the depth of tillage.
- Distribute weightof tractor over a larger surface tire area by decreasing tire pressure and/or using radial tires. This will reduce the pressure on specific points in the field.
- Reduce axel load for all machinery.
- Reduce the number of rounds on the field. Do not drive over the field unnecessarily.
- Incorporate crops with different rooting depths and types into your rotation.
- Increase soil organic matter content with compost, cover crops, or crop residue.

CONCLUSION

Fixing the issue after compaction might be very difficult and expensive. By chiselling or tearing a compacted layer can be broken up manually, which will aid in crop development during the current growing season but won't improve soil structure over time. Additionally, compaction will worsen if this method is continued year after year. Never use a chisel or rip a piece of dirt that is damp. Long-term prevention and relief of soil compaction depend on effective soil aggregation. There is more space for air and water in soil aggregates because the soil particles are bonded together. Organic materials, such as roots, organic chemicals created by soil bacteria, and fungi's hyphae hold aggregates together. The carbon in soil organic matter serves as a source of nutrition and energy for microorganisms. Increased soil organic matter can increase soil resistance to compaction because it feeds soil bacteria, increasing their number and activity.

Finally, while gypsum does not reduce soil compaction, it can promote water infiltration in soils with a high sodium content (sodic soils). Slower water infiltration occurs as a result of sodium ions' disruption of the soil's clay structure, which leads to clay particles' destabilisation and clogging of the available pore space. Using gypsumcalcium replaces the sodium in the soil, enhancing water infiltration. Gypsum can therefore enhance soil structure but cannot lessen the compaction of already-existing hardpans. To address and prevent soil compaction issues, additional management strategies that were outlined above must be put into practice.

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Chapter

6

SUSTAINABLE AGRICULTURAL PRACTICES

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HISTORY

In 1907, Franklin H. King discussed the advantages of sustainable agriculture in his book *Farmers of Forty Centuries* and suggested that future farming will be depending on sustainable agricultural practices (Kirschenmann, 2004). The term 'sustainable agriculture'was coined by Australian agronomist Gordon McClymont (Pittelkow*et al*., 2015). This term became popular in the late 1980s**.**

INTRODUCTION: WHAT IS THESUSTAINABLE AGRICULTURE?

'Sustainability'can be explained as the fulfillment of our own requirements without compromising the ability of future generations to meet their own requirements (Brundtland Report, 1987). The word sustainability is the derivative of the Latin word *sustinere* (*sus* means from below and *tenere* means to hold), which implies to keep in existence or to maintain. According to USDA's National Institute of Food and Agriculture, "Sustainable agriculture seeks to provide more profitable farm income, promote environmental stewardship, and enhance quality of life for farm families and communities."

In the quest of moderating exploitation of new renewable resources, multiple sustainable agricultural practices have been developed. There are a total of 30 sustainable agricultural practices (SAPs) in India (Gupta *et al*., 2021). The important practices are discussed in this chapter.

SUSTAINABLE AGRICULTURALPRACTICES (SAPS)

Over decades of science and practice, several important sustainable agricultural practices have emerged, such as:

***Organic Farming*:**

Organic farming is an important SAP for addressing India's current agricultural issues. Organic farming is a safe, environment friendly method of growing crops that doesn't harm the environment. According to IFOAM (2005a), healthy soil, sustainable ecosystem, and human health are the benefits of organic agriculture. Instead of using inputs with adverse impacts, it relies on biological processes, biodiversity, and cycles that are tailored to local conditions. Organic agriculture blends science, creativity, and tradition to enrich everyone's quality of life, protect the environment, and establish equitable relationships.

The fundamentalson which organic agriculture evolves and progresses are the tenets of Health, Ecology, Fairness, and Care. They convey the positive impact that organic farming can have on the globe as well as a goal to advance all forms of agriculture on a worldwide scale.

Figure 1: Inter-relationship of components of sustainable agriculture (Zhang *et al*., 2021)

Components:

- **Crop residues**: Crop residues are great source of nutrient recycling in soil. The crop residues include straws, stalks, cobs of maize and stems of beans, peas, potatoes etc.
- **Organic manure**: Organic manures are the keys to **s**ustainable soil. These manures enhance soil quality without endangering ecological stability. Organic manure includes bulky organic manures like FYM, compost, green manure (eg. *Sesbania aculeate* (Dhaincha), *Vigna unguiculata* (Cowpea), *Crotalaria juncea* (Sunhemp)), green leaf manures; concentrated organic manures like oilcakes, bone meals etc.
- **On-farmWaste Recycling**: Recycling organic waste is crucial for sustainable agriculture because it reduces the need for costly chemical fertilizers. Composting, anaerobic digestion, and thermo-chemical processes are used to recycle as much of the farm and home waste as possible, including trimmed branches, straw, and leftover fruit and vegetable pieces.
- **Biofertilizers**: Microbes when used as biofertilizer, increases crop yield by increasing the availability of micronutrient in soil and thus crop productivity. Some useful strains of microbes include symbiotic nitrogen fixing bacteria (*Rhizobium* sp.), asymbiotic nitrogen fixing microbes (*Azospirillum* sp., *Azotobacter sp*.), Phosphate solubilizing bacteria (*Bacillus*

sp., *Pseudomonas* sp., Vesicular Arbuscular Mycorrhiza (VAM), Zinc solubilizing bacteria, Plant Growth Promoting Rhizobacteria (PGPR) etc. (Kumar *et al*., 2017).

Figure 2: Components of Organic Farming (Source: TNAU Agritech Portal https://agritech.tnau.ac.in/org_farm/orgfarm_introduction.html)

Role in maintaining sustainability

Key elements of organic agriculture include enhancing soil fertility, conserving biodiversity, adopting localized production methods and avoiding chemical inputs. It is possible to stabilize the sensitive ecosystems and minimize their sensitivity to drought and insect infestations by using such strategies and cultivating a wide array of crops. By minimizing the chance of yield failure, stabilizing returnsorganic farming increases food security for small farmers' households. When possible, organic farmers take advantage of the natural dynamics, working with them rather than against them.

PERMACULTURE

Permaculture is a philosophy or working with nature that can be thought of as combination of the words “permanent agriculture” or “permanent culture”. Three fundamental principles of permaculture were propounded by Bill Mollison and David Holmgren in the 1970s and 1980s. The first is caring for the planet and all of its living things. Taking care of others is the second. Return of surplus, often known as reinvesting surplus back into the system, is the final tenet.

Components: Permaculture design techniques include spirals, hugelkultur garden beds, herb, keyhole and mandala gardens, mulching, growing crops without tillage etc.

Role in Sustainability: The goal of permaculture is developing an efficient and integrated culture of plants, animals, people and structures with little input and to integrate different scales, from family gardens to large farms.

BIODYNAMIC FARMING

Rudolf Steiner invented the biodynamic farming technique, which is described as a spiritual, ethical, and ecological approach that incorporates a holistic understanding of agricultural concepts. Some consider it to be an advancement over organic. Biodynamics combines ecology and overall growth practices based on the philosophy of "Anthropology". Farmers are motivated to manage their farms as a single alive organism, where farming is intertwined and supports each other. Including animals on the farm to improves soil quality and plant health. In terms of biodynamic, crops, animals and insects are extremely diverse.

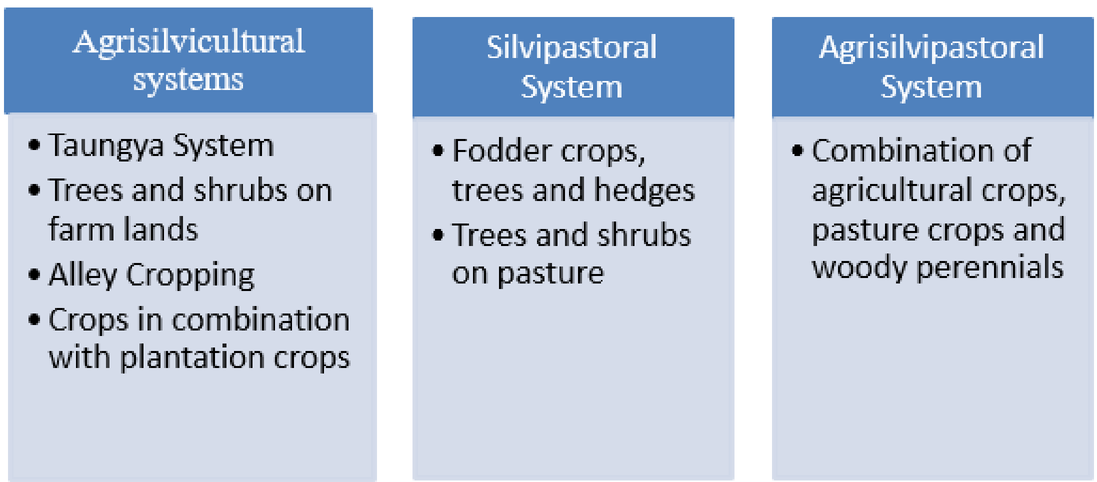
Components: Animals, plants, and soil are handled as one system in biodynamic farming, and the moon's and planets' phases are used to predict the timing of numerous events. Additionally, certain periods of the year involve burying crystals and pieces of deceased animals in the ground as part of biodynamic techniques.

Role in Sustainability: The purpose of biodynamic is to minimize the use of external inputs by creating the soil quality and fertility required for crop production. This goal is achieved by implementing practices such as spreading farm yard manure, composting cover crops or rotating crops. Its practices can be applied in fields, gardens, vineyards and other use of agriculture that manage different products.

AGROFORESTRY

As per FAOs definition, Agroforestry is the inclusion of agricultural crops/ or animals on same land management units along with woody perennials (multipurpose plantations, trees, shrubs, bamboos etc.) in different spatial or temporal sequences. Agroforestry is especially important for smallholder farmers because it can improve their access to food, income, and health.

Classification of Agroforestry based on constituents



Agroforestry and sustainable agriculture:

1. ***Maintaining Soil fertility***: In agroforestry systems, the soils are more abundant in organic carbon, nitrogen, phosphorus, potassium, and calcium.
2. ***Maintaining Soil quality***: Agroforestry systems help in controlling soil salinity. They also help in preventing runoff, improving water management, and betterment of groundwater quality.
3. ***Lowering requirement of input of agrochemicals***: Tree species in agroforestry systems add nutrients through addition of organic matter and root exudates, thus lowering the need for addition of external inputs.
4. ***Bio-Remediation***: It is possible for trees to absorb and immobilize pollutants from deeper soil layers. They effectively remove toxins from the soil and prevent groundwater pollution. The contaminants consist ofpesticides used on farms, heavy metals (such as cadmium, lead, and mercury), persistent organic pollutants (POPs), etc.
5. ***Climate change mitigation***: Agroforestry, which reduces deforestation and sequesters carbon, aids in addressing issues that are causing climate change.


Figure 3: Multifunctional agro-forestry system in India: Agroforestry systems with poplar between Maize crops (Kumar *et al.*, 2019)

Figure 4: AgriSilvi-pastoral System (Source: TNAU Agritech Portal https://agritech.tnau.ac.in/forestry/agroforestry_index.html)

HYDROPONICS

Figure 5: Hydroponic farming (Source: https://www.rimolgreenhouses.com/blog/5-reasons-hydroponic-growing-more-profitable-soil-growing)

Hydroponics grows plants in nutrient solutions to provide mechanical support without an inert medium (e.g., soil).It is an innovative farming technique.

AQUAPONICS

The aquaponic is a sustainable method for growing fish and vegetables. It is a system for growing plants in water with which aquatic organisms can be cultivated.In hydroponic systems, the nutrient rich waste waterderived from aquaculture fish is used to irrigate hydroponic plants.

Figure 6: Aquaponics

(Source: https://bsciencecenter.wordpress.com/2016/08/11/aquaponics-lab-at-burlington-high-school/aquaponics-system-definition)

INTEGRATING CROPS AND LIVESTOCK

Integration of animal and plant production may be the perfect recipe for farms to increase efficiency and profitability. Grazing can also be a great way to rotate plants. Cattle can be fed on diverse agricultural pastures instead of rotating crops so that the animals can consume a variety of vegetation. Agricultural pastures deliver a variety of nutrients to the cattle. Movement of the cattle is also important for the soil as the cattle waste can serve as manure and improve the soil nutrient content.

SYSTEM OF RICE INTENSIFICATION:

By altering the management of natural resources and planting pattern, the System of Rice Intensification, often known as SRI, is an agro-ecological system for raising the production of rice over the conventional system. SRI was developed in Madagascar in the 1980s and is based on the foundations of cropping that include reducing plant population significantly, enhancing soil quality and managing irrigation techniques to promote root growth and plant development, and ensuring robust establishment of seedlings.

Principles:

- Seedlings of 8-12 days age (2-3 leaf stage), which have high potential for tillering and rootingare transplanted.

- Planting of single seedling per hill;
- Square planting with wider spacing of 25 cm × 25 cm;
- Weed management with cono weeder/ rotary hoe; alternate wetting and drying (AWD) in SRI helps in aerating the soil and controlling the weeds compared to continuous flooding in traditional rice cultivation;
- Use of organic sources ofnutrients.

Figure 7: SRI Management (Uphoff, 2022)

SRI in sustainable agriculture:

- SRI principles and practices have been adapted for rainfed rice as well as for other crops (such as wheat, sugarcane among others)
- Reduction in input needs, e.g., 50% reduction in requirement of irrigation water can be achieved.
- Seed requirement in SRI can be reduced up to 90% over conventional.
- 20%-100% or more increase in yield is seen in different trials.

SOIL AND NUTRIENT MANAGEMENT

Conservation agriculture

FAO has defined Conservation agriculture as a agricultural management system that includes minimal soil disturbance and permanent soil cover (mulch) combined with rotations. CA is gaining popularity in many parts of the world because of its contribution to environmental sustainability. Conservation Agriculture maintains a stableorganic soil layer. This can be growing vegetation or decaying mulch. Its function is to physically protect the soil from the sun, rain, and wind while also giving nourishment to the soil biota. Mechanical tillage hampers the growth and development of soil flora and fauna. Conservation agriculture promotes soil health and maintains soil productivity.

Principles/ Components:

Permanent or semi-permanent organic soil cover. This includes use of Surface Mulch, cover crops etc.

Minimal soil disturbance

Crop Rotations

Figure 8: Conservation agriculture (Source: ICARDA)

CONSERVATION AGRICULTURE AND SUSTAINABLE AGRICULTURE

Agriculture in the next decade must develop the capability to sustain and enhance crop yield per unit area of land through more efficient use of natural resources while having minimal impact on the environment in order to meet growing population demands. Promoting and adopting CA systems can help to achieve this goal.

Precision chemical application

It is the practices that include mechanical and biological control to decrease pesticide use and control pest populations. This method uses the variable rate application technology (VRA). Unlike traditional agriculture, this method replaces the homogeneous input, uses the measurement of the on-site productivity difference, and gives the appropriate input according to the requirements generated by these differences.

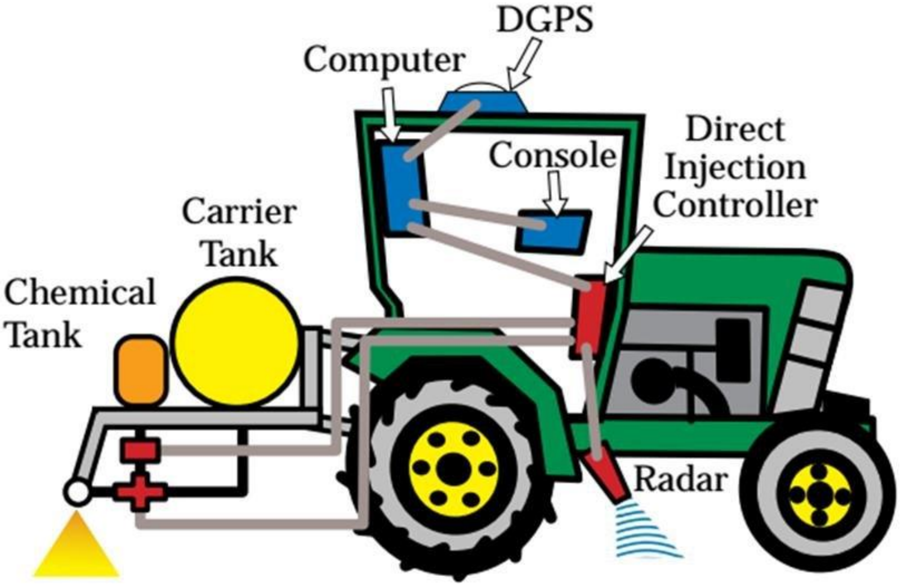


Figure 9: Components of the variable rate technologies for chemical application (Zakka *et al*., 2019)

***Cover crops*:**

Cover crops (e.g., Alfaalfa, Clover, Sudan grass, cowpea, Radish) can strengthen and protect soil health by supplementing soil nutrients, preventing soil erosion and preventing weed growth and reducing the requirement for future herbicides.

Crop rotation/diversity

It is practice of growing various crops in sequential seasons in the same field. Cro protation helps in removal of pests and weed control and also provideshealthy soil.Some of the crops that can be included in a rotation are perennial crops, complex intermediate crops, legumes etc. It is very useful to include legumes in crop rotation, because legumes increase the level of nitrogen in the soil and reduce the need for nitrogenous fertilizers.

Enhancing the Sustainability of the Farming Enterprises

The road to sustainable development is long and complicated. It includes a unique combination of biology, climate, soil and management conditions, so there is no "quick solution" to ensure sustainability. However, there are some principles that can help farmers develop more sustainable agricultural ecosystems. These include:

- Using water and nutrients efficiently.
- Developing ecologically-sound pest management programs.
- Improving energy efficiency of food production and distribution.
- Diversifying agricultural activities to diversify agricultural and economic risks.
- Promoting Crop rotations to improve crop growth and enhancing pest control.
- Includingorganic manures in nutrient management to improve the quality of crop produce and fertility of soil.
- Covering the ground throughout the year with cover crops, when commercial crops are not grown.
- Maintaining profitability.
- Protecting water quality.

CONCLUSION

A commitment to change social norms, economic structures and public policies are necessary for sustainable agriculture, along with approaches for resource preservation and production method modifications. The intricate, reciprocal, and dynamic relationship between agricultural output and society at large must be considered while developing agricultural production and management strategies.

The "food system" encompasses a wide range of stakeholders, including farmers, farm workers, unions, farm consultants, input suppliers, processors, merchants, consumers, researchers and policy makers, who all have different and frequently conflicting agendas. As new technologies bring about changes in the economy, society and politics, relationships between various actors evolve throughtime.To establish a more sustainable food system, a wide variety of ideas and tactics are required. These will range from focused, targeted efforts to change particular laws or practices to longer-term initiatives to reform important institutions, re-evaluate economic objectives and regenerating sustainable ecosystems.

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Chapter

7

BETTER CROP ROTATION, DIVERSITY AND COVER CROP FOR SUSTAINABLE SOIL MANAGEMENT

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ABSTRACT:

Sustainable soil management improves the efficiency of farming systems all over the world. Crop rotation, Diversity and Cover crop have the potentiality to improve soil condition and boost system productivity. Improved soil attributes such as increased soil water uptake and storage, and a greater number of beneficial soil organisms, may improve yield tolerance to drought and other hard growing conditions in a variety of crop rotations. Crop rotation, Diversity and Cover crop with a variety of crops benefit the farmers, reduce production risk and uncertainty, and enhance soil and ecological sustainability. Farmers may be able to diversify their sources of income by adopting these tools. This review provides the evidence of the significance of Crop rotation, Diversity and Cover crop.

CROP ROTATION

A planned sequence of planting several crops on the same field is known as crop rotation. Crop r otation is a technique for growing different crops on the same plot of land in a precise order in or der to maintain soil fertility and production over time (Folnovic, 2021). Continuous cropping, or f arming the same field year after year, is the opposite of rotations. Due of its capacity to save soil, it is a typical practise on sloping soils. Crop rotations can be utilised to enhance or preserve the s oil's healthy physical, chemical, and biological properties. They can be applied to slow down a fi eld's typical rate of erosion. Reducing erosion and enhancing soil quality can both be accomplished ed by include a grass or legume in a rotation. Legumes can reduce or even eliminate the demand for nitrogen fertiliser when they are utilised in crop rotation. Other crops build up potassium or phosphorus.

Crop rotation disrupts insect and pest reproduction and lowers their number. When specific plant species are included in crop rotation, plant nutrients are regenerated, reducing the need for chemical fertiliser. Crop rotation is a practical method for sustainable agriculture (Shrestha *et al.*, 2021). Diversified crop rotation refers to a series of numerous crop rotations comprising three or more crops, in contrast to monocultures and double farmed rotations (Wang *et al.*, 2020). By choosing a crop rotation strategy carefully, it is possible to maintain long-term soil fertility, eliminate trade-offs between crop viability and environmental effects, and disrupt the weed and disease cycle process through intrinsic nutrient recycling (Andam *et al.*, 2016). "The soil should act as a critical life cycle within the ecosystem and land-use limits for sustaining plant and animal development, controlling or improving the quality of water or the environment, and nurturing plant and animal health," said Doran and Zeiss (2000).

Benefits of crop rotation:

1. **Plant Nutrition:** The types and quantities of soil minerals used by each crop vary. If the same crop is grown year after year, the soil eventually loses the mineral required for plant health and growth. Reversely, when a plant dies and composts or is transformed into soil, it can sometimes replenish the soil's mineral deficiencies.
2. **Soil Structure:** Rotation protects and enhances soil structure, to start. Crops grow to varie d depths and have various root systems. Rotating the soil exposes it to deep diggers that g radually dig down into the top soil as well as shallow depth crops.
3. **Insect Control:** Insects may spend the winter in your soil. When your plants revive in the spring, they invade the leaves and vines in search of their favourite meal. These insects a ppear to be facing an ant that they are not feeding on when you spin.
4. **Disease Prevention:** Plant diseases can overwinter in plant leaves, roots, and vines that are buried in the ground, just like insects can. Crop rotation aids in preventing the recurrence of these diseases the next season.
5. **Water quality:** Reducing sediment loss, losses of dissolved and sediment-attached nutrients, and losses of pesticides can improve the quality of surface water. Deep-rooted sod crops, which may use nutrients from deep in the soil profile, can reduce nitrogen losses to ground water. Legumes also fix atmospheric nitrogen, which can minimise or completely remove the need for commercial nitrogen fertiliser for the subsquent.
6. **Crops:** Crop rotations also frequently promote strong root systems that are efficient at pulling nutrients from the soil, reducing leaching to ground water.

Important points related to crop rotation:

Rotations that incorporate small grains or meadows give greater erosion management.

- Crops must be suitable for specific types of soils.
- Any row crop or crop with a low residue can be replaced with small grains and meadow to improve erosion management.
- If you want to improve erosion control, you may always substitute corn (grains) for soybeans or any other crop with a low residue.
- For crop rotations, which include hay(meadow), The rotation can be lengthened by maintaining the existing hay stand for additional years
- Avoid planting a grass after a grass if possible

CROP DIVERSIFICATION

Crop diversification, which can take place on smaller or larger sizes, is the introduction or addition of additional crops to the current farming system. Through crop rotation or intercropping, it involves the technique of growing more than one variety of crops from the same or distinct species in a same area. It may be one of the most economically viable, reasonable, and environmentally sound approaches to lessen agricultural uncertainty, especially for smallholder farmers (Joshi, 2005). Crop variety ensures increased geographical and temporal biodiversity in farms, improves resilience, and makes agronomy more stable (Joshi, 2005). Reduced weed and pest pressures, decreased reliance on nitrogen fertilisers (especially if the crop mix includes leguminous crops), decreased erosion (due to the presence of cover crops), higher soil fertility and yield per unit area, and other factors all contribute to resilience (Lin, 2011). By substituting more exploitative methods and concentrating production systems on regenerative agriculture, diversification can improve climate resilience and the conservation of natural resources (soil, water, and biodiversity).

There are two main types of agricultural diversification prominent in India:

1. Horizontal Diversification: multiple cropping or mixing of crops instead of growing a single crop

2. Vertical Diversification: incorporation of industrialization along with multiple cropping, wherein farmers invest in supplemental activities like horticulture, agroforestry, livestock rearing, culture of aromatic plants etc.

Crop diversification is heavily dependent on technical advancements intended to boost productivity and sustainably intensify agriculture while simultaneously lowering input costs to increase farmers' income. The accommodating of new crops and cropping methods that are best suited to the current eco-regional circumstances while providing higher productivity and profitability is part of the dynamic aspect of diversification. Farmers can reduce their risk and gain access to local, national, and international markets by planting a range of crops. Agricultural intensification has historically aided in achieving food security; however, in order to continue addressing our family food, nutrition, and environmental security, we must reorient current cropping systems to be more sustainable.

It is necessary to develop a shared conceptual understanding of diversification. Often, terms such as diversity, diversification, crop rotation and mixed cropping are used interchangeably, preventing generalization of results. The crop diversification approach provides information on

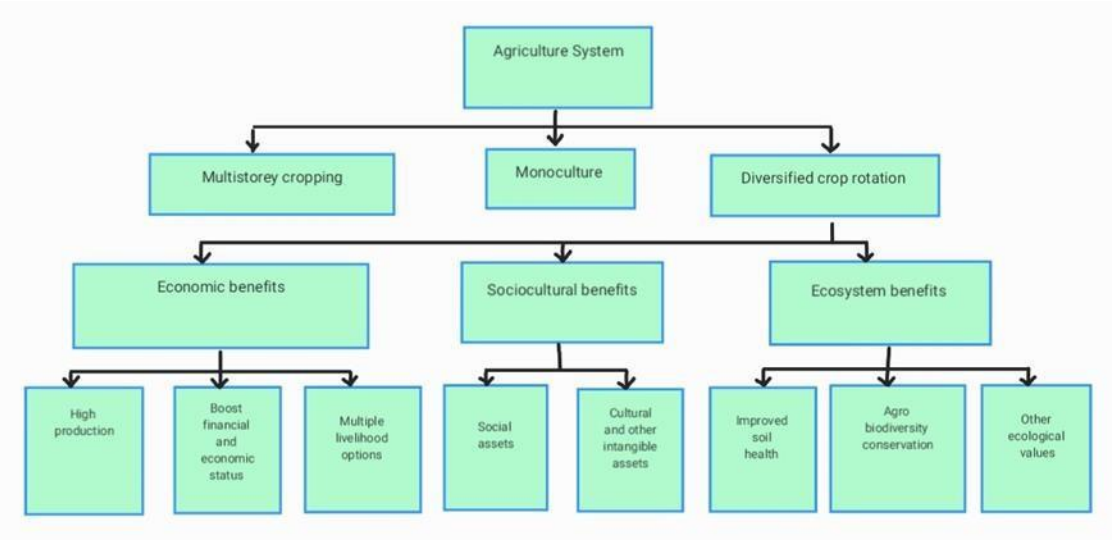
1. Problem definition
2. Baseline definition
3. Scale definition
4. Characterization of the experimental design including a minimum set of target variable
5. Defining the impact systematically to assess and report the effects of the diversification measures

6. Land deterioration, a decline in soil health, groundwater depletion, environmental contamination, and a decline in total factor productivity are the key obstacles to agricultural diversification.

   For crop diversification, future strategies must aim at

- Horizontal strategies that incorporate agricultural intensification and crop replacement with species best suited to certain ecoregions
- Good agronomic ecology practises and genome editing are two vertical approaches for increasing productivity that attempt to use expensive inputs like water, energy, fertiliser, and pesticides more wisely.
- Processing after harvest, value addition, branding, packaging, etc. to increase revenueMicro-ability irrigation's to efficiently utilise water, particularly in drylands
- High-yielding cultivars and hybrids are introduced through varietal diversification to increase productivity.
- Incorporation of legumes;
- Large-scale adoption of integrated pest management
- Risk reduction by intercropping, mixed cropping, the use of low-yield, high-value crops, and mixed farming

Such a strategy would call for scaling up innovations to increase resource-use effectiveness via suitable policies and programmes.



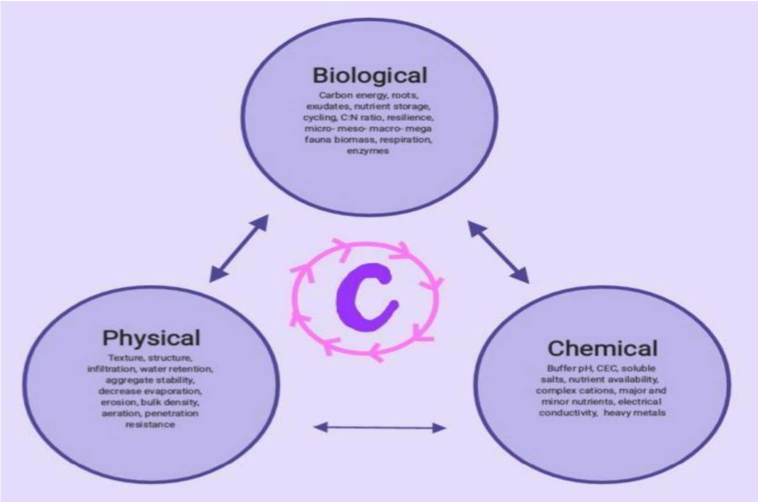
COVER CROPS

Plants called "cover crops" are those that are planted to cover the soil rather than to be harvested. Within an agro-ecosysytem, cover crops control soil erosion, soil fertility, soil quality, water, weeds, pests, diseases, biodiversity, and wildlife. After the cash crop has been harvested, cover crops may be planted. These plants are used to cover soil for specific purposes. In contrast to primary species, which are farmed for trade or human use, secondary species satisfy secondary farmers' requirements. They increase yields, strengthen the soil, and feed the animals. But that does not imply that these plants belong to a particular species. They can also be used as currency in various contexts and served on a plate (e.g. buckwheat). The distinction is that these species are used as grasses in that instance of fall cover crops.

Types of cover crop

According to their characteristics and potential uses, grasses, legumes, and broadleaf non-legumes fall into three basic categories. Most of the time, they perform multiple tasks at once, such as avoiding erosion, enhancing soil quality, providing grazing, etc.

1. **Grasses:** Grasses are annual cereals including wheat, rye, corn, oats, and others. They produce wastes that are simple to handle and develop fairly quickly. Their sturdy, erosion-resistant root systems have the appearance of fibrous threads. They do not have the ability to fix air nitrogen, but they do acquire soil nitrogen through their symbiotic relationship with Azospirillum in terms of nutrients.
2. **Legumes:** Legumes are renowned for enhancing nitrogen levels since they are nitrogen-fixing cover crops. When plants grow large, their strong taproot system helps combat unwanted undersurface compaction. Additionally, a larger plant may fix more nitrogen than a smaller one. Red and white clover, cowpeas, alfalfa, hairy vetch, and fava beans are a few examples of legumes.
3. **Broadleaf non-legumes:** They produce green manure, retain the soil in place, and absorb nitrogen from the soil. They normally pass away in the harsh winter temperatures, necessitating no additional termination. However, non-legumes utilised as fall cover crops need to be treated for weed control issues prior to seed settling. Brassicas, forage radishes, turnips, marigolds, mustard, etc. are examples of this type.



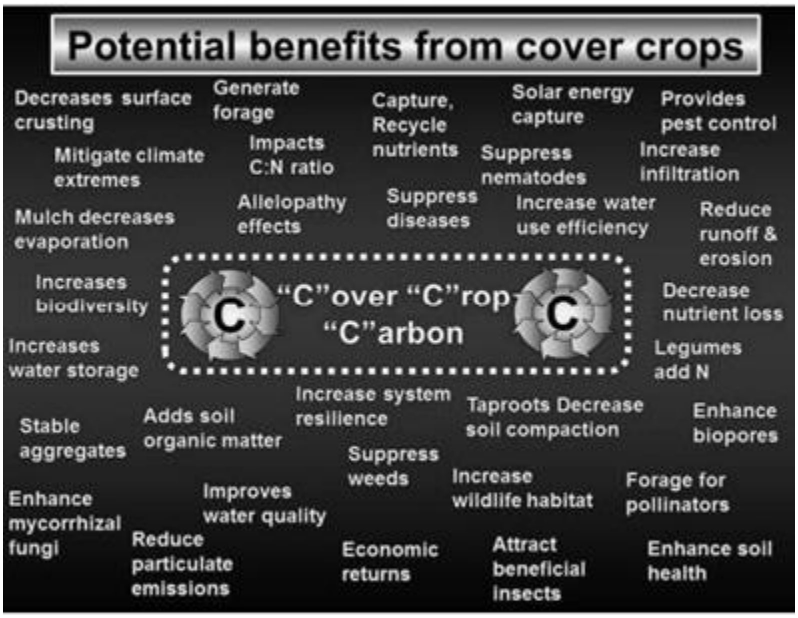
Benefits of cover crop

- **Soil erosion:** Cover crops are very efficient in preventing soil erosion. Soil erosion is a process that can reduce the productive capacity of an agro-ecosystem. Cover crops reduce soil loss by improving soil structure and increasing infiltration, protecting the soil surface, scattering raindrop energy and reducing the velocity of the movement of water over the soil surface. Dense cover crop stands physically slow down the velocityof rainfall before it contacts the soil surface, preventing soil splashing and erosive surface runoff. Even cover crop root networks help anchor the soil in place and increase soil porosity, producing suitable habitat networks for soil macrofauna. It keeps the enrichment of the soil good for next few years.

- **Soil fertility management:** Cover crops are mainly known for boosting soil fertility. These types of cover crops are basically known as green manure. They affect different pools of soil macro-nutrient and micro-nutrient.They have impact on nitrogen management and has received most attention from researchers and farmers beacause nitrogen is often most limiting nutrient in crop production. Green manure crops are grown for a specific period and then plowed under before reaching full maturity to improve soil fertility and quality. The stalks left block the soil from being eroded. In conventional farming, the nitrogen is typically applied in chemical fertilizer form so nitrogen fixing ability of cover crops can be used to replace fertilizer.
- **Soil quality management:** Cover crops can improve soil quality by increasing soil organic matter levels through the input of cover crop biomass over time. Increased soil organic matter enhances soil structure along with water, nutrient holding and buffering capacity of soil. Cover crops increased soil carbon sequestration which has been promoted as a strategy to help offset the rise in atmospheric carbon dioxide levels. Soil quality is managed to produce optimum circumstances for crops to flourish. The principal factors of soil quality are soil salination, pH, micro-organism balance and the prevention of soil contamination.
- **Water management:** By reducing soil erosion, cover crops often reduce both the rate and quantity of water that drains off the field, which would normally pose enviormental risks to waterways and ecosystems downstream. Cover crop biomass act as physical barrier between rainfall and soil surface, allowing raindrops to steadily trickle down through soil profile. Cover crop root growth results in the formation of soil pores, which in addition to enhancing soil macrofauna habitat provides pathways for water to filter through the soil profile rather than draining off the field as surface flow.Increase in water infiltration, the potential for soil water storage and it can improve the recharging of aquifers.In agroecosystems where water for crop production is in shortage, cover crops can be used as a mulch to conserve water by shading and cooling the soil surface.This reduces evaporation of soil moisture.
- **Weed management:** During the cover crop growth stage, thick cover crop stands frequently compete successfully with weeds and can stop the majority of weed seeds from germinating from completing their life cycle and reproducing. After the cover crop's development is finished, it is typically flattened down on the soil's surface rather than being integrated into the soil as green manure, where it can eventually create an almost impenetrable mat. This significantly lowers the amount of light that weed seeds can

receive, which frequently lowers their rates of germination. The "smother effect" refers to the fact that when weed seeds germinate, they frequently exhaust their supply of stored energy for growth before developing the structural strength to penetrate the mulch layer of the cover crop.

- **Disease management:** The allelopathic qualities of cover crops can break disease cycles, suppress weeds, and lower populations of parasitic, worm, bacterial, and fungal illnesses. It has been well established that members of the Brassicaceae family, including mustard species, can reduce the prevalence of fungi by releasing naturally occurring poisonous chemicals as glucosinolade molecules break down in their plant cell tissues.
- **Pest management:** Cover crops, commonly referred to as trap crops, are used to entice pests away from valuable crops and into what the pest perceives as a more desirable habitat. Trap crop zones can be developed in farms, in landscapes, or in crops. During the same growing season as the food crop, the trap crop is grown. Once pests are attracted to the trap in sufficient numbers to lower the pest populations, the small area these trap crops occupy can be treated with a pesticide.



CONCLUSION:

As people grow increasingly concerned about the need to produce high-quality food with a minimal negative impact on the environment, crop rotation, diversity, and cover crop are becoming more and more common as a strategy for preserving sustainable agricultural production. They promote the interactions of advantageous soil bacteria, disrupt the spread of illness, and lessen weed growth. They enhance the soil's physicochemical qualities and boost agricultural productivity as well as the effectiveness of land use. For long-term financial success, they are helpful exercises. In order for farmers to respond to market needs, they need these affordable, flexible technology. At the farmer level, adoption requires organisational and policy support. The scientific community should concentrate its current and future research plans and initiatives on creating crop rotation techniques that are more responsive to changing climatic circumstances.

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Chapter

8

INORGANIC AMENDMENT FOR SUSTAINABLE AGRICULTURES

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INTRODUCTION:

The main goal of modern agriculture is to boost crop yield while maintaining (or even reducing) soil mineral fertilization rates (Eprikashvili *et al*., 2016). Enhancing crop productivity, restoring polluted, saline, and acid soils, reducing metal uptake, and reducing the likelihood of environmental and climatic effects due to an abundance of nutrients (primarily N and P) in the soil have all been achieved in agriculture with the help of natural or synthetic inorganic amendments (Chatzistathis *et al*., 2020). Inorganic amendments are either mined or are manmade materials. The inorganic amendments can play a very effective role if applied on a need basis after proper soil tests. The amendment increases the amount of bioavailable nutrients, which facilitates the development of certain biofortified cultivars to boost crop yields. Additionally, inorganic amendment can help with the reclamation of disturbed soil areas, such as highly mined lands, as well as problems with alkaline or saline soils (Chauhan and Kulshreshtha, 2021). Various types of inorganic amendment are available in the sustainable agriculture system such as Zeolite, Vermiculite, Wood ash, Press mud, Lime, Flyash, Phosphogypsum etc.

Zeolites, one of the most popular inorganic amendments, is effective at reducing nutrient leaching, which has positive effect on the environment. The high NH_{4+} adsorption capacity of zeolite is particularly significant in agricultural soils that receive considerable N fertilization because it may regulate ammonia release and, subsequently, nitrification activity, N availability to crops, and N losses to the environment (either in the form of nitrates or in the aerial forms NH_3 or N_2O). Zeolite has been discovered to have an effect on other nutrients' availability (mostly exchangeable cations, such as K), in addition to its effect on soil N availability, because of its inherent adsorptive characteristics and high nutrient (particularly K) concentration. This has a significant impact on soil fertility and crop nutrition (Dostikhan *et al*., 2020). Vermiculite is a clay-like substance that occurs in nature; its magnesium form is made up of two layers of silicon tetrahedra with aluminium replacing some of the silicon in each layer, and a layer of OH groups and magnesium ions that together create a stack of mica with a high degree of bonding (Malamis and Katsou, 2013). In order to increase the pH of acidic soil, lime amendments are utilized. Different types of limestone, such as ground limestone, dolomitic limestone, and burned limestone, are used to remediate soil.

The formation of phosphoric acid from the phosphate-containing rock results in the production of phosphogypsum. Gypsum is a fairly soluble source of calcium and sulphur, two crucial plant nutrients, and is one of the early agricultural amendments used to recover alkali soils.Wood ash contains significant levels of calcium (25%) and potassium (5%), as well as smaller amounts of phosphorus (2%) and magnesium (1%), two essential plant minerals. There are also micronutrients like zinc, copper, molybdenum, sulphur, and boron. Similarly, other inorganic amendment used for different purpose (Chauhan and Kulshreshtha, 2021). Inorganic amendments have a variety of functions, yet there is limited information on how they can enhance crop nutrition (in place of chemical fertilizers or in conjunction with other inorganic/organic fertilizers, in terms of reducing their excessive rates), maintain yields, and promote sustainability. This chapter focuses on the aspect, how the different inorganic amendment sustainably increases the crop yield and soil fertility in the long run.

CHARACTERISTICS OF INORGANIC AMENDMENTS

Before choosing an inorganic amendment for the soil, it's crucial to remember that it contains a specific quantity of N, P, K, and other nutrients. The amendment that should be adopted primarily depends on the objectives to be met. A fast decomposable inorganic amendment should be used to improve soil physical properties and improve crop yield. The soils can be amended with the aid of utilizing specific soil additives depending on crops, permeability, and water retention (David and Wilson, 2005). These characteristics are listed below in detail.

Table 1: Characteristics of Inorganic amendments

S. No	Properties	Inorganic amendment
1-	Fixed Composition	They have a fixed chemical composition and contain both macronutrients and micronutrients because they have a fixed amount of each nutrient, such as inorganic mineral, chemical, or synthetic fertilizer.
2-	Characteristics	These are mineral- or chemical-based synthetic fertilizers that are produced artificially.
3-	Availability	These are widely available on the market. Specific nutrient-containing additions can be purchased as needed after assessing the soil quality.
4-	Source of material and composition	Along with other industrial waste products like Ca-montmorillonite mineral, bentonite gypsum, phosphate salt from the fertilizer industry, hydroxyapatite from phosphorite, fly ash from thermal power plants, basic slag from the steel industry, etc., these include vermiculite, perlite, tyre fragments, pea gravel, sand, etc..

5	Time required for nutrient uptake	Rapid nutrient availability to plant
6	Presence of pathogen	Relatively sterile
7	Storage	Store items in a dry, dark environment to prevent chemical reactions.

(Source: Saunders (2018), University of New Hampshire)

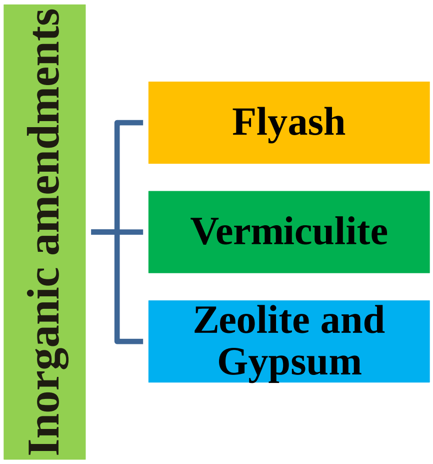

Figure1: Different types of Inorganic amendments

FLYASH

Thermal power plants all over the world are simultaneously creating several residues such Flyash, bottom ash, fluidized bed boiler waste, coal gasification gas, and flue gas desulphurization waste as a result of the increased demand for coal-based energy. Flyash refers to the residues that pose a serious concern when they enter the flue gas stream. In addition to being produced by the combustion of coal, Flyash is also produced by the cement industry, factory boilers, etc.; as a result, a significant amount of Flyash is produced, and it is predicted that this amount will continue to climb gradually in the near future (Rastogi and Paul 2020).In India, properly disposing of this enormous amount of FA is a significant problem.Flyash is now widely used in agriculture to increase crop productivity and soil fertility when used in the right amounts.In addition to the 11 most common elements (C, S, K, Ca, Mg, Al, Fe, Na, Si, O, and Ti), flyash also contains a variety of trace elements (B, Ba, Hg, Cu, Co, Mn, Pb, As, Ni, Cd, Cr, Sr, V, Ti, Zn, and Mo), as well as silicates, oxides, sulphates, and borates (Feng *et al*., 2018).

Due to its numerous physicochemical characteristics, including pH, low bulk density, electrical conductivity, clay and silt particles, high water holding capacity, and supplier of essential nutrients, flyash is an excellent soil ameliorator in agriculture, forestry, and wasteland recovery.The use of Flyash (FA) (100-650 tonnes/ha of land) as a soil conditioner and micronutrient fertilizer to improve the soil's nutritional quality and promote plant development has been the subject of numerous studies.Using a randomised block design, Bisoi *et al.* (2017) conducted an experiment with three replications on two cultivars of Indian wild rice (*Oryza* *nivara* and *Oryza rufipogon*) planted in various proportions of flyash, mine soil, and garden soil. The study found that all growth, yield, and antioxidant indices of both wild rice cultivars were raised by 50% flyash and mining soil. According to Haris *et al.* (2019), the 10 to 30% application of flyash improves carrot (*Dacus carota*) plant growth and photosynthetic pigment. Similar, result reported by Shakeel *et al*. (2019) in Indian mustard (*Brassica juncea*).

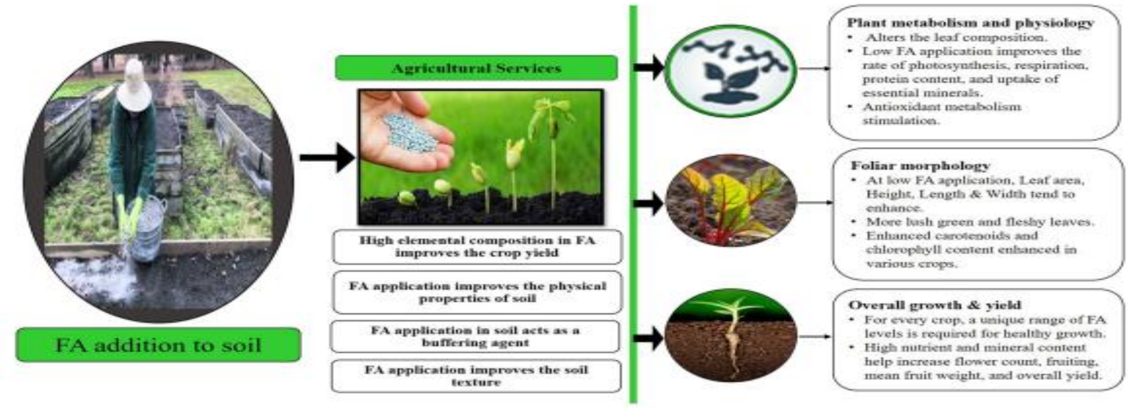

Figure 2: Positive impact of FA application in soil (Source: Varshney *et al*., 2022)

ZEOLITE

Zeolites contains (15000 ppm K) and regarded as one of the most popular inorganic amendments, is effective at reducing nutrient leaching, which has positive effect on the environment. They are historically being utilized to enhance agriculture efficiency. The high NH^{4+} adsorption capacity of zeolite is particularly significant in agricultural soils that receive considerable N fertilization because it may regulate ammonia release and, subsequently, nitrification activity, N availability to crops, and N losses to the environment (either in the form of nitrates or in the aerial forms NH_3 or N_2O). Higher N uptake, crop growth, and yields as well as improved N usage efficiency and less N losses due to nitrate leaching or denitrification/volatilization processes are all benefits of using N (inorganic) and zeolite together (Omar *et al*., 2015).

Zeolite has been discovered to have an effect on other nutrients' availability (mostly exchangeable cations, such as K), in addition to its effect on soil N availability, because of its inherent adsorptive characteristics and high nutrient (particularly K) concentration. This has a significant impact on soil fertility and crop nutrition (Dostikhan *et al*., 2019). In this regard an experiment was conducted to show its effect and result indicated that the levels of K, Ca, and Mg were much greater in zeolite than in vermiculite. This led to a notable rise in soil K as compared to the control, as well as a large increase in soil exchangeable K (more than 15 times greater, compared to vermiculite).

Aside from this, it also enhances the K content in the leaves and is a great source of K for plant nutrition, potentially reducing the need for inorganic fertilization (Chatzistathis *et al*., 2020). Nakhli *et al*. (2017) reviewed that these minerals are considered as soil conditioners to improve soil physical and chemical properties including infiltration rate, saturated hydraulic conductivity (Ks), water holding capacity (WHC), and cation exchange capacity (CEC).It is well accepted that adding zeolitic minerals to the soil enhances water retention and reduces deep percolation, which can reduce the amount of water needed for agricultural activities (Mumpton 1999; Polat *et al*., 2004; Sharpley *et al*., 1994; Talebnezhad and Sepaskhah, 2013; Ming and Mumpton, 1989).

Zeolites are capable of exchanging or adsorbing a variety of cations, such as cesium (Cs) and strontium (Sr), as well as heavy metals, such as cadmium (Cd), lead (Pb), nickel (Ni), manganese (Mn), zinc (Zn), chrome (Cr), iron (Fe), and copper (Cu), (Kazemian *et al*., 2001; Kazemian and Mallah, 2006; Faghihian *et al*., 1999a). Figure 2. Depicting the role of zeolite in sustainable agriculture. Zeoponics is the studyof plant growing in medium that contains zeolite and soil. This medium is nutrient-rich and has a large cation exchange capacity. As a result, there isn't a pressing need to supply irrigation water with fertilizers ((Rivero and Rodrguez-Fuentes, 1988; Gruener *et al*., 2003; Allen and Ming, 1995).

VERMICULITE

Vermiculite is a 2:1 clay mineral containing a crystalline structure similar to the smectites group. This clay mineral has a medium surface charge, and in recent years, vermiculite has been widely used to absorb metal cations. The sort of vermiculite manufactured for use in gardens is always exfoliated vermiculite. It has a lot of beneficial characteristics that can help your plants and soil. It has a neutral pH, is aerating, moisture- and nutrient-retentive, light, non-toxic, sterile, does not rot, or mould. Vermiculite is used as soil amendment, root cutting and seed germination.In this regard an experiment was conducted to show the effect of vermiculite on tomato crop, the result showed that the Zeolite only has a 0.57 mg kg iron level compared to the 14.44 mg kg iron in vermiculite (Chatzistathis *et al*., 2020). It is well accepted that adding zeolitic minerals to the soil enhances water retention and reduces deep percolation, which can reduce the amount of water needed for agricultural activities.

It is the ideal biostimulant for plant growth since it contains oxides of many metals, including magnesium, potassium, aluminium, and iron.Even during protracted droughts, you can maintain an appropriate soil moisture regime, because of its significant water absorption capacity (up to 500%).Vermiculite can be used to improve the structure of both light and heavy soils, create the ideal air-water regime of soil, significantly stimulate plant growth, reduce acidity and salinity in the range of 8–14%, increase fertilizer efficiency, decrease root rot, and increase crop safety and productivity by 10–17% (White Knight minerals, 2005). Vermiculiteis additionally utilized in landscaping and for storing fruits and vegetables (such as potatoes, carrots, apples, and pears) (White Knight minerals, 2005). *Zea mays* was used in a series of pot experiments by Parmar *et al*. (2022) to evaluate Pb, Cu, and Zn uptake as well as the function of vermiculite in metal immobilization in the soil root zone. In soils that have been treated with vermiculite, the buildup of metals was reduced (13.17% to 29.21% in above-ground sections and 4.18% to 69.74% in roots) and total plant biomass rose (1.43% in control soil and 10.54% in polluted soil).The study demonstrates that by incorporating vermiculite into the soil and using return flow techniques for reducing the phytoavailability of dangerous metals to plant uptake, groundwater pollution, and food-chain contamination may be controlled without reducing crop output.

Figure 3: Role of Zeolite in sustainable agriculture.

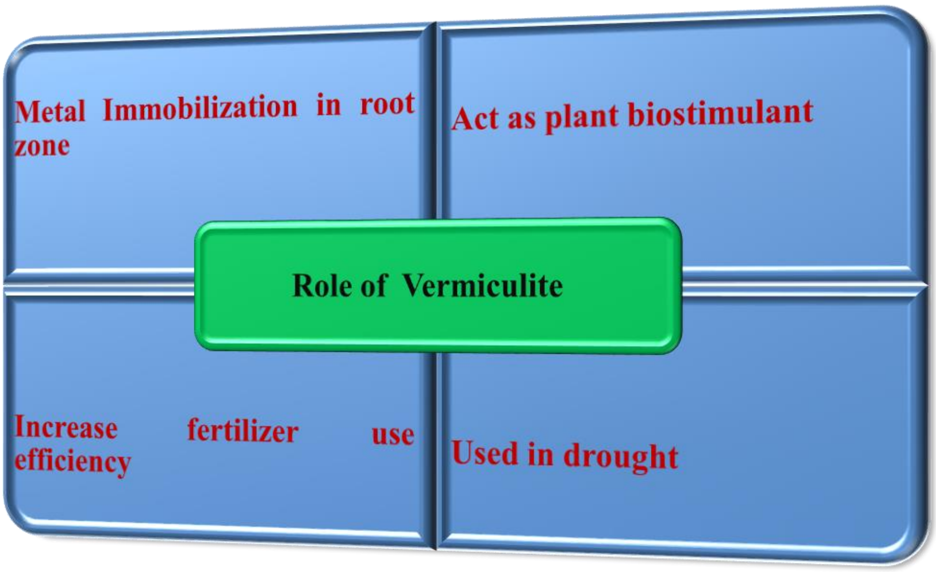

Figure 4: Role of Vermiculite in sustainable agriculture

To determine the impact of vermiculite treatment rates on the growth and yield of *Brassica napus*, a three-year field experiment was conducted. The experiment was carried out at the Marondera University of Agricultural Sciences and Technology (MUAST) farm in Zimbabwe's Mashonaland East Province during the summers of 2016/17, 2017/18, and 2018/19. Vermiculite was treated in a completely randomized block design (RCBD) with three replicates at five levels of 0 (control), 1, 2, 5, and 10 t ha^{-1}. In the research region, fertilizers were applied at the approved rates for basal and top-dressing. We measured the N and P uptake, fresh and dry matter yield, leaf nutrient concentration, and leaf breadth and length of B. napus. Result indicated that the *B. napus* produced more fresh and dry matter and had wider and longer leaves when application rates of 5 t ha^{-1} and 10 t ha^{-1} vermiculite were used (Pisa *et al*., 2020).

GYPSUM

Gypsum can enhance overall plant growth since it is a soluble source of the vital plant nutrients calcium and sulphur. Gypsum supplements can also enhance some soils' physical qualities, particularly heavy clay soils. These additives promote soil aggregation, which reduces soil particle dispersion, lessens the development of surface crusts, promotes the emergence of seedlings, and enhances water infiltration rates and movement through the soil profile. Additionally, it alsolessens the amount of soluble phosphorus present in surface water runoff as well as erosion losses of soil and nutrients. Gypsum application can reduce aluminium toxicity and subsoil acidity, among other chemical qualities. This encourages the development of deep roots and improves plants' capacity to take up enough water and nutrients during periods of drought. Gypsum is the most often used amendment for reclaiming sodic soil, and it can also be added to synthetic soils for use in gardens, greenhouses, and nurseries (Chen and Dick, 2011).

The sources of gypsum produced, when coal is burned to provide electricity, heat, or other kinds of energy, gypsum from flue gas desulfurization (FGD) becomes a new and significant volume source. In scrubbers that use limestone to force oxidation to remove sulphur dioxide from the flue gas stream following coal combustion, flue gas desulfurization (FGD) gypsum is produced (Chen and Dick, 2011). The recovered gypsum is of high quality and is appropriate for industrial (such as wallboard) and agricultural usage.

Figure 4: Gypsum is used as a calcium fertilizer to increase the output of peanuts (Tillman *et al*., 2010; Sumner, 2006)

Figure 5: Gypsum used as a soil addition to treat soils contaminated with salt or sodic. The control part is in the foreground, and the gypsum application area is in the background. (Xu, 2006)

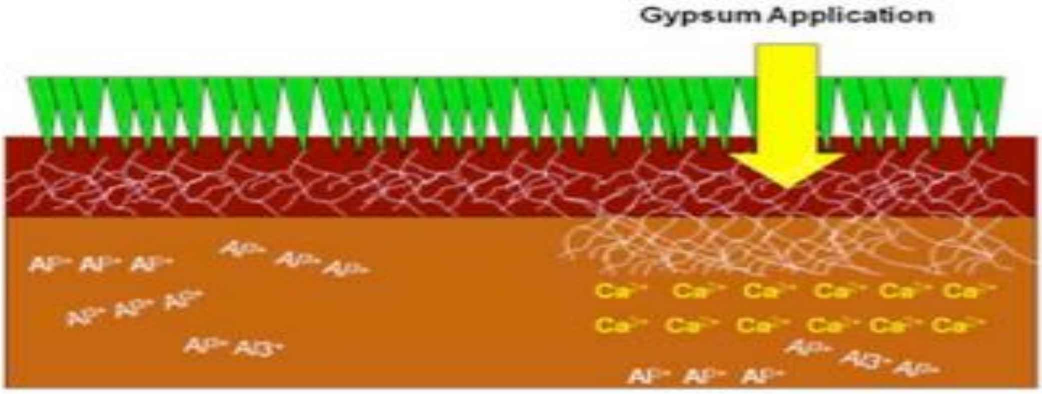

Figure 6: Gypsum as a soil additive to reduce acidity in the subsoil. Gypsum is 200 times more soluble than lime, and its addition to soil improves the transport of calcium and sulphur into soil profiles. Sumner and Larrimore (2006)

CONCLUSION

The role of these inorganic amendment in sustainable agriculture is justifiable as every one of them played vital role in improving crop yield as well as soil physico-chemical properties. But care should be taken in the regard of their use. First soil testing and then crop recommendation according to it should be followed. Otherwise in long run they may cause problem to the system as some of them contain potential toxic element also. Despite it, there use in judicious way can lead to the enhancement in crop yield as well as soil fertility and in this regard more experiment need to be conducted to obtain their suitable dose.

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Chapter

9

FUTURE TRENDS IN SUSTAINABLE AGRICULTURE

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INTRODUCTION

The term "sustainable" has gained a lot of popularity recently and is used to describe a variety of topics. Sustainability in agriculture aids in finding the ideal balance between the requirement to produce food and the maintenance of environmental ecosystems. In order to meet the expected 9.6 billion people on the planet's recommended daily calorie consumption by 2050, it is predicted that nearly 70% more food will be required than that is being produced now (FAO, 2017). Production of nourishment is made possible through sustainable agriculture, which preserves future generation's ability to try to do the same. When it comes to resource consumption, agricultural practices are frequently found to be somewhat inefficient as it is closely related to production costs. In this aspects, sustainable agriculture is equally important as it promotes economic stability for farms and helps farmers to improve their quality of farm life.

Sustainability in agriculture is a homogenousconcept with a combination of factorsthat demands social, economic and environmental aspects. In order to achieve the criteria of sustainability, working for and with the environment isbeneficial for present and upcoming generation rather than working against it. So, considering the above, the following things are to be kept in mind- SustainablePractices which promotes irreversible land changes, erosion control measures, soil moisture conservationetc should be adopted. It is important to guarantee that natural resources such as water, energy, soil, plants, animals, biodiversity, ecosystems, etc. are used responsibly and sparingly.

A long-term stability and productivity are required for sustainable agriculture, more renewable and diverse resources, such as wind energy, solar energy, etc. It should be utilized as opposed to total self-sufficiency. Even in the face of global agricultural consolidation and infrastructure expansion, a farm should be able to generate enough income to remain operational.

The sustainable agriculture depends on “3 R concept” i.e., Reduce, Reuse and Recycle should be given prior importance. This concept will make the farming sustainable as well aseconomically feasible. However, the ‘Waste is not waste until we waste it!’Diversity within and surrounding the farm should be encouraged. Practicing polyculturesuch as inter-cropping, mixed cropping etc. over monoculture, growing cover crops, planting trees around the farm e.g., agro-forestry practices that will act as windbreaks and also provide habitat for local birds. Besides these encouraging natural predators that keep pests away.

WHAT IS SUSTAINABLE AGRICULTURE?

Sustainable agriculture is not a piece-meal approach but a united holistic approach to the problems of the farm as a whole and is particularly specific to the small farmers who are today facing the brunt of increasingly cost-intensive and energy-intensive ‘modern’ agriculture. Sustainable agriculture is a farming system which utilize the principles of ecology and study the relationships between organisms and their environment. It is described as a site-specific, integrated system of plant and animal production practices with a long-term use. It has a set of values in its roots that reflects an awareness of both ecological and social realities. It entails design and management practices that support organic processes in order to preserve all resources, reduce waste, and protect the environment while preserving or enhancing farm profitability. Meanwhile working with organic soil processes is especially crucial. In order to produce food, sustainable agriculture systems are created to take full advantage of the soil’s ground water and nutrient cycles, energy fluxes, and microbial life.Such systems also seek to create nutritious produce that is free of contaminants that might otherwise be harmful to human health.In the era of innovative technologyand new advancements for improved cropping system and livestock, use of fertilizers, pesticides, herbicide and irrigation, the new aid of farming is transitioning from "farming for subsistence" to "farming for profits,". It is expected to meet the demand for goods and services from agriculture withoutthe negative effects on environment.

COMPONENTS OF SUSTAINABLE AGRICULTURE

The important aspects for achieving sustainable development over the period of the time span are thought to be human, economic, and social development. Human development, which includes health, education, housing, longevity, and access to basic utilities, is centered on ensuring that people have access to proper intake of nutritional food. Duringgreen revolution HYVs, fertilizers, and pesticides were utilized carelessly due to declining per capita cultivable land, water and natural resources, so there was a need to increase the agricultural production in order to fulfill the increasing demand. With advances in science and technology, sustainable plans are being adopted for sustainable agriculture considering the variables that are impacted by agricultural productivity, ecological safety, and economic viabilityas well asserve justice to social responsibility. A system productive and profitable can’t go hand in hand over the longer period if it is not ecologically sustainable. Environment is a system which cannot be maintained economically if it is not productive.

NEED FOR SUSTAINABLE AGRICULTURE

1. To increase food grain production

Almost one billion people worldwide are currently suffering from hunger. There will be 2 billion additional people to feed by the year 2050.The agricultural industry can hypothetically supply enough wholesome food for everyone. However, we will need to increase sustainability in production to satisfy future demand, particularly in developing nations where the majority of population growth is anticipated. In order to increase productivity, smallholder farmers must be encouraged because they are a crucial component of the answer.

2. Source of income that can help reduce poverty

In developing countries, agriculture is asource of income which accounts for 29% of GDP globally. In many parts of India, farming is an indispensable part of the rural economy. In the remote part of the country, agriculture plays a vital role to secure the livelihoods of the rural community by generating decent income and thereby provides a basis for inclusive growth and poverty reduction. Therefore, there is an outmost need to support farming systems that are viable for long run.

3. Adapting and mitigating climate change

Today, agricultural systems worldwide are challenged by climate change threats, such as increased energy costs. Sustainable agricultural practices help farmers to adapt the changes and to reduce greenhouse gas emissions. Sustainable agriculture also means opening the door to innovation that can help to make farming cleaner, less exposed to volatility in the prices of inputs and more tolerant to climatic variation.

VARIOUS SUSTAINABLE AGRICULTURE PRACTICES AND SYSTEMS USEFUL IN INDIA

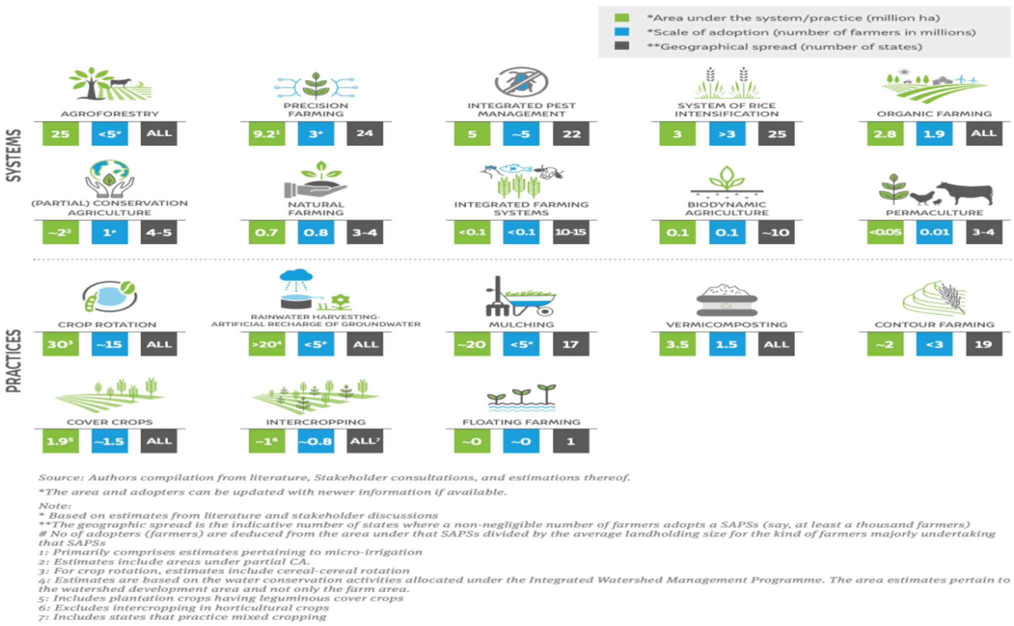

Figure 1: Various sustainable agriculture practices and systems in India

1. Systematic approach of sustainable Agriculture

1.1. Agro-forestry

Agro-forestry is an integrated strategy that makes use of the beneficial interactions that result from integrating crops with trees and shrubs. In order to develop more diversified, productive, profitable, with sustainable land-use systems, it combines forestry and agricultural technologies. In addition to providing farmers with an additional source of income, trees improve soil structure, stabilize soils, reduce nutrient runoff, and provide a favorable microclimate that protects crops from wind and heavy rain while maintaining a favorable temperature and soil. A multi layered edible "forest" makes up the permaculture-designed food forests. Almost all of the "trees" in such a "forest" are perennial food plants, such as a canopy of tall and dwarf fruit and nut trees, a layer of fruit shrubs, layers of perennial herbs, ground-level mushrooms and vegetables, climbing plants, and root vegetables under ground.

1.2. Precision Farming

Precision farming is the use of concepts and technologies like GPS (satellites) and GIS in order to control the spatial and temporal variability related to all aspects of agricultural output. It is a system for more effective resource management on farms by doingthe right thing, in the right place, in the right way and at the right time. In precision farming to producemore crop per drop of water, effective use of irrigation systems like micro irrigation in conjunction with fertigation is done. Precision farming is a strategy for better management of farm resources which serves the dual purpose of increasing output and decreasing ecological damage. In order to carry out precision farming complete understanding of the soil environment is necessary to reliably interpret soil data and forecast soil performance at each specific location. The fundamental step in the development of precision agriculture is to fully understand the variability of soil parameters in order to produce reliable soil interpretations and precise forecasts of soil performance at any specific site.

1.3. Integrated pest management

Integrated pest management (IPM), is an effective and environmentally aware approach of pest management that relies on integration practices for economic control of pests. Integrated pest management aims to suppress pest populations below the economic injury level (EIL). The natural predators of agriculturalpests are used to control insect, pests affected crop. Through prey-predator relationship, the population of harmful pests is kept under control.

The careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment.

1.4. System of rice intensification

The System of Rice Intensification (SRI) is an agro ecological crop management system established in Madagascar in the 1980s. This is a resource-efficient technique developed tocurb the external costs and create the way for a future of sustainable rice production. It is based on the techniques that boost yields while lowering agricultural inputs. In this method there is markable increase in rice yield with 8-90% savings in seeds, 25-50% savings in water and 10-20% reduction in costs as compared to traditional methods of rice cultivation.These technologies consist of:

A. Seedling care: Minimum disturbance to the seedling roots while transplanting young seedlings for optimal development and allowing plants more space between them.

B. Controlled water irrigation: Maintaining soil moisture without flooding it continually.

C. Improving the Soil health status by using organic fertilizers (like compost), weed control with a rotating hoe, and poking small holes in the ground to facilitate proper cycling of air, water, and nutrients.

Thus, SRI has a potential to become a sustainable solution that can play a significant role in climate change impacts and food security.

1.5. Organic farming

In Organic farming system, theuse of synthetic inputs such as fertilizers, pesticides, hormonesetc are reduced or excluded. They primarily rely upon different practices such as crop rotations, crop residues, animal manures,off-farm organic waste, mineral grade rock additives and biological system of nutrientmobilization and natural based plant protection. Major objectives of sustainable organic farming are:

- Improve crop yield
- Synchronization of the agricultural system with nature through soil renewal and nutrient recycling
- Enhance soil fertility through buildup of micro flora and micro fauna in soil
- Improving the soil quality without harming the biological diversity in theecosystem
- Achieving a harmony between crop farming and animal husbandry
- Keeping animals in an atmosphere that is close to their natural habitat
- Preserving and using traditional old knowledge in farming and management practices

1.6. Conservation agriculture (Partial)

The management of agro-ecosystems through conservation agriculture aims to raise and sustain production, boost earnings, and ensure food security while protecting and strengthening the environment and the resource. It is distinguished by three related principles-

i. Minimum mechanical disturbance

ii. A continuous organic soil layer

iii. Crop species diversification grown sequentially or in associations to all agricultural landscapes and land uses which can be benefitted from conservation agriculture concepts when they are combined with locally appropriate techniques.

It aims to improve biodiversity and soil biological activitiesabove and below the ground surface. External inputs like agrochemicals and plant nutrients of mineral or organic origin are applied optimally and in ways and quantities that minimize soil interventions like mechanical soil disturbance or less interference with biological processes.

For rainfed and irrigated production, conservation agriculture suggests effective agronomy practices, such as timely operations, and enhances overall land stewardship. Conservation agriculture is a foundation for sustainable agricultural output intensification. It is complemented by other well-known good practices like the use of high-quality seeds and integrated pest, nutrient, weed, and water management, among others. It expands the possibilities for integrating different production sectors, such as the integration of meadows and trees into agricultural landscapes and the integration of crops and cattle. Best crop management practices and conservation agriculture will increase sustainability and the effectiveness of the use of inputs. The soil is seen in sustainable systems as a delicate and living medium that needs to be fostered and conserved to maintain its long-term productivity and stability. Utilizing cover crops, compost, or manures, decreasing tillage, avoiding traffic on wet soils, and maintaining soil cover with plants or mulches are some ways to safeguard and improve the productivity of the soil. Regularly adding organic matter or using cover crops can improve the tilth and stability of the soil aggregate. In order to achieve sustainable production, reducing tillage and diversifying crops by including crops which are good in fixing soil nitrogen could be very successful.

1.7. Natural farming

It is an ecological approach given by a Japanese scientist named Masanobu Fukuoka. Natural farming which is also known as“the Fukuoka Method” or “the natural way of farming” or “do-nothing farming” is not merely a technique but a perspect of seeing ourselves as a part of nature rather than our separation or superiority over it. It rejects the use of modern technology and solely based on local conditions which demands no human supplied inputs and closely related to nature. It is connected to fertility farming, organic farming, sustainable agriculture, agroecology, agroforestry, eco-agriculture and permaculture.

Advantages of natural farming system are: The labour and physical work is substantially reduced as compared to other conventional farming systems, improve yield, increase farmers income, increase soil fertility, reduction in chemical inputs and water requirement, conserve environment etc.

1.8. Integrated farming systems

India is dominated by small and marginal farmers which constitute more than 85% farming community**.** For the sustainable development of small and marginal farmers, IFS is considered as a potential tool**.** Integrated Farming Systems (IFS) is the practical solution toincrease the demand for food production, sustainability and stability of income. It improves the soil nutrition for the small and marginal farmers with limited resources. It is the inter relation of different agricultural enterprises with crop based activity that will open up the ways to recycle the produces and waste matter of one component as input for the other component to bring improvement in soil health and reduce the cost of production of the products which will finally raise the total income of the farm. The main goal of Integrated Farming system is to increase the income and living standard of small and marginal farmers, which can be achieved through integration of agroforestry, horticulture, dairy, sheep and goat rearing, fishery, poultry, biogas, mushroom, sericulture, apiculture and by-product utilization of crops.

1.9. Bio dynamic farming

This method of farming places a strong emphasis on the farm's overall development and treats the farm as a living system. It is also taken into account how the soil, plants, animals, and microbes interact with one another in the ecosystem. The biodynamic system combines "dynamic" procedures with the impact of cosmic forces to grow the farm, its inhabitants, and its products with energy and with "biological" practices, which involve traditional organic farming methods to promote soil health. The biodynamic preparations can be prepared from cow dung, silica, and extracts of various plant components, such as yarrow flowers, chamomile flowers, oak bark, stinging nettle shoots, etc., and are applied either through field spraying orbycomposting.

1.10. Permaculture

Permaculture is an innovative structure for creating sustainable ways of living**.** It is a system that uses natural-world principles to guide the growth of human settlements, enabling people to coexist peacefully with the environment. Permaculture is the design of an ecologically sound way of living in our households, gardens, communities and businesses. It requires cooperation with the nature and care for the earth and its people.

Permaculture is based on the principles and practice that can be used by anyone, anywhere:

- City flats, yards and window boxes
- Suburban and country houses/garden
- Allotments and smallholdings
- Community spaces
- Farms and estates
- Countryside and conservation areas
- Commercial and industrial premises
- Educational establishments
- Waste ground

Permaculture encourages us to be resourceful and self-reliant. It is not a dogma or a religion but an ecological design system which helps us find solutions to the many problems faced by us both nationally and globally. The major goal of this system is to eliminate waste and boost system efficiency by "working smarter, not harder." In this case, emphasis is placed on the usage of perennial plants, such as fruit trees, nut trees, and bushes, which work together in a system that is supposed to imitate how plants in a natural ecosystem would work. Herb spirals, keyhole and mandala gardens, sheet mulching, and growing grain without plowing are examples of permaculture design techniques.

5.2. Practical approach of sustainable farming

2.1. Poly-cultures and crop rotation

Polyculture and crop rotation over monoculture is a very scientific and innovative approach to tackling pest and weed problems (as some pests prefer specific host), maintaining and enhancing the soil quality, coping with weather fluctuations, ensuring additional income for the farmers, and a healthy diet for the community. Here, emphasis is placed on the idea that crops grown in close proximity should complement one another.

Crop rotation isdefined as the growing of crops in a systematic and well-planned manner. It depends on the type of crop grown, the local economy andtraditioning. Generally typical crop rotation is exhausting and makes no or little contributions to soil fertility. Therefore, the fundamental task is to design a crop rotation that would boost soil fertility and allowing the next crop to fully benefit from the favorable moisture requirements present throughout its growing seasons. It is a common belief that pulses are the best crops to plant after winter cereals which improves soil fertility.

Objective of crop rotation

1. To prevent the accumulation of insect, pests, weeds and soil born diseases
2. To maintain soil fertility for the following crop
3. To prevent soil erosion which may cause from wind or water
4. To preserve soil moisture from one season for the next
5. To provide a balanced calendar of work throughout the season**.**

2.2. Rainwater harvesting

Now a days rain water harvesting has become an important issue in relation to water conservation and more especially in conservation farming. Due to changing climate, uneven distribution of rainfall is being seen which leads to water deficit in the soils spatially and temporally. Harvested rain water has many agricultural uses including gardening at home and in the agricultural fields, which reduces the garden owners and the farmers from dependency on other water sources for crop production thereby directly or indirectly reducing their operational costs. Moreover, rainwater has good property of not impacting negatively to crop plants. It does not add calcium carbonate to the crop plants, which is otherwise done by hard water forming a coating on the roots or leaf surfaces thereby preventing the plants from receiving optimum amount of sunlight, water, minerals, fertilizers and pesticides supplied to the plant. Harvested rain water can also be utilized for drinking purpose by the animal components in the integrated farming system.

2.3. Mulching

Mulching and groundcovers are both effective ways to give the soil a layer of protection, control the growth of weeds, retain soil moisture, and enhance soil health and fertility, by shielding the soil from direct sunshine. Mulch helps to reduce the amount of water that evaporates from soil, reduce the constant need of irrigation to the field. Moreover, mulch provides nutrients to sandy soil and improves its ability to hold water**.** Both organic (paddy straw, water hyacinth) and inorganic materials (plastic mulch) can be used as mulch. However, organic mulches are more valuable than inorganic ones due to the farmer's ease of decomposition and its ability to improve soil water retention.

2.4. Vermicomposting

Vermicompost is the product of the decomposition process using various species of worms, usually red wigglers, white worms, and other earthworms, to create a mixture of decomposing vegetable or food waste, bedding materials, and vermicast.The Vermicast (also called worm castings, worm humus, worm manure, or worm faeces) is the end-product of the breakdown of organic matter by earthworms. These excreta have been shown to contain reduced levels of contaminants and a higher saturation of nutrients than the organic materials before vermicomposting. This process is called vermicomposting. Certain earthworm species such as *Eiseniaandrei, Eiseniafetida* etc. feed on organicwaste materials and after digestion gives out the granular form known asvermicompost.This vermicompost are rich in micronutrients andmacronutrients, phytohormones and also contains microflora which are essential for the growth ofplants.

2.5. Contour farming

Contour farming refers to that farming which practices tillage, planting and other operations on or near a sloppy land. It can reduce soil erosion upto 50 percent. It also promotes water quality by reducing sedimentation and runoff and by increasing infiltration. Some species that can be adopted for contour farming includes *Centrosemapubescens, Desmodiumbuergeri, Medicago sativa, Mucunapuriens, Phaseolusacontifolius, Psohocarpuspalustris* etc. In some places farmers usually cultivate crops by using contour-furrow irrigation for controlling erosion and maintaining uniformity while distributing water. While doing so, it ensures high water use efficiency too.

2.6. Cover crops

Cover crops can be adopted for sustainable management of soil and water resources in the tropics, especially on steep land plantation crops. Adoption of cover crops have many advantages in respect of sustainable utilization of natural resources including fertility restoration, weed control, rain water conservation, avoiding repeated seeding and cultivation traffic and reducing energy costs. A number of cover crops can be grown for soil and water conservation depending on soil and ecological considerations. Some examples of cover crops are legumes, grasses, green manure crops, soyabean etc.

2.7. Inter-cropping

Intercropping refers to simultaneous cultivation of two or more crops in a field with maintaining a specific geometrical proximity. It is a sustainable way of practicing crop geometry that can enhance resource use efficiency for both nutrients and moisture, thereby facilitating low-input agriculture practices. It is an ecological mechanism for weed suppression, pest and disease control, soil resource conservation, yield increase and efficient use of light, space and water. Inter cropping ensures additional income to the farmers and reduces risk of crop failure as the intercrops are selected based on their differences in growing pattern to the main crops.

2.8. Floating farming

Floating farming is an art of growing crops on a water surface by using some floating materials. It is a way of producing food by utilizing areas that are waterlogged for long period of time. The methodology uses beds of rotting vegetation, which act as compost to the growing crop. Scientifically it can be referred as hydroponics. The practice of floating farming can be utilized in the areas where agricultural lands are submerged for a long period of time. So by adopting this practice, areas that are prone to flooding or those areas lying under riverine lowland can get benefit with a low input and without any harmful effect to the environment.

2.9. Crop production practices

In sustainable production practices multiple approaches are used. Principles are to select the appropriate management practices based on site specific management of soil, nutrient and pest as per the capability of the resource base that helpin conservingand increasing the productivity through increasing the resource use efficiency. It reduces dependency on monoculture and provides greater resilience, risk minimization against total system failure which is vital for achieving sustainable farming. Crop diversification can be achieved through incorporating technology, new markets, changes in policy, etc. They meet the certain goals, challenges and threats and thereby reduce risk. Addition of new crops to the existing cropping systems is the most widely accepted process for expansion of existing model. Horizontal diversification achieved high cropping intensities which ultimately increased productivity in small holder farming systems.

2.10. Animal raising

Industrial agriculture keeps the cattle's off the farm, protecting the crop from animal eating and keeping crops away from manure. But grazing animals and grassland have a positive relationship with one another. In addition to providing a wide range of nutrients to the animals through regulated grazing, heavy foot traffic prevents soil erosion by compacting the soil and the manure that is left behind enriches the soil.

FUTURE STRATEGIES FOR PROMOTION OF SUSTAINABLE AGRICULTURE

1. Diversification in agriculture

Any cropping system that includes crops with a range of maturities, a crop canopy, and high yielding potential is the need for today's average farmer. Based on the type of soil, total rainfall, and timing of the region's rains, a variety of cropping systems must be implemented in order to conserve soil and water, fully utilize groundwater, and maintain soil fertility. Depending upon the agro-climatic factors, it is certainly profitable to adopt double cropping, intercropping and mix cropping as these system help to increase land use efficiency. The benefits of intercropping include increased soil fertility, moisture retention, a decrease in weed, insect, and disease occurrence, year-round availability of feed and generate additional income. Various recommended intercrops with varying numbers of rows are as follows: Cotton: green gram/black gram (1:1), Pigeon pea: green gram/ black gram (1:2 or 2:4), Pigeon pea: Soybean (1:2) etc.

2. Appropriate technologies

The low-cost technology is considered financial burden for a marginal farmer whose earning source is only farming. Farmer have to make arrangements for seed acquisition, seed treatment, producing green manuring crops, making compost from farm waste or vermicompost from vermiculture, buying biofertilizers, biocontrol agents, biopesticides, chemicals, etc. with the limited financial resources. Organic farming has been proved to be cost-effective because many inputs are made on the farm by the farmers themselves. It is necessary to validate this method and promote it for various agricultural systems in irrigated and rainfed agriculture, where it can be profitable.

3. Approach and technology interaction

An innovative farming strategy i.e., adoption of better production technology including integrated pest management, soil and water conservation measures, plant nutrient management, and contract farming will increase crop yield; however, this won't be sufficient to support small and marginal farmers with small land holdings, as well as their families. Therefore, integrated farming is essential, in addition to increasing production and profitability through the provision of irrigation and high-quality inputs, loans from NABARD and affiliated regional rural banks, and through the provision of know-how through extension services. However, a farmer must seek to other industries for subsistence, such as dairy, poultry, sericulture, and cattle farming. For agriculture to be a profitable business, there is a need to address the long-term challenges of improving livelihood by offering more sources of income. This can be done by creating agro-industries in the farmland's surrounding areas after crop harvest, byproducts can be used to create work for at least one member of the struggling farming families so that he is not solely dependent on agriculture.

4. Infrastructure development and reforms of agricultural policies

India ranks second globally in terms of investments in rural infrastructure, but there are still a shortfall of storage facilities, a weak distribution network, and other services that are essential to a comprehensive and integrated food security system. Vegetables and other perishable items have been reported to have experienced post-harvest losses upto 40%. Processing adds value, which could increase farmers' revenue. So it makes sense to build food parks, agro-based businesses, cold storage facilities, etc. in crop-growing areas. The government of Maharashtra passed a resolution to convert the Agriculture Produce Marketing Committee's (APMC) current acts into a model law, which may be the best move toward marketing in rural areas.

5. Flexible institutional credit

Farmers require financial assistance before the crop season begins, so that farm inputs can be bought and stored for timely use. Credit facilities throughkisan credit cards and soft loanscan provide a livelihood security to the farmers.

6. Preservation of biodiversity

In order to sustain biodiversity in dry land areas, wasteland, native wildlife and flora, and unmanaged disturbed habitats need be maintained. Degradation of biological phenomenon has become a serious concern for all the life on the earth. Therefore, it is likely that natural calamities are increasing day by day, particularly drought during crop season. Rainfed crop planting through weather forecasting by GIS, LANDSAT, and other space satellites. Meteorological stations need to be established at appropriate sites in crop growing areas in order to limit the major constraints in planning of farm operations through accessibility of weather data in remote areas. Further to improve the quality of life for rural populations, energy conservation needs to be prioritized in the future.

7. Indoor vertical farming

Growing food in a controlled, enclosed environment while it is stacked one on top of the other is known as indoor vertical farming. Vertical farming has the potential to boost crop yields, circumvent land-use restrictions, and potentially lessen the environmental effect of agriculture by reducing supply-chain travel distances. Compared to conventional farming, the shelves that are installed vertically are great to minimize the large area of land which is required to cultivate crop. Due to its capacity to grow in small and less landmass, this technique of cultivation is widely reaching to cosmopolitan city and promote large scale farming. As few of these configurations don't require soil for plant growth, vertical farms are unusual in this regard. The majority of vegetable farms either use hydroponics, which involves growing vegetables in a bowl of nutrient-rich water, or aeroponics, which involves repeatedly misting plant roots with water and nutrients. In this method artificial grow lights are used instead of natural sunlight. Up to 70% less water is used by vertical farms than by conventional farms. The benefits of indoor vertical farming are clear, ranging from sustainable urban growth to crop yield optimization with lower labour expenses.

8. Soil management

Sustainable soil management involves preserving or improving a soil's potential performance over numerous crop cycles. Failure to do so frequently leads to the degradation of the soil in some ways. The prevention of degradation implementation of corrective actions to address any deficiencies as they arise should be the main goals of managing soil for sustainable production. Although prevention of soil from degrading is the important alternative, it may only be a theoretical feasible but not practically achievable, as depending on management practices and the inherent characteristics of the soil, some degree of soil and land degradation is convertible over one or more crop cycles.

Perhaps soil resilience is choosing the buffering capacity of the soil against physical, chemical, biological or mechanical impacts. Soil resilience refers as the mechanisms that enable it to resist pressures and changes imposed by tillage operation. As long as soil degradation has not reached critical levels, beyond which it may not be viable to replenish their productivity or other ecological functions. The core strategies for sustainable soil management are broadly described as follows: Preventing soil erosion, maintaining the fertility and nutrient status of the soil, enhancing soil organic matter content, promoting good soil structure, preventing different soil problems such as salinity, alkalinity, sodicity and nutrient toxicity and deficiency, enhancing soil biodiversity through different practices such as crop rotations, intercropping and mixed cropping etc.

9. Efficient use of inputs

Sustainable crop production supports proper quantities of inputs including organic matter, water, and mineral fertilizers is crucial. The quantity, flow, and effectiveness of input utilization, particularly, the use of fertilizers, water, and energy must be maximized in order to maintain the potential productivity of land in a way that is both environmentally responsible and economically sustainable. Improper management of the inputs had led to environmental contamination and land degradation. Both environment and production resources have been harmed due to excessive usage of nitrogen and phosphate fertilizers in high input agriculture. Overusing fertilizers frequently results in waste and runoff, which pollutes surface and ground water and causes nitrate accumulation. Similarly, intensive water utilization in irrigated agriculture causes countless issues which result in unfeasible productivity and production. To prevent the inefficient use of external inputs, such as fertilizers should be applied according to need based of the crop and thereby limit the wastages. Proper modification onfertilizer recommendations based on site-specific nutrient management should be opted. Inputs like nutrients and water must be used more effectively using established techniques in order to achieve sustainable crop production.

10. Good agronomic practices and agricultural policies

Sustainable agriculture objectives are frequently hampered by current politics in the national and state governments. To achieve social and economic fairness, economic viability, and environmental health at the same time, new political strategies are required. To enable farmers to fully benefit from the productivity is possible by alternative techniques, commodities and price support programs. To promote a varied and decentralized network of family farms rather than corporate concentration and absentee ownership, tax and credit rules should be changed. Research priorities at state agricultural colleges and the government might be appropriately changed to prioritize the creation of sustainable alternatives. The soul principle of marketing base should be interchanged with bio-pesticides or organic pesticides even encouragement of less pesticide utilization can be promoted. Policies should be made and societies must be formed at the state and national levels to solve these farmers issues.

CONCLUSION:

Agriculture is the backbone of our country. It plays a vital role for life sustenance on earth. Sustainable agriculture is an approach to utilize the available natural resources in such a way that it does not comprise the availability of the future. It isimportant as it promotes economic stability for farms and helps farmers to improve their quality of life. These systems are created to take full advantage of the soil natural water and nutrient cycles, energy fluxes, and microbial life. To meet the nutritional demand of the country by ignoring their negative effects on natural resources both in quantity and quality, sustainable agriculture plays a vital role. So, to sustain the natural resources for the future generation while fulfilling demand for current population, sustainable agriculture is an important adoptable strategy. Different components of sustainable agriculture like Integrated farming system, crop rotation, precision farming, agroforestry etc. that are eco-friendly, can be adopted for sustaining the natural resources for the future generation.

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Chapter

10

ORGANIC FARMING FOR SUSTAINABLE AGRICULTURE

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INTRODUCTION:

In today's world scenario there is rapid increasing population and agriculture is the only source to meet the drastic demand for running the lifestyle of these population. As a result, there should be increased production of food crops and higher productivity should be ensured. To do so use of various chemicals have gained importance. But prolonged use of such chemicals is posing great harm to the environment as a whole to the ecosystem. Different sources of air, water, soil pollution is increasing at an alarming rate. Here lies the need for implication of organic agriculture in modern livelihood. Sustainable agriculture is gaining ground which is the type of farming meeting the present demand without compromising the future need. There are three pillars of sustainability which are economic viability, environmental protection and social equity. This way we can able to minimize pollution and maximize productivity along with proper maintenance of soil fertility and thus leading to production of non-toxic crops.

In the last several decades, certain agricultural practices have changed as a result of technology advancements. Producing food in a sustainable way is crucial for addressing the problem of growing challenges including climate change, pollution, and biodiversity loss.

The Brundtland Report, which defines sustainable development as "development that fulfils the demands of present generations without compromising the ability of future generations to satisfy their own requirements," was published in 1987, and this is when the notion of sustainable agriculture began to gain popularity.

WHAT IS ORGANIC FARMING AND CONCEPT OF SUSTAINABLE DEVELOPMENT

Organic farming - an agricultural system using environmentally friendly pest control and organic fertilizers derived mainly from animal and plant wastes, as well as nitrogen-fixing cover crops. Modern organic farming was developed in response to environmental damage caused by the use of chemical pesticides and synthetic fertilizers in conventional agriculture and has many environmental benefits [1].

Compared to conventional agriculture, organic farming uses fewer pesticides, reduces soil erosion, reduces nitrate runoff into ground and surface water, and recycles manure from livestock. These benefits are offset by higher food costs for consumers and lower overall yields. In fact, yields from organic crops have been found to be about 25% lower than those from conventional crops, although this can vary widely from crop to crop. The challenge for the future of organic farming is to maintain environmental benefits, increase yields and lower prices while meeting the challenges of climate change and a growing world population.

Simply put, organic farming is a method of agricultural production that aims to create a balanced ecological production management system that promotes and enhances soil biodiversity and biological activity.

Inputs and synthetic chemicals from outside the farm are used as little as possible, and ma nagement approaches that protect, replenish, and improve ecological stability are followed. To achieve the goal of environmental sustainability and ecological harmony, organic farming also prohibits the use of antibiotics in livestock, plant growth enhancers, nonmaterial's, and genetically engineered products.

Some of the core components of organic agricultural production systems include natural livestock and crop production through adherence to an organic system plan; a thorough record-keeping system for all products from the point of production to consumption; and the use of buffer zones to prevent synthetic chemicals from unintentionally contaminating adjacent conventional farms.

In order to ensure that the requirements of future generations are not jeopardized, sustainable development is defined as development that meets present-day demands without overusing resources. There are anthropocentric and ecocentric value components in both the ecological interpretation of sustainability and the newly developed conservation concept of ecosystem health. The goals of sustainable development are crucial since they will undoubtedly aid in the creation of a sustainable biome.

United States Department of Agriculture (USDA) defined organic farming as follows-

"Organic farming is a system which avoids or largely excludes the use of synthetic inputs (such as fertilizers, pesticides, hormones, feed additives etc) and to the maximum extent, feasible rely upon crop rotations, crop residues, animal manures, off-farm organic waste, mineral grade rock additives and biological system of nutrient mobilization and plant protection.

Organic agriculture can be defined as "an integrated farming system that strives for sustainability, the enhancement of soil fertility and biological diversity while, with rare exceptions, prohibiting synthetic pesticides, antibiotics, synthetic fertilizers, genetically modified organisms, and growth hormones"[2][3][4].

A. History of Organic Farming

For thousands of years, agriculture was practiced without the use of synthetic chemicals. The first synthetic fertilizers were created in the middle of the 19th century. These early fertilizers were affordable, effective, and simple to ship in large quantities. The 1940s saw similar developments in chemical pesticides, earning the decade the moniker "pesticide period." [5] The short-term benefits of these new agricultural methods were outweighed by major long-term negative impacts, including soil compaction, erosion, and a general reduction in soil fertility, as well as safety concerns around the introduction of harmful chemicals into the food supply. [06]: 10 Scientists studying soil biology started looking for solutions to these negative effects in the late 1800s and early 1900s so that output levels could remain high.

The Institute of Plant Industry was established in 1921 by Albert Howard, the father of the organic movement, and his wife, botanist Gabrielle Howard, to advance conventional agricultural practices in India. Their scientific training helped them develop better tools and animal husbandry techniques, among other things. They also developed protocols for crop rotation, erosion prevention methods, and the systematic application of composts and manures by incorporating elements of Indian traditional farming practices. [7][8][9][10]. After experiencing traditional farming, Albert Howard was inspired to promote an organic agricultural method when he returned to Britain in the early 1930s[11][12][13][14].

Eight lectures on agriculture were delivered by Rudolf Steiner in 1924, with a focus on the moon, planets, non-physical entities, and elemental forces. [15] [16] As a result of the usage of chemical fertilizers, they were held at the request of devoted farmers who had seen deteriorated soil conditions, a decline in the health and growth of crops, and a decline in the quantity of animals. [17] The lectures were released in November 1924, and The Agriculture Course, the first English translation, was published a year later in 1928. [18]

Ehrenfried Pfeiffer, the creator of the seminal text on biodynamic farming (Bio-Dynamic Farming and Gardening) [19], visited the UK in July 1939 at Walter James, 4th Baron Northbourne's invitation to speak at the Betteshanger Summer School and Conference on Biodynamic Farming at Northbourne's farm in Kent. [20] Bringing together supporters of diverse organic agricultural methods so they may work together as part of a wider movement was one of the conference's main goals. During the conference, Howard ran into Pfeiffer. [21] The phrase "organic farming" was first used by Northbourne in the publication of his organic farming manifesto, Look to the Land, the following year. The Betteshanger meeting has been referred to as the "missing link" between biodynamic farming and other organic agricultural practices. [22]

Howard released his book An Agricultural Testament in 1940. He used Northbourne's phrase "organic farming" in this work. [23] Since Howard applied scientific concepts and expertise to a variety of conventional and natural agricultural practices, his work has gained widespread recognition, earning him the title of "father of organic farming." [6], In the United States, J.I. Rodale, who had a strong interest in both Howard's theories and biodynamics,[24] founded Rodale, Inc. in Emmaus, Pennsylvania in the 1940s to promote and teach organic farming to a larger audience as well as The Rodale Institute, a working organic farm for trials and experimentation. These developed into significant factors in the growth of organic farming.

Modern society's growing environmental consciousness has changed the supply-driven organic movement into a demand-driven movement. Farmers were drawn to premium prices and certain government subsidies. Many farmers in poor countries use conventional farming practices that are identical to organic farming, but they are not certified and might not use the most recent technological developments in organic agriculture. In other instances, farmers in poor nations have switched to contemporary organic techniques for financial reasons. [24]

B. Why Is Organic Farming Needed?

I. Food Security and Environmental Sustainability-

Research shows that organic farming can help to some extent with the global problem of achieving a pleasant and green environment. Studies on organic farming over a long period of time show that it can be a powerful mechanism for fostering ecological balance, biodiversity, and biological cycles, which are essential for environmental sustainability.

The primary goals of organic farming are soil management and conservation, nutrient cycle promotion, ecological balance, and biodiversity preservation. Based on this, the approaches excel in enhancing the ability to lessen the effects of climate change and promoting environmental preservation.

Organic farming may reduce emissions from fossil fuels and mitigate the effects of global climate change, primarily through the use of cover crops and grass clovers in organic rotations. Natural resources used to produce energy are less likely to be depleted when organic farming is used since its production techniques are more energy-efficient than conventional ones.

In addition, recent research published in Science-Digest emphasized that the promotion of organic farming might enhance yield output, particularly in underdeveloped nations where inputs for conventional agriculture are extremely expensive, and so help to increase food security.

II. Help local farmers by protecting their environment from hazardous pesticides-

It is crucial for the people and animals who live around the production to conserve biodiversity and groundwater, both of which are important to organic farming. The World Health

Organization estimates that poisoning from pesticides kills between 20,000 and 40,000 people annually.

Pesticide use has a significant influence on the local people as well as farmers, thus it is not just farmers who are impacted. Numerous studies have revealed a considerable rise in cancer incidence and other illnesses in the areas where production is taking place.

You can ensure that the manufacturing of organic products does not hurt local communities by purchasing them. Things can be done correctly more often the more we can help these farmers and their output.

III. The organic food sector is expanding quickly and promises high profitability -

According to natural marketing institute, global market trends show that consumers are more accepting of items made naturally. The institute emphasizes once more that the growth of natural food stores providing a variety of organic products has resulted in a threefold increase in the yearly sales of organic products over the past several years.

Additionally, organic goods made locally and regionally can be purchased at farmer's markets. As a result, it is anticipated that retail sales of organic goods would increase by more than 20% annually in the upcoming years.

The widening range of customers present around the world have undoubtedly aided in the increased popularity of organic goods and contributed to their status as the agricultural sector with the quickest rate of expansion. The advantages of organic foods over conventional agricultural produce in terms of health, greater quality, and flavour are largely responsible for the industry's rapid expansion and high profitability levels.

The agriculture industry is becoming a desirable economic choice as people become more and more conscious of the value of organic farming and food goods.

IV. Health Improvement for People

Compared to other food options, organic produce delivers the safest items for human consumption. Compared to normal agricultural food, they have lower chemical concentrations and don't have any substances that have undergone modification.

By lowering the amount of toxic and persistent chemicals that farmworkers, their families, the soil in which they work and play, the air they breathe, and the water they drink are exposed to, organic products reduce risks to the public health at all levels, including that of farmworkers, their families, and consumers.

To ensure that finished products are devoid of synthetic chemical components, genetically engineered manufacturing methods, and any other alleged natural poisons, organic standards establish stringent controls. Produce from organic farms thereby enhances human health by lowering the risk of diseases like cancer, infertility, and immunodeficiency.

V. RICH IN NUTRIENTS

Mineral and vitamin content have a role in a food's nutritional value. With less exposure to nitrates and pesticide residues than conventionally grown food, organically grown fruits, vegetables, and grains are rich in nutrients like Vitamin C, iron, magnesium, and phosphorus. Organic farming improves the soil's nutrients, which are then transferred to the plants and animals.

VI. Organic Produce Has a Rich Taste

The flavour of food also influences its quality. The flavour of organic food is frequently superior to other foods. Fruits and vegetables cultivated organically have more flavour because of the sugar they contain. Brix analysis, which is commonly employed in the wine, sugar, carbonated beverage, fruit juice, maple syrup, and honey sectors, may be used to assess the quality of fruits and vegetables. The sugar concentration of an aqueous solution is measured in degrees Brix.

VII. Analysis-Based Authentication Ensures High-Quality Products

As products undergo rigorous quality inspections and the production process is meticulously examined to qualify as organic food, consumers' interest in this type of food is rising. Food items are split into two categories: those with an animal origin and those with a plant origin (crops) (meat, milk and dairy products, eggs and fish).

C. Importance of Organic farming in Sustainable Agriculture

Organic farming can be profitable and organic food appeals to consumers as both a healthy and ethical choice.However, organic farming techniques have a number of positive effects on the environment for sustainable agriculture.

I. Reduced Chemical and Pesticide Exposure

According to the Organic Trade Association, if every farmer in the United States switched to organic farming, 500 million pounds of persistent and dangerous pesticides would no longer be released into the environment each year.

Use of chemicals and pesticides has a harmful impact on the ecosystem in numerous ways:

- Pesticides promote the development of disease resistance in bacteria, fungi, plant-eating insects, weeds, and plants.

- The land, water supply, and air are contaminated by the pesticides and chemicals sprayed on plants.
- These dangerous insecticides can persist for decades at a time (maybe longer).
- Synthetic chemicals also hinder wise agricultural techniques like crop rotation and cover crops, which may lead to additional detrimental environmental issues like erosion.

II. Organic Agriculture Promotes Water Conservation

Indian Rivers states that runoff from non-organic agriculture, which includes dangerous pesticides, toxic fertilizers, and animal waste, is a significant threat to river water pollution. Organic farming reduces contaminated runoff, preserving the quality of our water resources. Organic farming also promotes water conservation. In general, organic farmers take their time appropriately amending the soil and utilizing mulch, both of which assist conserve water. When cultivated conventionally, the in-demand commodity cotton needs a lot of irrigation and extra water. But organic cotton production saves water since it requires less watering.

III. Building Healthy Soil Through Organic Farming

Healthy soil is a must for growing nutritious food. If we use hazardous pesticides and chemicals on the soil, it may become incapable of thriving on its own. Natural farming techniques outperform chemical soil management by a wide margin.

IV. Erosion Reduction:

According to significant research comparing adjacent chemically treated and organic wheat fields, the organic field had eight more inches of topsoil and only had one-third the erosion loss.

V. Supporting the health and welfare of animals

Natural pest management is aided by organic farming, which encourages birds and other predators to dwell peacefully on fields and helps conserve more natural habitat areas. Furthermore, the clean, chemical-free grazing that animals on organic farms receive keeps them naturally healthy and disease-resistant. Happy and healthy organic animals are productive organic animals, which is a benefit for organic farmers.

VI. Biodiversity is Promoted by Organic Agriculture

Typically, the more stable Healthy biodiversity is promoted by organic farming, and this has a significant impact on how resilient a farm is to problems like severe weather, disease, and pests. Additionally, a surge in infectious illnesses may be directly correlated with decreased biodiversity, which is obviously bad for humans and the environment.

D. Ways of organic farming Introduction

Traditional farming techniques based on naturally occurring biological processes are combined with some contemporary technology and ecological science in organic farming systems. Agro ecology is the study of organic farming practices. Organic farmers are constrained by legislation to use only natural pesticides and fertilizers, while conventional farms employ synthetic insecticides and water-soluble synthetically refined fertilizers. Pyrethrin, a naturally occurring insecticide that may be found in Chrysanthemum flowers, is an illustration. Crop rotation, green manures and compost, biological pest management, and mechanical cultivation are the main techniques used in organic farming. In order to increase agricultural productivity, these measures make use of the natural environment. Legumes are planted to fix nitrogen into the soil, natural insect predators are promoted, crops are rotated to confuse pests and renew soil, and natural materials like potassium bicarbonate and mulches are used to control disease and weeds. More conventional agriculture has adapted many of the techniques created for organic agriculture. For instance, integrated pest management (IPM) is a comprehensive approach that prioritises organic pest control wherever possible and only employs synthetic pesticides as a last resort in conventional farming.

i. Crop Diversity:

Diverse crops are encouraged by organic farming. The advantages of polyculture, or growing numerous crops in one area, a practise that is frequently used in organic farming, have been demonstrated by the study of agroecology. Variety in vegetable crop planting encourages a larger assortment of beneficial insects, soil microbes, and other elements that contribute to overall farm health. Crop diversity prevents extinction of species and promotes the health of the ecosystem.

ii. Soil management:

To replenish nutrients depleted from the soil by previous crops, organic farming heavily relies on the natural breakdown of organic matter using methods like green manure and composting. This biological process—often referred to as "feeding the soil to feed the plant"—is fueled by microorganisms like mycorrhiza and enables the continuous natural synthesis of nutrients in the soil throughout the growing season. Crop rotation, cover crops, minimal tillage, and compost application are just a few of the techniques used in organic farming to increase soil fertility. Reducing tillage prevents soil from being turned over and exposed to air; as a result, less carbon is lost to the atmosphere, increasing the amount of soil organic carbon. Carbon sequestration, which can lower greenhouse emissions and aid in the reversal of climate change, is an additional advantage of this. To thrive, plants require a variety of nutrients in varied amounts. For organic farmers, providing enough nitrogen and, more specifically, synchronising nitrogen supply with plant needs is a difficulty. In order to fix atmospheric nitrogen through symbiosis with rhizobial bacteria, legumes (specifically, the Fabaceae family) fix nitrogen through crop rotation and green manure ("cover crops"). Although intercropping, which is occasionally used to reduce insects and diseases, can help improve soil nutrients, there may be issues due to the competition between the crop and the legume, thus there has to be more room between crop rows.

Crop leftovers may be ploughed back into the ground, and since various plants excrete varied quantities of nitrogen, synchronization may be aided. Additionally, organic farmers employ animal manure, certain industrial fertilizers like seed meal, as well as other mineral powders like rock phosphate and green sand, a naturally occurring type of potassium-rich potash.

iii. Weed Management

Annual crops must be rotated according to organic standards, which mean that a single crop cannot be planted in the same place without a separate, intervening crop.Crops with different life cycles and weed-suppressing cover crops are widely used in organic crop rotations to deter weeds that are connected with a particular crop. Selection of competitive crop types, high-density planting, close row spacing, and late planting into warm soil to promote early crop germination are further cultural methods used to increase crop competitiveness and decrease weed pressure.

The mechanical and physical weed control techniques employed on organic farms may be roughly categorized as follows:

- Tillage - Turning the soil between crops to mix crop residues and soil additives; remove current weed growth and prepare a seedbed for planting; turning soil after sowing to kill weeds, including cultivation of row crops;
- Mowing and cutting - Removing top growth of weeds;
- Flame weeding and thermal weeding - Using heat to kill weeds;
- Mulching: Using organic materials, plastic films, or landscape fabric to stop the development of weeds. Some opponents have expressed worry that tillage may be contributing to the pandemic of soil erosion, citing research done by Cornell University's David Pimentel and published in 1997 that revealed a global epidemic of soil erosion. 'Crop rotations and cover cropping (green manure), typical of organic agriculture, minimise soil erosion, insect issues, and pesticide use.

iv. Genetic Modification

Organic farming, which rejects the use of genetically modified plants and animals, is a crucial aspect of genetic modification. The Mar del Plata Declaration, which was unanimously adopted by more than 600 delegates from more than 60 nations at IFOAM's 12th Scientific Conference, was released on October 19, 1998. It forbade the use of genetically modified organisms in agricultural and food production. Even though there is substantial opposition to the use of any transgenic technology in organic farming, agricultural researchers Luis Herrera-Estrella and Ariel Alvarez-Morales continue to support their usage as the best strategy for sustainable agriculture, especially in the poor countries.

v. Livestock

Livestock is an organic fertiliser (organic livestock); it may and must be treated with medication when it is ill; but medications cannot be used to encourage growth; its diet must be organic; and they must be pastured. Additionally, horses and cattle were formerly a fundamental aspect of farms, providing work for ploughing and carting, fertility via the recycling of manure, and fuel in the form of food for farmers and other animals. Domesticated animals are a desirable component in organic farming, especially for full sustainability, or the ability of a farm to function as a self-renewing unit, even if small agricultural enterprises nowadays frequently do not include livestock.

E. Steps to promote organic farming for Sustainable agriculture

The Indian government offers many programmes to aid in encouraging organic farming throughout the nation.

i. Paramparagat Krishi Vikas Yojana (PKVY)

The PGS (Participatory Guarantee System) certification programme Paramparagat Krishi Vikas Yojana supports cluster-based organic farming. The programme supports cluster creation, training, certification, and marketing. A farmer receives assistance of Rs. 50,000 per hectare for three years, of which 62% (or Rs. 31,000) is given as a financial incentive to use organic inputs.

ii. National Food Security Mission (NFSM)

The National Development Council (NDC) issued a resolution at its 53rd meeting on May 29, 2007, calling for the beginning of a food security mission to boost yearly production of rice by 10 million tonnes, wheat by 8 million tonnes, and pulses by 2 million tonnes by the conclusion of the Eleventh Plan (2011-12). As a result, in October 2007 the "National Food Security Mission" (NFSM), a centrally sponsored programme, was introduced.

The mission was a resounding success, as it increased output of rice, wheat, and pulses as intended. By the end of the 12th Five Year Plan, the Mission would have produced an extra 25 million tonnes of food grains, consisting of 10 million tonnes of rice, 8 million tonnes of wheat, 4 million tonnes of pulses, and 3 million tonnes of coarse cereals. Major modifications in methodology, standards of financial aid, and programme implementation strategy were made in light of experience and input from the States, and these changes are reflected in the new operating guidelines.

It has been decided to continue the programme beyond the 12th plan, i.e. from 2017–18 to 2019–20, which is concurrent with the Fourteenth Finance Commission (FFC) period, with new targets to achieve 13 million tonnes of additional food grain production by 2019–20, made up of rice, wheat, pulses, and coarse cereals, totaling 5 million tonnes, 3 million tonnes, and 2 million tonnes, respectively.

iii. National Mission on Oilseeds and Oil Palm (NMOOP)

India is one of the major edible oil-producing and consuming countries in the world. The Central Government introduced the National Mission on Oilseeds and Oil Palm or NMOOP during the 12th Five Year Plan to support the development and sale. This scheme aims to boost the production of edible oils and expand the oil palm areas. The fund allotted under the National Mission on Edible Oils scheme is distributed between State and Central Governments. This fund released to the Department of Agriculture is shared in a ratio of 75:25. The state and national levels reserve 1% from this fund to utilise during crisis periods, while 10% is reserved for Flexi-fund.

iv. Capital Investment Subsidy Scheme (CISS) under Soil Health Management Scheme

The significance of organic farming, which is a complete system based on the core premise of minimizing the use of external inputs and avoiding the use of synthetic pesticides and fertilisers, has been highlighted by growing awareness of the need of nutritious and safe food. A Capital Investment Subsidy Scheme for Commercial Production Units for Organic and Biological Inputs has been created under the National Project on Organic Farming in response to this problem. The National Centre of Organic Farming, in partnership with the National Cooperative Development Corporation (NCDC) or NABARD, implements the programme on behalf of the Department of Agriculture, Cooperation, and Farmers' Welfare.Under this scheme, 100 percent assistance is provided to state government, government agencies for setting up of mechanised fruit and vegetable market waste, agro waste compost production unit up to a maximum limit of Rs 190 lakh per unit (3000 Total Per Annum TPA capacity). Similarly, for individuals and private agencies assistance up to 33 percent of cost limit to Rs 63 lakh per unit as capital investment is provided.

v. Mission Organic Value Chain Development for North Eastern Region (MOVCDNER)

The scheme promotes third party certified organic farming of niche crops of north east region through Farmer Producer Organizations (FPOs) with focus on exports. Farmers are given assistance of Rs 25,000 per hectare for three years for organic inputs including organic manure and bio-fertilizers among other inputs. Support for formation of FPOs, capacity building, post-harvest infrastructure up to Rs 2 crore are also provided in the scheme.

F. Future Prospectus

India is an agriculture-based country with 67% of its population and 55% of manpower depending on farming and related activities. The fastest-growing population in India’s fundamental requirements is met by agriculture, which contributed 30% of total GDP. It has been discovered that organic farming is an ancient Indian tradition that has been followed for millennia in innumerable farms and rural communities. Modern farming methods' introduction and the growing weight of the population have given rise to a preference for conventional farming, which uses synthetic fertilizers, chemical pesticides, the employment of genetic modification techniques, etc.

Even in developing nations like India, there is a growing demand for produce cultivated organically since consumers are more conscious of the safety and quality of their food, and the organic approach has a significant impact on soil health because it uses no chemical pesticides. Additionally, there is a great potential for money generating with organic farming. India's soil is endowed with a variety of naturally occurring organic nutrient supplies, which support organic farming.

India is a nation with an established traditional agricultural system, creative farmers, vast drylands, and minimal usage of chemical pesticides and fertilisers. Additionally, sufficient rainfall in the country's mountainous north-east, where just a little amount of chemicals are used over an extended period of time, results in naturally organic fields.

The field of organic farming has seen the development of a number of newer technologies, including the integration of mycorrhizal fungi and nano-biostimulants (to boost agricultural productivity in an eco-friendly way), more conscious mapping of cultivation areas using sensor technology and spatial geodata, 3D printers (to aid the nation's smallholders), production from side streams and waste along with main commodities, and promotion and improvement of sustainable agriculture. BeeScanning App is another milestone in the growth of organic farming. It allows beekeepers to combat the parasitic mite Varroa destructor and serves as the foundation for population modelling and breeding programmes.

G. CONCLUSION

Food produced by organic farming is safer and more nutritive. As consumers look for organic foods because they believe they are safer and healthier, the popularity of organic food is rising drastically. So possibly eating organic food insures food safety from farm to fork. Compared to conventional farming, organic farming is more environmentally friendly. Organic farming promotes consumer health by preserving the purity of the environment and the health of the soil. Additionally, the organic produce industry is now expanding at the quickest rate in the entire world, including India. Organic farming supports a nation's ecological health, consumer health, and economic development by generating money in a holistic manner. Given that India is now the largest producer of organic food in the world, we may infer that supporting organic farming in India would help create a soon-to-be economically, environmentally, and nutritionally healthy country.

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Chapter

11

ROLE OF SOIL MANAGEMENT IN REALIZING UN SUSTAINABLE DEVELOPMENT GOALS

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INTRODUCTION:

Soil is a dynamic natural body that primarily supports agriculture. It is considered a non-renewable resource because of the extremely long duration of time taken during soil formation.In the recent years, owing to the exponential growth of population, the per capita land availability is decreasing. Increasing soil degradation due to wind and water erosion, salinization, heavy metal contamination, loss of organic matter, soil compaction due to intensive tillage operations, contamination from fertilizer and pesticide residues from intensive cultivation have caused concern at the global level. To ensure that the productivity goals to feed the growing populations are met, focus should be given on maintaining the soil health. For that proper and sustainable management of the soil is the need of the hour.

1. SOIL MANAGEMENT

Soil management refers to the operations, practices, and treatments that are undertaken to protect soil and improve its performance in terms of crop production. It includes practices which are both organic and inorganic to improve agricultural productivity. Recently, emphasis is given to organic farming due to its sustainable nature and its emphasis on improving soil health. Some soil management practices that affect soil health:

- Minimum tillage to reduce soil compaction and increase soil aeration and water infiltration.
- Growing cover crops to reduce air and water erosion.
- Integrated Nutrient Management to improve soil fertility.
- Adding organic manure into the soil to improve carbon content and increase microbial populations.
- Growing green manuring crops to improve soil physical, chemical as well as microbiological properties.

2. SUSTAINABLE MANAGEMENT OF SOILS

According to the principle 3 in the revised World Soil Charter, "Soil management is sustainable if the supporting, provisioning, regulating, and cultural services that the soils provide are maintained or enhanced without significantly impairing the soil functions that enable those services or biodiversity. The balance between supporting and provisioning services for plant production and the regulating services the soil provides for water quality and availability and for atmospheric greenhouse gas composition is a major concern".

Sustainable soil management aims at achieving the following (FAO, 2017):

1. Reducing the rates of soil erosion by water and wind.
2. The soil structure is not degraded a stable physical condition is providedto facilitate movement of air, water, and heat, as well as root growth.
3. Sufficient soil surface cover (e.g. mulching, growing plants, plant residues, etc.) must be present to protect the soil.
4. Restoring soil organic matter and maintaining stable soil organic matter levels in the soil to improve its overall health.
5. Availability and flows of nutrients should be appropriate to maintain or improve soil fertility and productivity and to minimize nutrient loss to the environment.
6. Minimal soil salinization, sodification and alkalinization etc.
7. Water which maybe from precipitation and supplementary water sources such as irrigationis efficiently infiltrated and stored to meet the requirements of plants and ensure the drainage of any excess.
8. Contaminants are kept below toxic levels as they have the possibility to cause harm to plants, animals, humans and the environment.
9. Soil biodiversity should be maintained and it provides a full range of biological functions.
10. Optimum and safe usage of inputs in the soil is an important aspect of soil management systems for producing food, feed, fuel, timber, and fiber.
11. Soil compaction is minimized through responsible land use planning.

The sustainability of soil systems is affected by natural and anthropogenic processes (Doran and Zeiss, 2000) which consists of a framework of complex interrelated processes. To address such complex problems for soil sustainability, an interdisciplinary approach is needed. (Fig. 1) (Hou *et al.*, 2020).

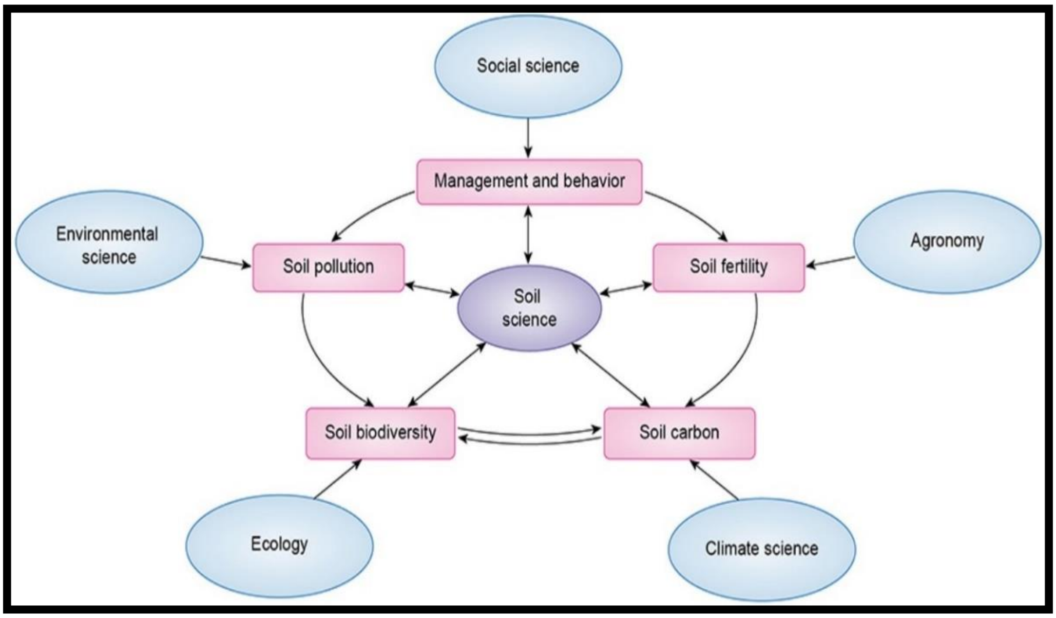

Figure 1: A framework for interdisciplinary research in soil sustainability linking soil science with social science, environmental science, ecology, climate science, and agronomy

In present times, sustainable management of soils is not only dependent on the preference and capacity of the farmers but also on the development and implementation of environmental protection and climate mitigation policies at the global and regional levels (Juerges and Hansjurgens, 2018). As the need for sustainable soil management became clear, FAO established the Global Soil Partnership (GSP) in 2012 to develop synergies among national and international organizations for global action to stimulate a sustainable use of soil resources. The GSP aims “to develop awareness and contribute to the development of capacities, build on best available science, and facilitate or contribute to the exchange of knowledge and technologies among stakeholders for the sustainable management and use of soil resources.” The GSP covers nine regional soil partnerships (RSP) around the world. The core principle of the GSP and its RSPs is a country-driven, bottom-up approach. In this, regional partnerships play an important role to maintain an efficient communication between RSP's member countries. In Europe and Central Asia, this is performed by the European Soil Partnership (ESP), which was established in 2013 (Erdogan *et al.*, 2021).

3. UN SUSTAINABLE DEVELOPMENT GOALS

Soil acts as a base for agricultural production, plant growth, animal habitation, biodiversity, carbon sequestration and environmental quality, which are critical for achieving the United Nations' Sustainable Development Goals (SDGs). However, soil degradation is a concerning problem in many places throughout the world all thanks to factors such as soil pollution, erosion, salinization, and acidification. So as to achieve the SDGs by the target date of 2030, there is a need to use and manage soils in a manner that is more sustainable than is currently practiced.

The United Nations General Assembly, in 2015, established 17 goals with 169 targets to be achieved by 2030, which are named the Sustainable Development Goals (SDGs).Goals such as, no poverty, zero hunger, good health and wellbeing, clean water and sanitation and climate action (UN, 2015) are included among various others.The 2030 Agenda for Sustainable Development adopted a number of targets in 2015aimed at restoring degraded soil, working to achieve a world with minimum land degradation and implementing improved agricultural practices that is aimed to improve soil quality and minimize soil contamination. The SDGs have become important goals for global development and international collaboration. Soil has an important role to play in the United Nations SDGs, most notably SDGs 2, 3, 6, 12, 13, and 15 (Bouma and Montanarella, 2016).

In rural areas, most people live in poverty where agriculture is the main source of income. In such areas, soil plays a pivotal role in productivity and income (Bender et al., 2016). Soil also affects water quality, GHG emissions, and other important environmental conditions in regard to the SDGs (Franzluebbers, 2005). The relationships between soil and the relevant SDGs are illustrated in Fig. 2 (Hou *et al.,* 2020).

Figure 2: The relevance of soil to the United Nations' Sustainable Development Goals (SDGs)

Successful realization of SDGs can be ensured through efficient interdisciplinary interactions for sustainable soil management.

Maintenance and restoration of healthy soils along with its proper functioning is an underlying principle of several targets of the Sustainable Development Goals (SDGs). Sustainable management of soil can help in achieving SDGs as follows (Fig. 3) (Keesstra *et al.*,2016):

1. **Food security (SDGs 1, 2 and 3): soil fertility and the role of soils for food security in developing countries:**

The technologies developed and adopted in developed countries for maintaining soil fertility and thereby improve crop productivity are not feasible at sustaining soil productivity in the context of smallholder family agriculture (Tittonell and Giller, 2013). Some methods of maintaining soil fertility:

- Innovation in the different forms of "precision" agriculture that take into account the diversity, heterogeneity and dynamics of smallholder farming systems.
- A system to ensure nutrient acquisition and management. Agronomy has traditionally addressed the problem of crop nutrition by thinking and acting at the scale of individual fields, and often looking at single resource groups; however, nutrient management cannot be decoupled from management of other farm resources and processes such as recycling are crucial to overall systems efficiency.
- Agro-ecological strategies for the restoration of degraded soils and the maintenance of soil physical properties. Exponential growth of population in tropical regions of the developing countries is the leading cause of accelerated soil degradation, as it means that more land previously under forest or grazing use is brought into annual cultivation; less land available

per household prevents soil maintenance practices such as fallow or pasture rotations, leading to greater frequency of soil ploughing and less organic matter inputs (Diarisso *et al*., 2015)

2. **Health (SDG 3): soil and public health – a vital nexus:**

Modern public health, to prevent disease, prolong life and promote health through organized activities and informed choices of society –needs to understand and manage soils and health. Soils sustain life. They affect human health via quantity, quality, and safety of available food and water, as a source of essential medicines, and via direct exposure of individuals to soils. So, soil management to reduce contamination of harmful chemicals, prevent soil, water and air pollution can help in ensuring healthy lives. Soil is also a huge reservoir for antibiotics which can help in addressing the antibiotic resistance (Ling *et al*., 2015) and also potent medicines to treat such tough-to-treat diseases as tuberculosis and cancer (Hartkoorn *et al*., 2012).

3. **Water security/resources (SDGs 3,6): soil water and sustainable development goals:**

Provision of clean and sustainable water by the soils is another aspect of achieving SDGs. In addition to storing and transmitting water, soil is also responsible for filtering it. SDG 6 is related to ensuring availability and sustainable management of water and sanitation for all. This will not be achieved without protecting and enhancing the ability of the soil to deliver clean, fresh water. Soil management for a better water environment requires the support and efforts of local communities. So their efforts need to be supported and strengthened (SDG 6.8).

4. **Climate change (SDG 13): impact of climate change on soils and opportunities for mitigation:**

Urgent and globally effective action is needed to combat climate change and its harmful impacts. Proper soil management can help in reducing the adverse affects of climate change by CO_2 sequestration, sustainable resource management and restoration of degraded soils. The maximum technical mitigation potential from soil carbon sequestration is around 1 Gt (thousand million tonnes) of carbon per year, but the economic potential at carbon prices between USD 20 and 100 per tonne of CO2 equivalents is 0.4–0.7 Gt carbon per year (Smith, 2012). This is important for climate mitigation, as well as for meeting SDGs, since SDG 13 is to “take urgent action to combat climate change and its impacts”.

5. **Biodiversity (SDG 15): functions of soil biodiversity**

Aim of SDG 15 issustainable management of forests, combating desertification, reducing and correcting land degradation and minimize biodiversity loss. Although discoveries are going on about the distribution of soil biodiversity across the globe, it is becoming evident that it is negatively affected by many human activities, including land use change and management intensification. So, methods to protect soil biodiversity is the need of the hour. Measures should be taken to promote soil biodiversity include reduced soil tillage, increasing soil organic matter, erosion control, prevention of soil sealing and surface mining activities, and prevention of extreme soil perturbation.

6. **Land management (SDG 2, 13, 15): the challenge to implement effective soil conservation:**

Sustainable development goal 15 focuses on sustainable use of terrestrial ecosystems, combat desertification, and halt and reverse land degradation. Many ecosystem services and soil functions are connected to this SDG. To reach this goal, good land management plays an essential role. Intensification of industrialized agriculture leads to the excessive application of agrochemicalscausing heavy pollution of ground and surface waters and may also lead to erosion when lower organic matter contents result in a decrease in quality of soil structure. This kind of agriculture, even if economically attractive the sustainability of these new systems is bringing us further away from reaching the objectives of SDG 15.

Figure 3: Overview of SDGs with their links to soil

To achieve these SDGs, Keesstra *et al.*(2016) suggests the following to people who study Soil Science:

- ***Embracing the SDGs*****:** the UN SDGs provide a widely recognized societal framework that allows soil science to demonstrate its relevance for realizing a sustainable society by 2030.
- ***Showing the specific value of soil science*****:** research should explicitly show how modern soil information can be used to improve the results of inter- and transdisciplinary studies on SDGs related to water scarcity, food security, climate change, biodiversity loss and

health threats. Implications for society should be communicated in terms that appeal to stakeholders, citizen at large and the policy arena.

- ***Taking leadership in overarching systems-analyses of ecosystems*: ** given the integrative nature of soils, soil scientists are in a unique position to initiate and guide a comprehensive systems analysis of ecosystems, integrating land-related SDGs.
- ***Raising awareness of soil organic matter as a key attribute*** of soils to illustrate its importance for soil functions and ecosystem services. It is also needed to demonstrate how soil management can manipulate the organic matter content and quality of any given soil.
- ***Improving the transfer of knowledge*: ** inter- and transdisciplinarity require effective communication of soil knowledge and expertise to outsiders with little knowledge about soils.
- ***Facilitating communication with the policy arena*: ** research should be framed in terms that resonate with politicians in terms of the policy cycle or by considering drivers, pressures and responses affecting impacts of land use change.

CONCLUSION

Since its inception, the GSP has been successful in raising awareness about soil at the global level, specifically on the UN SDGs and the 2030 Agenda. Soil, a cross-cutting theme, is a relevant aspect in relation to climate change (UNFCCC), biodiversity (CBD) and desertification (UNCCD). However, many SDGs are related to targets that directly consider soil resources. Poverty (SDG 1), food security (SDG 2), food safety (SDG 3), clean water (SDG 6), urban development (SDG 11), consumption and production pattern (SDG 12), climate regulation (SDG 13), land-based nutrient pollution of the seas (SDG 14), terrestrial ecosystem service sustainability (SDG 15) and partnership building for the Goals (SDG 17) all aredirectly or indirectly dependent on the provision of ecosystem services where soils play a key role (Bouma et al., 2019).However, to successfully achieve the United Nations' Sustainable Development Goals (SDGs), we are dependent on soil health. Not enough attention has been put towards soil by the scientific community or the policy makers in their SDG efforts. Soil scientists have not been adequately involved in the discussion on SDG targets and indicators which might be due to the focus on pure Soil Sciences. (Bouma et al., 2019). But, for ensuring successful implementation of SDGs around the world, there should be an effective collaboration of the workforce from multiple disciplines and an effective extension system for transfer of information and knowledge sharing to arrive at sustainable solutions. Interdisciplinary studies initiated by, or in collaboration with, communication engineers and computer scientists hold much potential in advancing our capability in sustainable use and management of soil resources (Hou *et al.,*2020)

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Chapter

12

ORGANIC AMENDMENTS FOR SUSTAINABLE AGRICULTURE

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INTRODUCTION:

Sustainable agriculture, which emphasises producing commercially while avoiding environmental harm, is challenging to implement. "conventional" agriculture is frequently thought to involve methods that could harm the environment. These include excessive tilling of the soil, the overapplication of readily soluble inorganic fertilisers (sometimes referred to as "chemical fertilisers"), and the over application of pest-control remedies (herbicides, insecticides, fungicides, etc.). One of the main issues influencing food production is the speedy diminution of nutrients on smallholder farms as population pressure rises and fallow cycles decrease. Therefore, replenishing soil nutrients is indispensable with the intention ofbring to a standstill the loss of soil fertility. The typicalsources for preserving soil fertility and environmental quality might continue to be organic sources related to plant nutrients as organic amendments. This could be done by applying both mineral and organic fertilisers (Wakene *et al.*, 2005). "Sustainable" agriculture looks for alternatives to these methods, solutions that are both economically viable and less likely to harm the environment.

Organic materials made from plants and animals may have a variety of qualities that can increase agricultural performance, soil fertility, and environmental quality. When used as amendments to highly deteriorated soils connected to mining activities, these materials can be especially helpful. As a result, organic amendments (OAs) are any substances derived from plants or animals that are added to or integrated into soil with the intention of improve or replace the soil's physical, chemical, and biological qualities, hence creating a conducive environment for production and productivity (Pettygrove *et al.*, 2010). A mix of organic substancesand soil organic matter management is required to manage nutrients in crop production systems while maintaining productivity and quality. Regardless of whether the methods are regarded as "traditional" or "sustainable," farming depends on having sufficient levels of soil fertility and plant nutrients. Sustainable farming emphasises on the utilisation of organic materials as per soil amendments and acting as a sources of plant nutrients, even though it is frequently a much broader term than "organic" farming.

SOURCES AND KINDS OF ORGANIC AMENDMENTS

Thousands of years ago, organic amendments were first used to enhance the fertility and quality of soil. Compost and animal manure are currently the most often used organic soil additions, but peat moss, wood chips, straw, sewage sludge, and sawdust are also utilised. The various resources can generally be divided into the aforementioned groups.

1. MANURE AND COMPOSTS

Manure is made up of animal bedding, faeces, and urine that have been churned and stacked to a certain level of composting. Additionally, its composition is influenced by where it comes from, how long it is stored before being applied to soil, and how long urine and faeces are expelled and combined. Manure provides organic matter and nutrients for crops, soaringthe fertility of the soil (Goss *et al*., 2013). Manures are appropriately referred to as low analysis organic fertilisers because they only contain a limited amount of plant nutrients. Realizing its beneficial impact on the physical, chemical, and biological characteristics of soil has rekindled interest in the field of combining organic manures with chemical fertilisers.

Manures are broadly classified as:

(i) **Bulky organic manures**: These are bulky or voluminous in nature and contain low concentrations of plant nutrients and large quantities of organic matter e.g., farmyard manure (FYM), compost, green manure (GM) and crop residues, etc.

(ii) **Concentrated organic manures**: These encompass relatively greaterpercentage of plant nutrients than the bulky one and can be of plant (e.g., oil cakes) or animal origin (e.g., blood meal, fish meal, meat meal, hoof meal).

Table 1: Animal Excreta production per day

Animal	**Urine (ml kg^{-1} live wt)**	**Quantity of dung (Kg day^{-1})**
Horse	3-18	9-18
Cattle	17-45	18-30
Buffaloes	20-45	25-40
Sheep and goats	10-40	1-2.5
Pigs	5-30	3-5
Poultry	-	2.5-3.5

Source: Reddy, S.R.2005. Principles of Agronomy. Kalyani Publisher, Ludhiana.

Table 2: Nutritive value of animal solid and liquid excreta

Animal	Dung (mgg^{-1})			Urine (%)		
	N	P	K	N	P	K
Cattle	20-45	4-10	7-25	1.21	0.01	1.35
Sheep and goat	20-45	4-11	20-29	1.47	0.05	1.96
Pig	20-45	6-12	15-48	0.38	0.1	0.99
Poultry	28-62	9-26	8-29	-	-	-

Source: Reddy, S.R.2005. Principles of Agronomy. Kalyani Publisher, Ludhiana.

FARMYARD MANURE (FYM)

It is the degraded product of the cattle's leftover fodder, urine, manure, and litter. The quality of the food supplied to the animal, the source of the excrement (cow, bullock, or horse), the type of litter, and the storage method all affect the amount of nutrients in FYM. It is prepared either in pits, trenches, or piles with optimal dimensions of 6 metres, 2 metres and 1 metre as length, width, and height respectively. The cattle shed's litter, which has been saturated in dung and pee, is dumped every morning. until the pile is 0.5 metres above the ground. It is then shaped into a dome and covered with a mixture of mud and cow dung slurry. The FYM has an average composition of 0.5% N, 0.2% P_2O_5, and 0.5% K_2O and is ready for usage in 4-6 months. When this FYM is applied to the soil, only 30% of N, 60-70% of P_2O_5, and 75% of K_2O are available to the crop in the first year of application and the remainder in subsequent years. During preparation and storage, a sizeable proportion of N in FYM is lost, primarily as NH_3 volatilization and/or NO_3^- leaching. By adopting better techniques, a biogas plant (gobar gas plant), or chemical preservatives, it is possible to reduce N losses in FYM (e.g., gypsum or SSP). Unfortunately, less than half of the cattle dung in India is applied to the soil and is instead utilised to make cakes and fuel for cooking in rural homes. Methane (CH_4), a flammable gas that is produced by biogas plants and can be used for cooking and lighting, is produced by these plants. A significant amount of biogas slurry, which may replace 25% of the chemical fertilisers and is a very rich source of plant nutrients, is also created throughout the process. With 1.6-1.8% N, 1.0-1.2% P_2O_5, and 1.2-1.8% K_2O, it has more plant nutrients than FYM and compost. Its significant water content is the main drawback. Therefore, it needs to be dried before usage. The slurry can also be applied directly through irrigation as an alternative.

Sheep and Goat Manure

The excreta/droppings of sheep and goats are encompassing a handsome amount of nutrients (3 per cent N, 1 per cent P_2O_5 and 2 per cent K_2O) than FYM and compost both. There are numerous modes to apply this in field. One method includes sweeping of animal sheds are disposed in pits for decomposition and applied to the field afterward. But this mechanism grounds the loss of the nutrient existing in urine. The other method is sheep penning, in whichanimals are kept overnight in the field and urine and faecal matter added to the soil followed by incorporation of the same into a shallow depth by working blade harrow or cultivator or cultivator.

Poultry Manure

The excretory product of birds'gets fermented very rapidly, ifit left exposed i.e., 50 percent of its nitrogen is lost within 30 days. Poultry manure is high in nutrient (3.03 per cent N; 2.63 per cent P_2O_5 and 1.4 per cent K_2O) than the bulky one.

COMPOST

Composting is the breakdown of organic wastes of both plant and animal origin into organic manure that is rich in humus and plant nutrients by a variety of microbes operating in a warm, humid, aerobic or anaerobic setting. Composting is basically an aerobic and anaerobic biological process that lowers the C/N ratio of the substrate by decomposing organic waste. The ultimate product is compost, an amorphous, humified substance that is having a brown or dark browncolour. It is more stable and nutrient-rich than FYM. The difference between FYM and compost is in the substrate. In contrast to compost, FYM uses a variety of waste organic materials as its substrates, including dung, urine, and litter (straw, stalk, stubble, husk, weeds, biodegradable household and factory waste, etc). Composting emerges as the most broadly applicable procedure for treating a wide range of unique wastes in the entire field of waste reprocessing **(**Pérez-Piqueres *et al*., 2006). The majority of the pathogens in the substrate are mostly eliminated by composting. Compost is formed from a variety of agricultural wastes, including crop residues, farm weeds and grasses, leaves, wood ashes, litter, urine-soaked earth and bedding materil from cattle sheds, and other similar materials. It can also be made in urban areas from comparable materials (made of city organic wastes, like night soil, wastes from fruit and vegetable market, business centres, offices, streets and household refuses and other wastes). Composting of urban or solid waste is practised in large cities using mechanical composting equipment and contemporary technologies. Composting can be classified as aerobic or anaerobic depending on how much oxygen is used during the decomposition process. With oxygen present, aerobic composting occurs quickly and is characterised by high temperatures, the presence of aerobic microbes, and ideal moisture levels. An example of this is the Indore technique. Anaerobic composting, on the other hand, occurs without the presence of air or oxygen (such as the Bangalore technique) and is characterised by low temperature, an unpleasant odour, the formation of intermediate products, and a slow process. Moisture content, temperature, pH, C/N ratio, aeration, and inoculation are a few factors that might impact the composting process (Scotti *et al*., 2015). Compost that has properly decomposed should be pH neutral, have a C/N ratio of less than 20, and contain more than 16% C, 0.5% N, 0.5% P_2O_5, and 1% K_2O (w/w).

Compost doesn't contain a lot of nutrients. Thus, to boost the nutrient content of the finished product, enriched compost can be created by additionof nitrogen, sub-standard minerals such rock phosphate and waste mica throughout the composting process. To dissolve the rock phosphate, bacteria like *Bacillus polymyxa*, *Pseudomonas striata*, and fungi like *Aspergillus* *awamori* can be added to the composting mixture. Similar to this, waste mica can be dissolved using microorganisms that dissolve potassium, such as *Bacillus mucilaginosus*. Compost accelerators are cellulolytic and lignolytic microbes that are employed to speed up the composting process. Examples include *Trichoderma viride, Trichurus spiralis, Paeciliomyces fusisporus,* and *Phaenerocheate crysosporium*.

On-farm compost has recently taken the place of commercial compost in agriculture. Composting on-site could be a practical, affordable, and environmentally sound biological method for reusing leftover agricultural biomasses (Pane *et al*., 2015). On-farm compost manufacturing could help to address the issue of disposing of agricultural biomasses and vegetable feedstock while also giving farmers access to high-quality compost for the enhancement of soil quality.

VERMICOMPOST

Vermicompost is made with the help of earthworms. Earthworms eat all kinds of organic material, keeping 5–10% for growth, and excreting vermicast, which has been physically and chemically broken down by the movement of the muscular gizzard that is located in their intestine. Recycling non-toxic animal, agricultural, and industrial wastes is a practical and affordable procedure. N, P, K, Ca, Mg, vitamins, enzymes, and compounds related to growth-stimulation are abundant in vermicasts. Additionally, the compost heap doesn't need to be turned further because the worms do it for you. Earthworms of the species *Eisenia foetida, Pheritima elongata, Eudrilus eugeniae*, and *Perionyx excavatus* are the most effective.

Table 3: Nutritive value of vermicompost

Nutrient	Content
Organic carbon	9.5 – 7.98%
Nitrogen	0.5 – 1.50%
Phosphorous	0.1 – 0.30%
Potassium	0.15 – 0.56%
Sodium	0.06 – 0.30%
Calcium and Magnesium	22.67 – 47.60 meq$(100g)^{-1}$
Copper	2 – 9.50 mg kg^{-1}
Iron	2 – 9.30 mg kg^{-1}
Zinc	5.70 – 11.50 mg kg^{-1}
Sulphur	128 – 548 mg kg^{-1}

Source: Reddy, S.R.2005. Principles of Agronomy. Kalyani Publisher, Ludhiana

2. Municipal biosolids and septage

Municipal biosolids firstly, faces the general screening and grit removal followed by sedimentation (Primary Treatment) to remove suspended organic material. Then the microbes present in it will digest the easily metabolised fraction (Secondary Treatment). Some other treatment facilities exclusion of N and P from solutions (Tertiary Treatment). The material must be stabilised as the last step of the treatment process. This can be done by heating and drying the material, stabilising it with alkalis to raise the pH, heating and aerobic or anaerobic digestion, or composting. After being spread onto the ground as a liquid or, after dewatering, as a cake, the stabilisation procedure aims to decrease or eradicate pathogens and lessen the material's appeal to scavengers. Common names for these substances are municipal biosolids and sewage biosolids (**Goss *et al*., 2013**). Biosolids can be used in soils related to agricultural activities since they contain nutrients and organic matter, but only in accordance with regulations that set limitations for the presence of heavy metals, weeds, and human and plant infections.

Sewage and Sludge

In terms of the waste leaving the city sewer system, sludge and sewage are the liquid and solid portions, respectively. Aquatic bearingsuspended and dissolved solid organic waste, which could potentially harm water bodies, makes up the majority of raw sewage(rivers). Therefore, it must be processed in some way to lessen the amount of organic materials before it can be disposed of properly. During treatment, the sludge component settles and is separated from the liquid portion (sewage). The sewage is used for irrigation, and the sludge, which is rich in plant nutrients, is used as manure. According to estimates, India's major cities' sewage systems might annually produce roughly 1.2 Mt of N, 1.0 Mt of P_2O_5, and 0.8 Mt of K_2O. Vegetables cultivated using them include an excessive quantity of organic and nitrogen loading due to anaerobiosis, an imbalance in the C:N and C:P ratios, the plugging of soil pores by colloidal debris, and bacterial contamination. Using untreated sewage water repeatedly can also make soil ill. Using treated sewage water that has been diluted (1:1) with good water will boost crop productivity. Another disadvantage of using sewage and sludge in agriculture is the presence of heavy metals, primarily Pb, Cd, Cr, and Ni depending on the source of industry from which the sewage and sludge derives. Recurrent sewage application tends to increase the concentration of metals in soils and make them more accessible to plants as a result, which may cause them to contaminate our food.

Green manure, crop residue and cover crops

The process of "green manuring" entails producing a crop and either turning it into the soil as undecomposed green plant components or ploughing it in situ in order to enrich the soil and increase its fertility as well as its physical qualities (Goss *et al.*, 2013). Green manure crops are the plants raised for this purpose. If it is a legume crop, the green manure crop provides organic matter in addition to nutrients, especially N. There are two categories of green manuring:

(i) **In-situ green manuring**: This process refers to growing a green manure crop and ploughing it into the same field. Sunnhemp (*Crotalaria juncea*), dhaincha *(Sesbania aculeata*), cowpea (*Vigna sinensis*), berseem (*Trifolium alexandrinum*), and lucerne (*Medicago sativa)* are the most significant in-situ green manuring crops

(ii) **Green leaf manuring**: Green leaves and delicate twigs are delivered to the field for integration on these plants, which are produced elsewhere. *Leucaena leucocephala* (Subabul), *Glyricidia maculata*, *Sesbania speciosa*, *Pongamia pinnata* (Karanj*)*, *Pongamia glabra*, and *Cassia tora* are well-known green leaf manuring plants.

Table 4: Biomass production and N accumulation of green manure crops

Crop	**Age (Days)**	**Dry matter (tha^{-1})**	**N accumulated ($kg\ ha^{-1}$)**
Sesbania aculeata	60	23.2	133
Crotalaria juncea	60	30.6	134
Cow pea	60	23.2	74
Pillipesara	60	25.0	102
Sesbania rostrata	50	20.6	146

Source: Reddy, S.R.2005. Principles of Agronomy. Kalyani Publisher, Ludhiana

Table 5: Nutrient content of green manure crops

Plant	**Nutrient content (%) on air dry basis**		
	N	**P_2O_5**	**K**
Crotalaria juncea	2.30	0.50	1.80
Sesbania aculeate	3.50	0.60	1.20
Sesbania speciosa	2.71	0.53	2.21

Source: Reddy, S.R.2005. Principles of Agronomy. Kalyani Publisher, Ludhiana

In general, legumes with good nodulation (N_2-fixing capacity), rapid growth, deep rootedness, low water requirements, short duration (4-6 weeks), and sensitive foliage habit facilitating rapid decomposition should be used as green manuring crops. Flowering stage ideal to incorporate green manure crops since they degrade more quickly before becoming fibrous and taking longer to decompose after this point.

In addition to protecting soils, preparing land for a perennial crop, or providing animal feed, cover crops can be helpful in crop rotations to fill in brief gaps in cultivation. Cereal crops contribute after-harvest straw, but legumes like soybeans, cowpeas, and clover are typically favoured because they can fix nitrogen (N) from the atmosphere by working with bacteria at the root level. Legumes can be used as green manure to supplement the organic matter that the soil acquires from the burial of full plants by adding N. Even non-legumes species like buckwheat, millet, annual ryegrass, and forage sorghum are employed to provide biomass and control weeds. The major advantages of green manure and cover crops are the nutrient and organic matter addition to the soil as well as the improvement of microbial activity and water retention capacity. A cover crop is any crop cultivated to cover the soil and stop wind and water erosion, regardless of whether it is incorporated into the soil (Sullivan, 2003). For instance, sod can be protected over the winter by growing cover crop in the late summer or fall. A summer cover crop will improve deficient soils or get the ground ready for a perennial crop (Sullivan, 2003).

Table 6: Nutrient content of green leaf manure

Plant	Scientific name	Nutrient content (%) on air dry basis		
		N	P_2O_5	K
Gliricidia	*Gliricidia sepium*	2.76	0.28	4.60
Pongania	*Pongamia glabra*	3.31	0.44	2.39
Neem	*Azadirachta indica*	2.83	0.28	0.35
Gulmohur	*Delonix regia*	2.76	0.46	0.50
Peltophorum	*Peltophorum ferrugenum*	2.63	0.37	0.50
Weeds				
Parthenium	*Parthenium hysterophorus*	2.68	0.68	1.45
Water hyacinth	*Eichhornia crassipes*	3.01	0.90	0.15
Trianthema	*Trianthema portulacastrum*	2.64	0.43	1.30
Ipomoea	*Ipomoea*	2.01	0.33	0.40
Calotrophis	*Calotropis gigantea*	2.06	0.54	0.31
Cassia	*Cassia fistula*	1.60	0.24	1.20

Source: Reddy, S.R.2005. Principles of Agronomy. Kalyani Publisher, Ludhiana

3. CONCENTRATED ORGANIC MANURES

Compared to bulky organic manures, concentrated organic manures have higher concentrations of the three main plant nutrients (N, P, and K) (FYM and compost). Raw materials of either plant or animal origin, such as oilcakes, fish dung, dried blood, bone meal, etc., are used to create the concentrated organic manures. The leftovers following oil extraction from oil-bearing seeds are known as oilcakes. Non-edible oilcakes are typically utilised as manures, whilst edible oilcakes are used as animal feed. Oilcakes are sometimes referred to as organic nitrogenous fertilisers since they have a higher concentration of nitrogen (N) than P_2O_5 and K_2O. A combination of proteins, lipids, and calcium phosphate make up bones or bone meal. These are good suppliers of phosphate, nitrogen, and lime. Acid soils respond well to the slow-acting organic P fertiliser known as bone meal. All soil types and crops can benefit from using fish manure because of its rapid action. It can be purchased as dried fish, fish meal, or fish powder. When transplanting, the fish may occasionally be pushed into the ground whole or in small pieces. However, it is only really used in coastal places where it is conveniently accessible. Another concentrated organic manure, guano (dried sea bird excrement), contains significant amounts of nutrients, particularly N and P_2O_5, although it is not produced in India.

Table 7: Nutrient content of Concentrated Manures

Oil-cakes	Nutrient content (%)		
	N	P_2O_5	K_2O
Non edible oil-cakes			
Castor cake	4.3	1.8	1.3
Cotton seed cake (undecorticated)	3.9	1.8	1.6
Karanj cake	3.9	0.9	1.2
Mahua cake	2.5	0.8	1.2
Safflower cake (undecorticated)	4.9	1.4	1.2
Edible oil-cakes			
Coconut cake	3.0	1.9	1.8
Cotton seed cake (decorticated)	6.4	2.9	2.2
Groundnut cake	7.3	1.5	1.3
Linseed cake	4.9	1.4	1.3
Niger cake	4.7	1.8	1.3
Rape seed cake	5.2	1.8	1.2
Safflower cake (decorticated)	7.9	2.2	1.9
Sesamum cake	6.2	2.0	1.2

Source: "Hand book of Manures and Fertilizers" 1964.

4. **BONE MEAL**

Animal bones, slaughterhouse waste, and finely and coarsely ground waste constitute bone meal. It is applied to plants as an organic fertiliser and to animals as a dietary supplement. Bone meal is largely utilised as a source of protein and phosphorus in slow-release fertilisers. A speedier release of nutrients may be possible with finely ground bone meal compared to bone meal that has been ground more coarsely. There are significant levels of total nitrogen, phosphorus, and calcium in meat and bone meal (MBM).

Table 8: Average nutrient content of concentrated (animal based) organic manures

Organic manures	Nutrient content (%)		
	N	P_2O_5	K_2O
Blood meal	10 - 12	1 - 2	1.0
Meat meal	10.5	2.5	0.5
Fish meal	4 - 10	3 - 9	0.3 - 1.5
Raw bone meal	3 - 4	20 - 25	-
Steamed bone meal	1 - 2	25 - 30	-

Source: "Hand book of Manures and Fertilizers" 1964.

5. **FOOD RESIDUES AND WASTE**

Unsold or unmarketable garden-fresh foodstuffs from supermarkets are additional supplies of material from municipal places that have been converted to compost and afterward applied to agricultural land, regularly.

6. **WASTE FROM MANUFACTURING PROCESSES**

Residual organic material from pressing oil seeds, hoof and horn meal, fish offal, dried blood, animal hair, feathers and shoddy (waste material from preparing wool), residue of paper mills, resulting after sugar extraction from sugar beet (*Beta vulgaris* L.) and/or Sugar cane, distillery wasteetc. have all been applied in this way. Distillery Effluents/Spent wash, aby-product of manufacturing of ethyl alcohol from molassescomprisesubstantialquantities of organic matter and plant nutrients like K, S and appreciable amount of N and P which can be used as per irrigation water and as an amendment (for alkali soils). Though, sinceit is havinggreat load of organic compound, subsequentincrement in biochemical oxygen demand (BOD) and chemical oxygen demand (COD) is obvious thus making them unsafe for direct useon to agricultural lands. But it can, still, be applied to diverse crops without harm afterwardusing appropriate dilutions. Although bio-methanation digesters reduces the organic matter in spent wash load but still not efficiently reduces the same.

7. **BIOFERTILIZERS**

In order to increase the productivity of soil and/or crops or augment the plant nutrient supply, biofertilizers are substances that contain one or more carrier-based (solid or liquid) alive microorganism species that possess the capabilities to mobilise nutritionally significant elements from immobilised forms through biological mechanisms including nitrogen fixation, phosphate solubilization or mobilisation, secretions of plant growth-promoting substances, or cellulose and lignin biodegradation. They are environment-friendly and cost- effective supplement to both the organic and inorganic nutrient sources. They are documentedas per one of the elementsof integrated plant nutrient supply (IPNS) system.

Table 9: Different types of Biofertilizers

Group of biofertilizers	Sub-group	Examples
Nitrogen fixing	Free-living	*Anabaena spp., Azotobacter spp, Beijerinkia, Derxia, Aulosira, Tolypothrix, Cylindrospermum, Stigonema, Clostridium, Klebsiella, Nostoc, Rhodopseudomonas, Rhodospirillum, Desulfovibrio, Chromatium,* and *Bacillus polymyxa*
	Symbiotic	*Rhizobia (Rhizobium, Bradyrhizobium, Sinorhizobium, Azorhizobium, Mesorhizobium, Allorhizobium), Frankia, Anabaena azollae,* and *Trichodesmium*

	Associative	*Azospirillum spp. (A. brasilense, A. lipoferum, A. amazonense, A. halopraeferens, and A. irakense), Acetobacter diazotrophicus, Herbaspirillum spp., Azoarcus spp., Alcaligenes, Bacillus, Enterobacter, Klebsiella,* and *Pseudomonas*
Phosphorus (microphos)	Phosphatesolubilizing	*Bacillus megaterium* var. *phosphaticum, B. subtilis, B. circulans, B. polymyxa, Pseudomonas striata, Penicillium spp., Aspergillus awamori, Trichoderma, Rhizoctonia solani, Rhizobium, Burkholderia, Achromobacter, Agrobacterium, Microccocus, Aereobacter, Flavobacterium,* and *Erwinia*
	Phosphatemobilizing	Arbuscular mycorrhiza (*Glomus sp., Gigaspora sp., Acaulospora* sp., *Scutellospora* sp., and *Sclerocystis sp*.), ectomycorrhiza (*Laccaria spp., Pisolithus spp., Boletus spp., Amanita spp*.), ericoid mycorrhizae (*Pezizellaericae*), and orchid mycorrhiza (*Rhizoctonia solani*)
Micronutrients	Potassium solubilizing	*Bacillus edaphicus, B. mucilaginosus,* and*Paenibacillusglucanolyticus*
	Silicate and zinc solubilizing	*Bacillus subtilis, Thiobacillus thioxidans,* and *Saccharomyces sp.*
Growth promoting	Plant growth promoting rhizobacteria	*Agrobacterium, Achromobacter, Alcaligenes, Arthrobacter, Actinoplanes, Azotobacter, Bacillus, Pseudomonas fluorescens, Rhizobium, Bradyrhizobium, Erwinia, Enterobacter, Amorphosporangium, Cellulomonas, Flavobacterium, Streptomyces,* and *Xanthomonas*

Modified from Singh et al. (2014)

8. BOG/PEAT MOSS

The decomposing leftovers of Sphagnum moss, native to numerous parts of the world, are known as peat moss. It is a natural and organic soil conditioner assiststo retain moisture and regulates the air nearbyplant roots to create the best conditions for growth. Clay-rich soil is made easier to aerate and loosen by peat moss. Peat moss will aiddropthe pH in soils with high alkaline levels because it is naturally acidic. When added to soil, peat moss helps stop the leaching or discharge of nutrients.

9. BIOCHAR

Biochar, a carbon-rich, fine-grained solid porous by-product material, when biomass (e.g., agricultural crop residues, wood, waste, raw materials, like forest, animal compost, and plant residues etc.) is subjected to thermo-chemical conversion process known as pyrolysis. Here the biomass is heated all throughthe process of pyrolysis in an oxygen-depleted/less environment (Chia *et al*. 2012). Biochar can be formulatedby three pyrolysis systems as slow, fast and gasification. Slow pyrolysis involves heating of biomass in the absence of oxygen at temperatures of in between 350 to 600°C by means of gentle heating rates and extended residence times. In contrast fast pyrolysis is a process involving rapid heating of small biomass particles, in seconds; at high temperature in the absence of oxygen. (Bridgwater, 2012). Gasification can be viewedas discrete form of pyrolysis and combustion, using a limited quantity of oxygen, at araised-uptemperature in the range of 800-1000˚C (Panwar *et al*., 2012). One more process is used to manufacture biochar is hydrothermal carbonization (HTC) better recognised as wet pyrolysis.

TYPE OF BIOCHARS

Biochar is highly variedsubstance with a diverse kindof properties. This textdivides biochar into 6 categories based on the main type of biomass utilised in its manufacture, allowing estimate of its qualities:

- **Lignin-rich biochar:**is created from biomass with a high lignin concentration, such as wood, sawdust, and other tree parts
- **Cellulose-rich biochar:** produced from cellulose-rich biomass, such as grasses, straws, grains, etc.
- **Nuts/shell biochar**: Biochar made from materials that shield nuts, such as their husks and shells.
- **Manure/Waste biochar**: originated from pyrolysis of manures, biosolids or any green waste.
- **Algae biochar**: shaped from fresh and seawater algae.
- **Black carbon**: Any other biochar shaped from biomass not includedin the above classes and black carbon forms that are formed naturally

WHY BIOCHARS ARE IMPORTANT IN SOIL/AGRICULTURE?

The heat treatment pays to biochar its large surface area and its typical ability to stick around in soils with unpredictablebiological decay, having half-life reaching from decades to centuries (Zimmerman, 2010). Theoretically, biochar can play a many-sidedcharactersboth directly and indirectly in soils. In order to improve the soil's quality, hold nutrients, and promote plant growth, biochar can be used as a soil conditioner or amendment. A distinct benefit of biochar, by the way, is its nutrient value, which it provides to plants directly or indirectly through improving the soil environment. This reduces fertiliser leakage to environment, which increases the efficiency of fertiliser use. The nutritional composition and availability of biochar depends on the pyrolysis conditions as well as the type of feedstock (Bera *et al.,* 2017). Crop output is upsurged with biochar, and nutrient leaching is lessened (Parvage *et al.,* 2013). Additionally, biochar offers benefits including enhancing the physical and biological characteristics of soil

(Bera *et al.,* 2019). Furthermore, biochar can modify the root morphology of crop plants by promoting the growth of the fine root,lengthening the specific root and reducing the width and density of the root tissue. Under nutrient-deficient soils, the better-quality root settings allow plants to utilise more soil volume and yet under nutrient-starving soils (Olmo *et al*., 2016). In line with this, biochar improves the qualities of soil that allow it to hold onto nutrients and water (Rens*et al.,* 2018). Due to variations in pore size distribution, soil solution flow pathways, and nutrient residence times, it may alter many soil properties (Major *et al.,* 2009).

BENEFITS OF ORGANIC AMENDMENT USE IN INTENSIVE AGRICULTURE

In order to effectively counteract soil degradation caused by the stress conditions of agricultural management, sophisticated and appropriate methods are required for soil management in intensive agriculture. There are several distinct types of organic amendments that have undergone various levels of processing. The most common uses of composts are to boost soil organic C content, supply vital nutrients (such N and P), and enhance microbial populations and activity. This section will explain the advantages of using organic amendments in intensive agriculture systems to improve soil quality (physical, chemical, and biological fertility), increase crop yields, and reduce the spread of disease.

PHYSICAL FERTILITY

The use of organic amendments raises soil organic matter and carbon, which boost upsoil quality by escalatingsoil aggregate stability, porosity water holding capacity, and (Khaliq and Abbasi, 2015) decreased soil bulk density (Karami *et al*., 2012). Additionally, organic soil amendments derived from manufacturing waste, like biochar, can influence the particle size distribution and aggregate stability of soil. These effects significantly outperform those of other remedies, indicating that the incorporation of biochar into soil enhances soil structure. Organic soil additives can have an indirect impact on soil's physical characteristics. Lucas *et al.* (2014) showed that organic additions with large amounts of bioavailable C produced from cellulose can stimulate fungal proliferation and enhance soil structure through stabilising soil aggregates, suggesting a use of organic amendments to influence the structure of the soil's microbial population and to encourage aggregation in soils.

CHEMICAL FERTILITY

Without applying organic amendments into the soil, intensive agriculture negatively affects soil chemical properties, resulting in a decrease in soil C content, which has a negative impact on soil microbial biomass, soil enzymatic activities, functional and species diversity, as well as a sharp rise in soil salinity (Bonanomi *et al*., 2011). Numerous empirical investigations conducted in various agricultural systems have shown that applying organic amendments i.e., compost, FYM and Manure etc. is a successful method for recovering soil organic carbon stock (Zhang *et al*., 2015). The primary mechanism is connected to how saprophytic soil microbes behave: these organisms devourorganic matter and demand both organic C and N in a mostly persistent stoichiometric ratio known as C/N ratio.If the C/N ratio is greater than the threshold value of 25–30, organic C or N can restrict microbial development, resulting a quick drop in both the rate of microbial feeding and organic matter decomposition, permitting for long-term C storage.However, when an organic matter having high C/N ratio is added to the soil, mineral N may become momentarily trapped inside microbial biomass, which may reduce plant development and agricultural yields (Hodge *et al*., 2000). Finding organic supplements with precise biochemical properties that successfully balance the exchange amid recovery of organic C stock and mineralization of nutrients is therefore a vital first step in ensuring the sustainability of soil quality management. Though organic amendments instigatea delayed mineral N release that is protracted over time, chemical fertilisers often cause a quick release of mineral N.Although using compost possibly will encourage nitrification, and minimises N leaching, lowering the risk of nitrate contamination of groundwater. By adding organic amendments, the Cation Exchange Capacity (CEC) of the soil improves. The availability of necessary nutritional cations for crop productivity is enabled by high CEC values (BulluckIii *et al*., 2002). In addition, after application to organic material, anions such as phosphorus demonstrated an increase in solubility (Zaccardelli *et al*., 2013).

BIOLOGICAL FERTILITY

Microorganisms are crucial to the breakdown of organic substances. The diversity of soil microbial populations, influencethe rate at which the organic C of soil is mineralized, is the primary determinant of soil fertility and agricultural sustainability. After being applied to the soil, organic amendments encourage the development and diversity of microbialpopulations and communities, demonstrating a significant relationship between soil biological fertility and content of soil organic C. Due to the readily usable energy sources added to the soil, the use of organic soil amendments like compost impacts the biological characteristics and enzymatic activities of the soil **(**Shen and Bartha, 1997). The fast responses of soil biological characteristics to perturbations make them useful markers of soil fertility. They include traits directly connected to microbial activity and biomass as well as traits directly related to the breakdown of organic substances, like the activity of hydrolytic enzymes. Dehydrogenase, phosphomonoesterase, and β-glucosidase were found to have a rapid and intense increase in activity after applying organic amendments. This indicates that repetitiveusage of organic amendments must be schemedto stimulate microbial growth, activity and functionality, as a result, enhancethe soil biological fertility. In addition to conventional organic supplements like compost, the use of manufacturing process by-products is generating a lot of interest. The enzymatic activity like organic amendments can respond favourably to the alternative usage of seed meals as organic amendments, showing a positive impact on soil biological fertility.

POTENTIAL CONTAMINANTS ASSOCIATED WITH ORGANIC AMENDMENTS

Organic amendments are of natural origin and sources of C for microorganisms, pathogenic to humans. Inorganic nitrogen and sulphur molecules are produced during the decomposition of proteinaceous and nucleic acids, and certain enzymes can also release trace metals like Cu and Zn. Metals, microorganisms, organic and inorganic substances originating from industrial sources, runoff building's roofs, roadways, and parking lots, as well as microbes, can all be found in municipal garbage. Additionally, faeces-based amendments may include elements that are not absorbed from food and water, antibiotics used to cure illness or prevent it, sex hormones, and growth hormones.

CONCLUSIONS:

Sustainable agriculture seeks to coexist peacefully with the environment. The challenge with sustainable agriculture is that it necessitates an in-depth knowledge of how natural processes operate on the part of the farmer. Due to its special requirements, farmers that practise sustainable agriculture may called for more managerial skills than even existing "conventional" agriculture.

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Chapter

13

BIOFERTILIZERS: ROLE IN SOIL HEALTH FOR SUSTAINABLE AGRICULTURE

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ABSTRACT:

Soil would persist to be a mass of rocks and mineral formed by the weathering of rocks in the absence of life. In addition to serving as a substrate for plants and housing the intricate food chain of soil biota, soil is crucial for supporting terrestrial life. Soil is imperative for supporting life because it serves as a substrate for plants and hosts millions of soil microorganisms. Since, agricultural land is scarce and diminishing over time due to human population growth, this poses a serious threat to one's ability to access food. In order to fulfill the requirements of the growing population, it is imperative that agriculture production should substantially increase over the following few decades. However, the emphasis of this chapter is on Biofertilizers. Too much reliance on synthetic fertilizers for increased crop production inevitably has serious consequences for both ecological system and human health. Biofertilizers can mobilize nutritionally important elements in soil via biological processes such as N_2 fixation, phosphate solubilization and mineralization, secretion of plant growth-promoting substances and biodegradation. Biofertilizers, which contain both living and dead organisms as well as organic waste, are the potential substitutes to chemical fertilizers.

KEYWORDS: Biofertilizers, Classification, Advantages, Constraints

INTRODUCTION:

A fertilizer is any substance, organic or synthetic, when applied to plant or soils supplies one or more nutrients required for normal growth.These provide plants with essential macronutrients (N, P, K, Ca, Mg and S) as well as various micronutrients (Fe, Cu, B and Mo).As the population grows, so does the demand for more food, which highlights the importance of plant nutrition and chemical fertilizer (Cakmak, 2002).Chemical fertilizers, also known as mineral fertilizers, depend primarily on synthetic-organic or inorganic compounds. Standard fertilizers with nitrogen (Urea, Ammonium Nitrate, CAN and AmmoniumSulphate), phosphorus (Rock phosphate, DAP and SSP), and potassium (Potassium nitrate, Muriate of Potash) are in high demand in the market. Although nutrients like nitrogen and phosphorus are abundant in soil, one limitation to plant growth isthat plants must compete with soil microorganisms for these nutrients because most nitrogen is found in soil organic matter whereas phosphorus precipitates with calcium (in alkaline pH), iron and aluminium (in acidic pH). Chemical fertilizers, which are now widely used, have depleted soil health by rendering the soil ecology highly vulnerable for soil microfauna and microflora, which are largely accountable for managing soil productivity and providing plants with some critical and essential nutrients.It is crucial to limit the use of synthetic fertilizers in agriculture due to the aforementioned downsides, without compromising crop output, by incorporating and utilizing safe, sustainable fertilizer inputs.Compost and manure are excellent for practically all plant types and also helps to improve the soil's physical, chemical, and microbiological characteristics. However, a negative aspect is that it must be supplied in large quantities.

Biofertilizers can mobilize nutritionally important elements in soil via biological processes such as N_2 fixation, phosphate solubilization and mineralization, secretion of plant growth-promoting substances and biodegradation.

BIOFERTILIZER: URGENT NEED IN AGRICULTURE

As a result, different types of biofertilizers give crop plants the nutrients they need to grow, harm the environment only minimally, and increase soil biodiversity. Future consumption is anticipated to rise as a result of an overall rise in fertilizers need to produce more food on a finite amount of arable land, rising chemical fertilizers costs, dwindling soil fertility, worries about environmental risks, and a growing danger to sustainable agriculture.

CLASSIFICATION

Bacteria, fungus, and cyanobacteria are the most significant types of microorganisms employed in the production ofbiofertilizer, a large majority of which are symbiotic with plants. Based on their nature and function, the most essential forms of microbial fertilizers include those that meet demand of nitrogen and phosphorus. When applied to seeds, soils or plant surfaces, a biofertilizer of specified effective living microbial culture can colonize the rhizosphere or the interior of the host plant, thereby promoting plant growth by enhancing the availability, supply or absorption of primary nutrients to the host.

1. Nitrogen-Fixing Microorganisms

Nitrogen is a major limiting factor despite being the most prevalent and abundant element in the environment since it is difficult for plants to fix and assimilate. Several bacteria can have a wider range of relationships with plants., can, nonetheless, fix a significant amount of nitrogen. This feature enables efficient plant uptake of fixed nitrogen while reducing losses due to leaching, volatilization anddenitrification. These microorganisms can include:

(a) **Free-living:** *Azotobacter chroococcum*, which is prevalent in arable soils, is capable of fixing 2-15 mg N g^{-1} of carbon source in culture media and producing an abundance of slime, which aggregates soil. Regardless to the prevalence of antagonistic microbes in the soil and a lack of organic matter, the population of *A. chroococcum* in Indian soils seldom reaches 105/g soil (Kumawat*et al*, 2017).

(b) **Symbiotic Association:** A genus of Gram-negative soil bacteria called Rhizobium is well known for its symbiotic association with numerous leguminous plants.Rhizobium is classified into distinct types based on their growth rate and the plant with which they are associated.Rhizobial biofertilizers are available in powder, granular, and liquid forms.PEPV16 a strain of *R. leguminosarum* that was cultured from *Phaseolus vulgaris* nodules can solubilize phosphate and produce siderophoresand indole acetic acid (Flores-Félix*et al.*, 2013).Frankia, a diazotrophic bacteria, can encourage the growth and development of N_2-fixing nodules in the roots of many dicotyledonous plants viz. Casuarina, Alnus (Alder) Myrica, Rubus, etc.Typically utilized to restore degraded land are nitrogen-fixing microbial biofertilizers that may flourish in poor and disturbed soils. When actinorhizal plants are infected with Frankia, plant growth, biomass, roots and shoots N content, and survival rate after transplantation in fields are all augmented (Thirugnanam and Dharumadurai, 2023). Several cyanobacteria *viz. Trichodesmium*, *Nostoc*, and *Anabaena* possess the ability to use atmospheric nitrogen (N_2) as a source of nitrogen, which is known as nitrogen fixation. An enzyme called nitrogenase is responsible for nitrogen fixation in cyanobacteria, as it is in many other biological systems. The process of inoculating soil with a specific mixture of cyanobacterial species is currently referred to as "algalization". The average of the findings from all research revealed a 15-20% significant rise in grain yields in field tests. If inoculation is carried out continuously for 3 to 4 crop seasons, it has been claimed that the cyanobacteria introduced as a consequence of algalization can become established permanently (Mishra and Pabbi, 2004).

(c) Living in rhizosphere (associative/associated): These nitrogen-fixing bacteria are less closely associated with roots than endophytic symbionts. *Acetobacter, Diazotrophicus and Herbaspirillum* spp. have been reported in sugarcane, maize and sorghum (Boddey *et al.*, 2000) while *Azospirillum* with remarkable host specificity that includes a wide range of annual and perennial plants (Bashan and Holguin 1997). Apart from nitrogen fixation, it also aids in biotic stress tolerance, which is mediated via mechanisms of increased systemic resistance mediated by antioxidants, osmotic adjustment, and the generation of phytohormones, specifically IAA (Fukami *et al.*, 2018).

2. Phosphorus-Solubilizing and Mobilizing Microorganisms

Phosphate solubilizing microorganisms (PSMs) are a type of helpful bacterium that hydrolyzes insoluble phosphorus compounds into soluble P that plants can absorb. PSMs include various species of bacteria (*Rhizobium*, *Bacillus* and *Pseudomonas*), fungi (*Aspergillus* and *Penicillium*), actinomycetes, and Arbuscular Mycorrhizal (AM). PSMs employ a number of methods to make phosphorus available for plant absorption. Lowering of soil pH, mineralization and chelation are examples of these. (Girmay, 2019). The myccorhizal biofertilizers are also known as phosphate absorbers or phosphorus-mobilizing biofertilizers. More than 80% of all land plants have functional mutualistic symbioses with mycorrhizal fungi, in which the fungus relies on the host for photosynthates and energy and gives the host a wide range of benefits in return (Thakur and Singh, 2018). The fungus mycelium spreads from the root surfaces of the host plant into the soil, increasing the surface area for the plant to more effectively access and acquire nutrients, particularly from sources of insoluble phosphorus and other elements like zinc, copper, calcium(Singh and Giri, 2017).The ectomycorrhiza of basidiomycetes establishes a mantle on the root surface of many trees, viz. Eucalyptus, pine etc., and enters the intercellular spaces of the cortical area, where it absorbs the sugars and other nutrients produced by the plant. By expanding the surface area of their roots, these fungi absorb water and minerals. They also solubilize soil humus organic matter, allowing inorganic nutrients to be released and absorbed.Arbuscular mycorrhizal (AM) fungi, such as *Glomus*, are inter-cellular, non-specific, obligate endosymbionts with unique arbuscules and vesicles in the roots that, by acting as an extended root system, extract moisture and several micronutrients from depth and even farther soil niches while also increasing phosphorus mobility and accessibility to stimulate development and growth in host plants

3. Other Mineral Solubilizing Biofertilizers

Bacillus edaphicus (for wheat), *Bacillus subtilis*, and insoluble zinc compounds in soil, such as zinc sulphide, zinc carbonate, and zinc oxide, can be solubilized by *Saccharomyces spp.*, resulting in better biomass yields. While metabolising, microorganisms can hydrolyze silicates and aluminium silicates by supplying protons promoting hydrolysis and organic acids forming complexes with cations and retaining them in a dissolved state.

Table 1: Types of biofertilizers

Sl. No.	Types	Sub-group	Examples
1.	Nitrogen-fixing	Free-living	*Anabaena, Nostoc, Azotobacter, Clostridium, Klebsiella, Rhodospirillum, and Bacillus polymyxa, Beijerinkia*
		Symbiotic	*Frankia, Rhizobia, Anabaena azollae*
		Associative	*Acetobacter diazotrophicus, Azospirillum spp.*
2.	Phosphorus	Phosphate solubilizing	*Aspergillus awamori, Penicillium spp., Bacillussubtilis, B. polymyxa, Pseudomonas striata*
		Phosphate mobilizing	*Arbuscular mycorrhiza (Sclerocystis spp., Glomus spp., Acaulospora spp. Gigaspora spp.), ectomycorrhiza (Pisolithus spp., Boletus spp., Laccaria spp., Amanita spp.)*
3.	Micronutrients	Potassium solubilizing	*Bacillus edaphicus, and Paenibacillusglucanolyticus, B. mucilaginosus*
		Silicate and zinc solubilizing	*Saccharomyces spp., Bacillus subtilis*
4.	Growth promoting	Plant growth promoting rhizobacteria	*Pseudomonas fluorescens, Bacillus*

4. Plant Growth-Promoting Microorganisms

These are beneficial bacteria that inhabit the soil around plant roots called the rhizosphere. PGPR inoculants, also known as "bioprotectants," promote growth by preventing plant disease, enhancing nutrient uptake termed as Biofertilizers, or releasing phytohormones termed as Biostimulants. Phytohormones or growth regulators that enhance the number of fine roots in crops can be released by some *Bacillus* and *Pseudomonas spp*., which significantly improves the absorptive surface of root system for water and nutrient absorption. Among the phytohormones are Cytokinins, IAA, Gibberellins, and Ethylene production inhibitors are produced by PGPR.

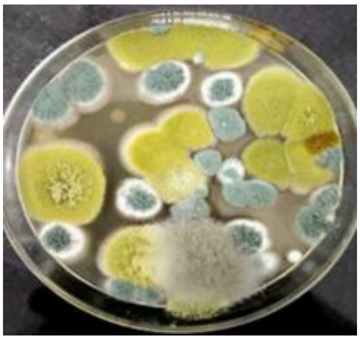

Figure 1: *Aspergillus* colonies

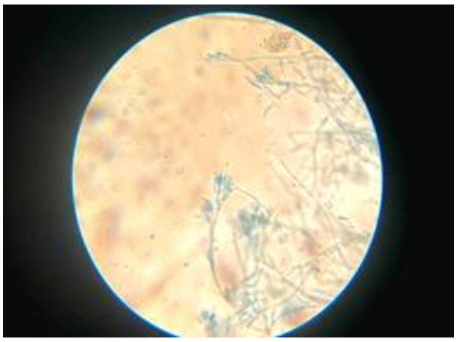

Figure 2: *Penicillium spp.* under microscope

Figure 3: *Acetobacter* biofertilizer

Figure 4: Potassium Mobilizing Biofertiliser

Figure 5: *Pseudomonas* Biofertilizer

Figure 6: Phosphate Solubilizing Bacteria

Methods of Application of Biofertilizers:

(a) Seed Treatment: In this case, 200 g of biofertilizer is dissolved in300-400 ml of water and gently mixed up with 10 kg of seeds using an adhesive such as gum acacia, jaggery solution, and so on. The seeds are then spread out in the shade on a clean sheet/cloth to dry before sowing.

(b) Seedling Root Dip: For transplanted crops, this technique is employedie. Rice. Before being transplanted, the seedling roots are soaked for 8–10 hours in water that has been treated with the suggested biofertilizers.

(c) Soil Treatment: 200 kg of compost are combined with 4 kg of each suggested biofertilizer, and the mixture is left overnight. Before sowing or planting, this mixture is incorporated into the soil.

Advantages of Using Biofertilizers:

- Their use results in soil enrichment, and over time the soil's quality increases.
- Due to the production of growth promoting hormones, biofertilizers increase root proliferation.
- The biofertilizers convert nitrogen in atmosphere and make it available to plants. They enhance the phosphorus content of the soil by solubilizing and releasing inaccessible fixed phosphorous.
- They make a significant contribution to a 10–25% increase in crop output.

Constraints in Biofertilizer Technology:

- Constraints related to technology include the absence of high-quality carrier materials and competent technical staff in production units.
- Farmers have lack of knowledge about the advantages of the technology because there is no immediate difference in the growth of the crops as there is with synthetic fertilizers.
- Constraints on marketing include the lack of retail stores or a producer's market network, as well as the inability to access the appropriate inoculant at the ideal time and location.

CONCLUSION:

Biofertilizers, which are vital aspects of organic farming, contribute significantly to long-term soil fertility and resilience by fixing atmospheric nitrogen and mobilization fixed nutrients in the soil into plant-available forms.Given the expense and negative effects that synthetic fertilizers have on the environment, farmers may find it to be a viable choice to increase production per unit area by using biofertilizers.

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Managing Soil Health For Sustainable Agriculture

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