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SUSTAINABLE MANAGEMENT OF SOIL HEALTH

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PREFACE

A summary of how to improve soil health can be found in the new book "Sustainable Soil Health Management" by ***Dr. Surajyoti Pradhan, Dr. Prem Kumar Bharteey and Dr. Sushmita Thokchom****. This book is a compilation of important articles written by renowned experts in the field of managing soil health and Sustainable Agriculture. Soil is essential for economic and social growth because it provides food, fodder, fiber, and renewable energy to support human, animal, and plant life. However, in our rush to grow more food, soils have been particularly abused to the point where they are now threatening our health and well-being. Because there is no chance of increasing cultivated area further, much of the desired increase in food grain output must be done through increasing productivity per unit area. Soil health, a physical, chemical, and biological process, is currently displaying signs of tiredness as a result of intensive cultivation, over-mining of nutrients by crops, and lower replenishment through organic and inorganic sources of organic nutrients. One of the reasons for stagnant or declining yields is frequently attributed to the ongoing reduction in soil health. Our soils are not only not very fertile, but over time, multi-nutrient deficits are being created in many regions due to improper, unbalanced, and inefficient nutrient utilization. This, along with ineffective field water management, is the main factor contributing to low nutrient and water use efficiency, which raises production costs. Every year, there is a net deficiency of around 10 million tonnes of nutrients added and removed from the soil in Indian agriculture. Soils are currently displaying a lack of secondary nutrients such as sulphur, as well as a lack of/toxicity of certain micronutrients. The ICAR institutes, SAUs, and All India Co-ordinated Research Projects (AICRP) have developed a number of location-specific and environmentally friendly technologies to improve and maintain soil physical, chemical, and biological health and yield sustainability. This can be achieved only by implementing sustainable methods and sustainable solutions in agriculture which have been discussed in the current book in order to protect, maintain, and promote soil health and to achieve the objective of increased productivity and sustainability without causing any harm to the soil system or the environment, suggestions have also been made to review, improve, and reinforce the current programs. We hope that this book imparts basic and innovative knowledge of several soil health and Sustainable agriculture*

- Editors

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CHAPTER 1

SOIL HEALTH AND IT'S CO-RELATIONSHIP WITH SUSTAINABLE AGRICULTURE

Surajyoti Pradhan*[1], Prem Kumar Bharteey[2], Ayush Bahuguna[2], Nidhi Luthra[2] and Sudhir Pal[2]

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Soil health is indeed a crucial concept in agriculture and environmental science. It encompasses the overall well-being and functionality of soil as a living ecosystem. The five vital functions you mentioned are often used to evaluate and describe soil health:

1. **Sustaining plant and animal life**: Soil provides a habitat for a diverse community of organisms, from microorganisms like bacteria and fungi to larger organisms like earthworms and insects. These organisms play essential roles in nutrient cycling, decomposition of organic matter, and soil structure formation, ultimately supporting plant growth and providing a food source for higher trophic levels
2. **Regulating water flow and storage:** Healthy soil can retain and release water effectively. It acts as a sponge, absorbing and holding moisture during wet periods, reducing runoff and erosion. During dry periods, it slowly releases stored water, helping to maintain a stable moisture supply for plants.
3. **Filtering and buffering potential pollutants:** Soil acts as a natural filter, removing and immobilizing contaminants from water that percolates through it. It also serves as a buffer against the leaching of harmful substances, ensuring that pollutants do not reach groundwater or surface water bodies.
4. **Cycling and recycling nutrients:** Soil plays a critical role in nutrient cycling, transforming organic matter into nutrients that are accessible to plants and other organisms. Nutrient cycling ensures that essential elements like nitrogen, phosphorus, and carbon are available for plant growth and microbial activity, promoting ecosystem productivity.
5. **Providing physical stability and support:** Soil structure is essential for plant root anchorage and penetration, as well as for allowing air and water to move through the soil. Healthy soil maintains good physical structure, preventing compaction and promoting aeration, which is crucial for root development and overall plant health.

Principle of Soil health management:

The major principles of soil health management are centred on the following key practices which are ultimately required for maximizing profitability.

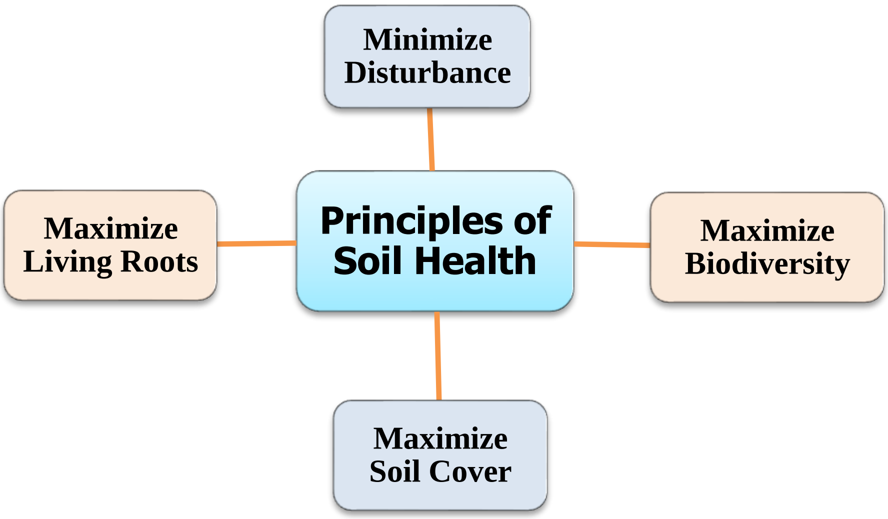


Fig.1 Principles of Soil Health

Soil health assessment:

It is impossible to assess soil health solely by looking at agricultural production, water quality, or any other single result. We analyze indications since it is impossible to directly measure soil health. Indicators are quantifiable characteristics of soil or plants that offer hints about the soil's capacity for function. Physical, chemical, and biological qualities, functions, or traits of soils can be indicators. They could also be physical or aesthetic characteristics of plants. Suitable indicators

Different indicators for soil health:

Organic matter content in the soil: promotes soil fertility, soil structure, soil stability, and resistance to soil erosion. Numerous plant nutrients, including nitrogen, phosphorus, and sulfur, are stored in soil organic matter. The amount of nitrogen, phosphorous, and sulfur present in an acre is approximately 1,000 pounds per percentage point of organic matter in the top 6 inches of soil. The majority of nutrients included in organic materials are not, however, readily absorbed by plants. Nutrients in organic matter must be transformed into inorganic forms by soil organisms through decomposition and mineralization before they can be utilized by plants.

Physical properties: compaction, plough pan, water movement, porosity, and tilth; bulk density, infiltration, soil structure and macropores, soil depth, and water holding capacity => retention and transport of water and nutrients; habitat for soil microbes; estimation of crop yield potential.

Chemical properties: electrical conductivity, reactive carbon, soil nitrate, soil pH, and extractable phosphorus and potassium => biological and chemical activity thresholds; plant and microbial activity thresholds; and nutrient availability and potential N and P loss in plants

Biological properties: Earthworms, microbial biomass C and N, particulate organic matter, possibly mineralizable N, soil enzymes, soil respiration, and total organic carbon are biological factors that result in microbial catalysis and a C and N repository, soil productivity, and the ability to supply N.

Soil assessment using modern tools and models:

Diffuse reflectance spectroscopy (DRS) in the visible to near-infrared (wavelength range: 350-2500 nm) region (VNIR) is emerging as a viable alternative to traditional laboratory methods for evaluating a variety of soil parameters (Van der Meer, 2018). The DRS approach is appealing since it is quick, environmentally benign, and non-invasive, and DRS data may be acquired using both proximal sensors and onboard remote sensing systems. Singh *et al.* (2019) have demonstrated that the DRS-and wet chemistry-based soil testing techniques yield equivalent nutrient recommendations for cocoa growing. This is a crucial conclusion in favour of supplementing the wet chemistry approach with the DRS approach of soil testing, yet studies also indicate that the accuracy of the DRS approach is questionable and needs constant modification. The potential to use remote sensing to deploy these sensors on aircraft and satellite platforms and capture hyperspectral data for quantitative soil surface property mapping is another benefit of VNIR technology (Sahoo, 2022).

Soil health issues in India:

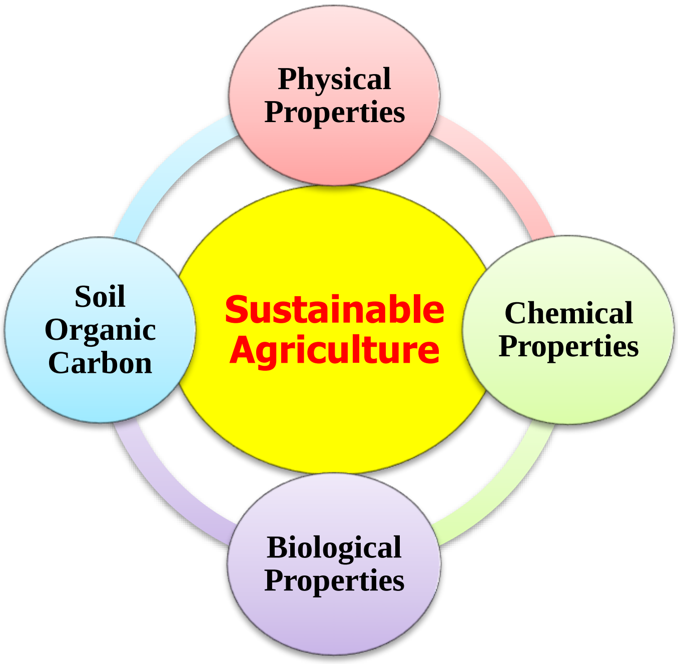
According to the New Delhi-based **National Academy of Agricultural Sciences (NAAS)**, the annual soil loss rate in our country is about 15.35 tonnes per ha, resulting in a loss of 5.37 to 8.4 million tonnes of nutrients.

- **Soil erosion:** It is the removal of soil by natural factors, primarily water and wind, more quickly than its replacement can occur. It has an impact on the nation's overall economy and agricultural productivity.
- **Stream erosion:** It involves the separation and removal of soil components using water. It shows up as rilling, gullying, sheetwashing, and the rain-peeling process. The slope, vegetation cover, and soil characteristics all affect erosion rate.
- **Erosion by wind:** The top soil layer is removed by the wind, and wind erosion is worsened when the soil is dry, poorly aggregated, and vegetated.
- **Human-made causes of soil erosion are** Deforestation, which depletes the soil of its organic matter, Overgrazing weakens the structure of the soil incorrect agricultural practices, including plowing, a lack of crop rotation, and shifting cultivation

  Indian soils often have high potassium levels but low levels of nitrogen and phosphorus.

The Indo-Gangetic plains, Central India, and North East India have low phosphorus levels. Additionally, there is a national shortage of nitrogen; however, it is greater in central and southern India than in the Gangetic plains. Long-term unbalanced fertilizer nutrient use has also been reported to have a negative impact on soil health. According to a 2017 analysis by the Fertilizer Association of India, the optimal n-p-k utilization ratio is 4:1; however, from 6:2.4:1 in 1990 to 6.7:2.7:1 in 2016, this ratio has decreased. According to the 54th report of the Parliamentary Standing Committee on Agriculture (2017–18), the imbalance in the usage of fertilizers is caused by a biased subsidy policy in favor of urea and excessive prices for other fertilisers. Indian soil is becoming less fertile as a result of extractive farming methods such as crop waste clearance and in-field burning (common in north-west India). In India, 55% of the soil has always been nitrogen deficient. Then, 42% are phosphorus-poor, and 44% are organic carbon deficient.

Soil health components for sustainable agriculture:



In the scientific literature, the phrases "soil health" and "soil quality" are frequently used interchangeably, and some people think that they are functionally equivalent. Scientists favor the phrase "soil quality," whereas farmers prefer "soil health" (Karlen *et al.*, 2003). For, the purpose of monitoring soils, (Ritz *et al.* 2009) identified and tested 183 biotic markers. The most prevalent parameters for biological indicators were: (1) soil microbial taxa and terminal restriction fragment length polymorphism; (2) soil microbial community structure and biomass using extracted lipids, particularly phospholipid fatty acids, as signature lipid biomarkers; and (3) soil microbial biomass. (3) Multiple substrate-induced respiration of soil, (4) multi-enzyme profiling of biochemical processes, (5) worms, including maturity index (the distribution of nematodes across functional groups), taxonomic number, and abundance of individual functional groups (6) Microarthropod, (7) on-site visual observation of soil fauna and flora, (8) pitfall traps for ground-dwelling and soil invertebrates, and (9) microbial biomass, the total amount of life belowground. However, they came to the conclusion that more research is needed to ascertain how these biological indicators are responsive to changes in management, how they are connected to soil functions, and how they might be used to shed light on certain ecological processes. Determining the components of soil health is crucial for the effective use of global and national agricultural monitoring systems and therefore for the long-term sustainability of our agricultural systems. According to research, healthy soil inhibits pathogens, supports biological processes, breaks down organic matter, inactivates harmful substances, and recycles nutrients, energy, and water [Sahu *et al.*, 2017]. The definition of soil quality given by Karlen *et al.* [2003] was "the capacity of specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation." Additionally, Bouma *et al.* (2017) gave a broader definition of soil quality as "the intrinsic capacity of a soil to contribute to ecosystem services, including biomass production." Regarding specific ecosystem services, the idea of soil quality provides useful applications [Toth, 2008]. "Soil quality," refers to the biological qualities and functions of soil that interact closely with its chemical and physical aspects. As was already mentioned, "soil quality" and "soil health" are used interchangeably in the literature. In terms of timeline, they can be distinguished; "soil health" refers to the state of the soil over a short period of time, while "soil quality" refers to the state of the soil over a longer period of time, very similar to the state of a person at a certain time (health) and over a long period of time (quality of life) [Acton *et al.,* 1995]. In order to test soil status and track the impact of past, present, and future land usage on agricultural sustainability, the phrases "soil health" and "soil quality" were utilized. Soil salinization, acidification, compaction, crusting, nutrient shortage, decrease in soil biota biodiversity and biomass, water imbalance, and disruption of the elemental cycle are unsuitable agricultural practices that degrade soil quality [Lal, 2015]. In a nutshell, preserving and restoring soil health enables producers to work in synchronous with the land – not against which will not only pave the way to reduce erosion, maximize water infiltration, enhance nutrient cycling, and save money on inputs but also ultimately improve the resiliency of their farm.

Government initiatives for soil health management:

The Government of India has also launched several programmes for the welfare of farmers like distribution of Soil Health Cards, the selling of neem oil-coated urea, a nutrient-based subsidy policy for P and K fertilizers, organic farming, Paramparagat Krishi Vikas Yojna, National Mission on Sustainable Agriculture, National Action Plan for Climate Change (NAPCC), National Water Mission, National Mission for a Green India under NAPCC, Mission for Integrated Development of Horticulture, and National Mission on Oilseeds & Oil Palm etc.

Conclusion:

The practice of intensive agriculture, which is used to supply the food needs of an ever-growing population, has a severe impact on the health of the soil. Plant productivity and soil health are both supported by a balanced microbiome. The interaction between soil-dwelling microorganisms and plants is intricate. In this discourse, which is mediated by root exudates, there is still a lot more translating needed. In order to enhance the nutrient status of the soil and agricultural productivity, biofertilizers are an economical and environmentally friendly component of the plant and soil. To summarize, different practices which may include efficient utilization of soil macro and micro-organisms as well as bioengineered micro-organisms, Climate-smart diversified cropping system, Use of Integrated nutrient management in initial years and slowly moving towards harnessing the full potential of Organic manure along with compost, application of biochar as well as adopting IFS and integrating nano technology into all of these can unquestionably achieve sustainable soil health management. It can be achieved through conservation and restoration of soil organic matter, sequestering more carbon, enhancing water infiltration, and improving wildlife and pollinator habitat as a result, all while reaping more revenues and, in some cases, higher yields in a sustainable way

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CHAPTER 2

ROLE OF MICRO-ORGANISM FOR IMPROVING SOIL HEALTH

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Introduction:

Soil is the three-dimensional body that supports the life system on earth. It helps in maintaining ecosystem balance which plays a crucial role in peaceful coexistence. Besides these, soil is formed by the chemical and biological weathering of underlying rocks. Generally, the soil is a reservoir that supplies a greater part of the world's biodiversity reserve, subjugated by microorganisms, *viz.* bacteria, fungi, actinomycetes, and algae. Besides these organisms, soil biota contains a large variety of animals like nematodes, protozoans, macro and micro-arthropods and earthworms. Moreover, a large population of macro fauna species are inhabiting in the uppermost layers of soil*i.e.*, the soil surface and the litter layer (Beck *et al.*, 2005). Even soil biota is involved in the cycling of nutrient residues, organic matter and energy. Thus, soil organisms are an integral part of soil including plants, animals, microorganisms and their interactions. They are responsible for supporting ecological balance in ecosystems, plant metabolism and their nutrient uptake, crop yield and productivity, water cycling and soil formation process, thereby regulating soil erosion and water purification (Mendes *et al.*, 2016). The growing population demands higher food production which is mainly met through the use of chemical inputs viz. fertilizers, insecticides, pesticides, growth hormones, etc. which have served as mandatory needs. Haphazard application of such chemicals can cause detrimental effects on crop as well as soil health. There was a need to consider soil health status while incorporating such synthetic sources otherwise we might face indiscriminate problems and hurdles in the future. In order to mend these discrepancies, we should think of a holistic approach so that amelioration of soil health status can meet the current soil health. So, the production of better crop yield, quality products and expression of better crops need compatible relations between soil fertility and microorganisms. Therefore, the protection of soil microorganism population in their niche in association with soil health is of utmost important in this pretext. Soil health is defined as the ability of soil to function within the environment and network, to withstand biological productivity according to Doran *et al.*, 1994, maximize environmental quality, and endorse plant and animal health. The dynamics of microorganisms uphold ecosystem balance in agriculture. These microorganisms exist in rhizospheres which constitute a complex group of saprophytes, endophytes and actinomycetes both beneficial and harmful ones.

Re-evaluating the physical and practical assortment of soil microorganisms

Microorganisms play a significant role in assisting all floras in their environments. Soils act as residence to thousands of diverse species of bacteria and soil itself can be viewed as a living organism. It was found that one cubic foot of soil contains over 10,000 species of bacteria, 100 species of protozoa, 10,000 nematodes, 100 species of algae and over 5000 individual insects. Overall soils contain valuable bacteria, fungi, algae, protozoa, nematodes, cyanobacteria as well as earthworms. So, living organisms are a vital component in maintaining soil physical, chemical and biological equilibrium thereby sustaining their health status. Besides affecting soil structure and fertility, plants and soil microorganisms attain their nutrients from soil and in turn change soil properties by organic litter deposition and metabolic activities of microorganisms. They affect plant growth directly through the management of hormone signaling, speeding up the decomposition of organic matter, regulating deliverance of nutrients in the form of nitrogen, phosphorous, potassium, hydrogen and carbon in soil and protection against pathogens.

Importance of microorganism

Soil microorganisms play chief roles as chemical engineers, through the cycling of carbon and decomposition of organic matter; impelling soil pH by nitrification and denitrification; anthropogenic complexes' degradation, fixation of nitrogen and phosphorus solubilization making it available for plants; and influencing mobility of heavy metals. Soil microorganisms have a direct impact on human health since they form the basis for those antibiotics administered to control diseases (Mendes *et al.,* 2016). Not all forms of elements added into the soil are directly taken up by the plants. Initially, they are converted into inorganic form by the microorganisms through mineralization which can be easily taken up by the plants for their metabolisms. The nitrogen need by the plants is available in the form of organic nitrogen which is first converted into amino acid and then to ammonia which then thereby undergoes a nitrification process through different nitrifying bacteria viz. *Nitrosomonas* and *Nitrobacter* through different biochemical processes. Thus, a healthy population of soil microbes can enhance the efficiency of fertilizer for plant uptake. It also affects the structure and fertility of different soils thereby responsible for maintaining soil quality and health. It also helps in increasing soil aeration and penetrability.

Carbons promote the populations of soil microbes. One of the carbon sources is humus (Humic acid) which plays many roles in the soil profile. Besides its role in helping plants uptake most of the difficult elements namely primarily metals through the natural chelation process, humus also helps in maintaining moisture on sandy soils. A good level of humus in the soil will help to retain soil moisture as well as improve the soil structure (drainage/pore space). Apart from these, the soil microorganism has diseases controlling mechanism against several pests and diseases.

Types of soil organisms

Soil organisms are classified into two types – macro-organisms and micro-organisms. Macro-organisms are those which can be seen with our naked eye while micro-organisms are those which are not visible but can be observed under microscope

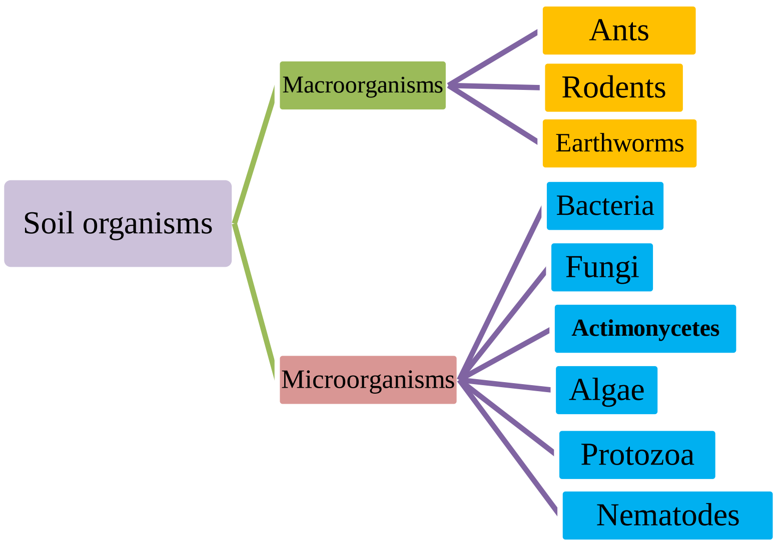

Fig. 1: Diagrammatic representation for classification of microorganisms in soil

A relative study has shown that proportion/percentage of various soils micro-organism can be briefly summarized as: aerobic bacteria (70%) and anaerobic bacteria (13%), actinomycetes (13%), fungi (3%) while algae, protozoa and viruses constitute0.2-0.8%. However, the main role of soil organisms is in nutrient transformation. It was recorded that one gram of topsoil may comprise-of one billion bacteria which then can reach up to 100 million actinomycetes, one million fungi and 100 nematodes.

Soil micro-organisms

Soil microorganisms are classified into different types viz. bacteria, fungi, actinomycetes, algae, protozoa, nematodes, etc.

A. Bacteria

Bacteria are the smallest freely living prokaryotes and single-celled organisms. Typically, the size of bacterial cells ranges from 0.5 to 1.0 μm in diameter. The majority of bacterial species exist as single forms but some occur as filaments of loosely joint cells. Because of their small size and general similarity of structure, the classification of bacteria usually depends on physiologic and biochemical characters rather than the morphogenetic ones. They may be rod-like *bacilli*, spherical *cocci* and *spiral* forms. Bacteria are microscopic single-celled organisms. They are the most abundant microbes in the soil. Soil bacteria are involved in numerous biogeochemical cycles and play a distinctive role in crop production. Soil rhizosphere contains distinguishing types of bacteria that interact with plants and increase soil fertility and health. Free- living bacteria beneficial also known as PGPR promotes plant growth (Hayat *et al.*, 2010) which has been reported in sugarcane crops (Kushwaha*et al.*, 2020). So, plant growth promotion (PGPR) mechanisms by bacterial endophytes are quite comparable to the activity of rhizospheric bacteria. Since most of the PGPR bacteria were sequestered from stems, roots and soils. Those PGPR bacteria belong to the genera of *Enterobacter, Pseudomonas, Kleibsiella, Azospirillum, Rhizobium, Rahnella, Delflia, Caulobacter, Xanthomonas, Achromobacter, Agrobacterium, Burkholderia, Gluconacetobacyer*, etc (Ghevariya and Desai, 2014).

Even there are weak bacterial species that can be wiped off by slight alternation in the soil setting. In retorting to variations in temperatures and soil moisture, bacterial populations can shatter in just a few days. On the contrary, some of the bacteria can withstand a wide range of variability such as severe heat, cold, or drying. Moreover, there are some bacterial species that are plant-specific dependent.

Bacterial classification

Bacteria species can be categorized into four groups as follows:

1. Decomposers:

Decomposers are those bacteria present in the soil that eat dead and decaying plant residues, organic matter and waste which then release nutrients that are needed by living organisms. They are the essential component for various life forms in the early stages of most of the nutrient cycles whether nitrogen, carbon, or sulphur cycles. Even some of the decomposers can break down pesticides and hazardous pollutants present in the soil and the surrounding environment. These decomposers play a special role in immobilizing nutrients in their cells, thus inhibiting nutrient loss from the root zone such as nitrogen.

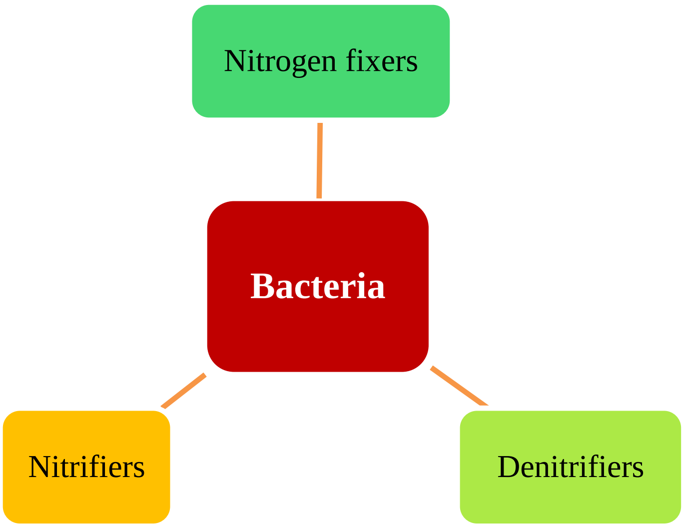

Fig. 2: Classification of different mutualist bacteria

1. **Nitrogen fixer bacteria:** These microorganisms convert nitrogen gas from the atmosphere and convert it into a form that can be used by plants for their metabolic activities. Visibleroot nodules are created when bacteria infect a growing root hair. Through this association, the plant supplies carbon to the bacteria for their cycles, and the bacteria which in turn convert nitrogen gas (N_2) from the atmosphere into a usable form for plant uptakes.
2. These nitrogen-fixing organisms are of different types. They include – Free-living nitrogen-fixing organisms, associative symbiotic organisms and Symbiotic fixation microorganisms. The free-living nitrogen-fixing microorganisms are again subdivided into Aerobic bacteria which include *Azotobacterchroccum* fixed commonly in crops like

wheat, rice, cotton and sugarcane while anaerobic bacteria include *Clostridium*. The associative symbiontbacteriainclude*Azospirillum* which are associated with roots of grasses inside roots symbiosis. It is used for sorghum and pearl millet. The symbiotic fixation microorganisms include nodule-forming bacteria viz. *Rhizobium* is an aerobic and heterotrophic bacteria that symbiotically fixed atmospheric nitrogen with the presence of leghaemoglobin in nodules of legume roots. When leaves or roots from the host plant decompose, soil nitrogen increases in the surrounding area.

3. ***Nitrifyingbacteria*:** This is the microbial conversion of ammonium (NH_4^+) to nitrite (NO_2^-) then to nitrate (NO_3^-) mediated by microbes known as nitrifiers which is a preferred form of nitrogen for grasses and most row crops. At first, ammonium undergoes microbial oxidation by *Nitrosomonas* and is converted into nitrite (NO_2-) which is then converted into nitrate (NO_3^-) by *Nitrobacter*. Nitrifying bacteria required an optimum temperature of 30 to 35˚C with an optimum pH of 6.5 to 7.5. However, nitrate can be leached easily from the soil, so some farmers prefer to use nitrification inhibitors instead of conventional fertilizers to reduce the activity of one type of nitrifying bacteria. Nitrifying bacteria are suppressed in forest soils so that most of the nitrogen remains as ammonium.
4. ***Denitrifying bacteria:*** Denitrifying bacteria are anaerobic micro-organisms that are active when oxygen is absent, such as in saturated soils. These are the micro-organisms that help in the formation of N_2 or elemental nitrogen or loss of gaseous nitrogen form of nitrogen by biological reduction of NO_3^- and NO_2^-. They convert nitrate to nitrogen (N_2) or nitrous oxide (N_2O) gas. Denitrifying bacteria include *Pseudomonas* and *Bacillus*.

Role of bacteria in soil:

Bacteria play a crucial role in the agricultural perspective as most of the soil needs an optimum population of soil bacteria to maintain and perform most of the plant's morphological functions. It also regulates soil equilibrium for crop growth as they contribute to the carbon cycle through fixation and decomposition, mineralization of nitrogen through various microbial bacteria, denitrification of the nitrogen under saturated conditions. Many types of beneficial bacteria are important for agricultural prospects, e.g., *Rhizobium, Azospirillum, Azotobacter, Pseudomonas, Bacillus* and *Clostridium*.

Biochemical process of bacteria

Some of the brief biochemical mechanism upheld by bacteria includes-

a) Nitrogen fixers (*Nitrobacter*sp.)

b) Degradation of sulphur (sulphur degradation and hydrocarbon degradation) by *Thiobacillusferroxodans, DesulphovibrioandDesulphomaculatum*

c) Used for remediation (*Pseudomonas sp.*)

B. Fungi

The fungi constitute a large and diverse group of plant kingdoms. They are eukaryotic, plantlike, spore-bearing organisms that lack chlorophyll and other photosynthetic pigments. Consequently, they depend on the other organisms for their nutrition. They have a network of branched filament structures called hyphae and the tangled mass of hyphae is the mycelium. The fungi secreted enzymes that act on starch, cellulose, pectin, lignin, sugars, etc. The enzyme includes amylase, cellulose, pectinase, ligninase, invertase, maltase, etc. Fungi also have a cell wall composed of chitin and glucans.

Fungi in soils

Fungi are well-established soil residents, because of their wide flexibility and adaptability to various environments in response to hostile conditions (Singh *et al.*, 2023). Due to Their different ability to exudate extracellular enzymes results in aggravating different types of organic matter, components of soil decomposers and thereby amending carbon and nutrients balance (Žifˇcáková *et al.*, 2016). The dead and decayed organic matter is converted into biomass, carbon dioxide, and organic acids by fungi. In addition to this, numerous fungi species have the capability to bio-sorbstoxic metals viz. zinc, mercury, copper, and cadmium (Frac *et al.*, 2018) that might affect their reproduction and inhibit their growth (Baldrian, 2003). The activity and fungi miscellany is measured by various plants and other living organisms(biotic), soil pH, structure, moisture, salinity and temperature (abiotic factors) (Rouphael *et al.*, 2015).

Fungi can be established in almost every environment and can survive in a wide range of pH and soil temperature. Soil fungi can be categorized into three efficient groups as follows:

(1) biological controllers

(2) ecosystem regulators and

(3) species participating in organic matter decomposition and compound transformations (Gardi and Jeffery, 2009).

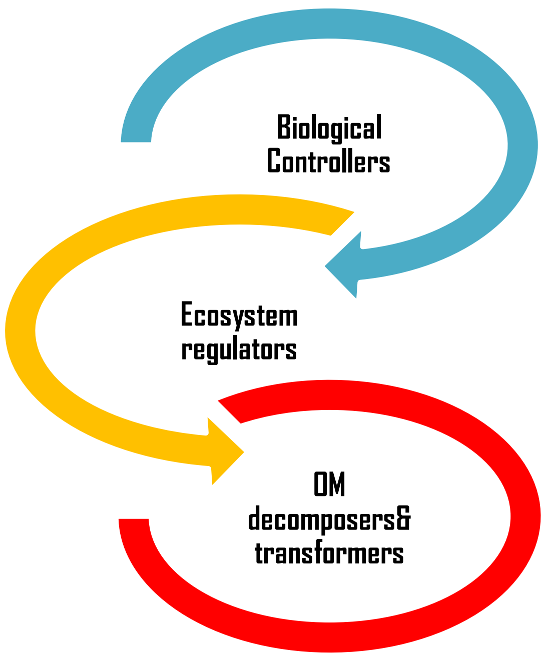

Fig. 3: Diagrammatic representation of fungal classification in soil

Among the different fungi classes, biological controllers are those that can regulate pest, diseases, and the growth of disease incidence in other living organisms (Bagyaraj and Ashwin, 2017). In support of the above criteria, it was found that mycorrhizal fungi mend plant growth and development by enhancing nutrient uptakes and fortification against pathogens (Bagyaraj and Ashwin, 2017). The ecosystem regulators are accountable for the formation of soil structure and modification of other organism habitats thereby amending the physiological dynamics in the soil environment

Role of fungi in soil

- Fungi also contribute to the fixation of nitrogen, production of bio control agents against root pathogens, hormone production and drought protection (El-Komy *et al.*, 2015). They also play an important role in the decomposition of residues and stabilization of soil organic matter (Treseder and Lennon, 2015) and release of nutrients from soil minerals. Saprotrophic fungi also play a precarious role in the carbon cycle.
- They also help trap nematodes that are harmful to plants through the production of plant hormones which may be harmful to nematodes.
- Since fungi dominate the soil biomass production, they also help in root water and nutrient uptake through *Mycorrhizae* - which live in or on plant roots.
- Fungi also produce hormones and antibiotics that help plant growth and prevent diseases which benefit them by taking in the nutrients from the roots they live in.
- Saprotrophic fungi are also involved in the global carbon cycle. *Arbuscular Mycorrhiza* (AM) and Ecto Mycorrhizal (EM) fungi form symbioses with the prevalent host plants. Even lichens show symbiotic associations between a fungus and green algae which are bipartite symbiosis, and even with cyanobacteria of tripartite symbiosis.

Biodiversity of fungus population in soils and its impact on soil health status for agricultural and horticultural crops

Fungi play an important role in plant defense against pathogenic microorganisms. It also acts as a biological agent, which influences soil health. It also contributes in decomposition of organic matter and provides nutrients for plant growth (Frac *et al.*, 2015). The assessment of fungal biodiversity involves determination of biodiversity indexes and structure analysis of fungal population. It helps in determination of the functions aspects fungi play in affecting soil quality and plant health as quality indicators. Application of dissimilar types of organic manure has a significant impact on soil health, through direct and indirect effects (i.e. via physicochemical alternation) on soil fungal communities present in soil. Some of the agronomic and cultural practices, such as the use of cover and rotational crops, mulching, strip cropping, composts and tillage practices are expected to affect the other groups of soil fungi, exclusively beneficial micro-fungal populations (Abawi and Widmer, 2000).

It has been observed that reduced tillage operation might decrease the breakdown of hyphae creating stable fungal populations, recollecting more nutrients and providing more rigid effects against pathogenic microorganisms (Gross and deVarennes,2002). It should be considered that fungal diversity determines ecosystem variability, plant biodiversity and crop productivity (Wagg *et al.,* 2014). Among the different fungal populations, arbuscular mycorrhizal fungi also known as (AMF) are the most important beneficial microorganisms in agricultural and horticultural aspects (Smith and Read, 2008).

The significant effects of arbuscular mycorrhizal fungi (AMF) symbiosis include: stimulation of nutrient cycles, improvement of plant rooting and their establishment, enhancement of soil structure, augmented uptake of less mobileions, boost plant tolerance to stresses, and enrichment of plant diversity (Azcón-Aguilar and Barea, 1997). In the case of disease control systems, most of the diseases of crop plants can be controlled by some antagonistic fungi such as *Glomus* sp. or *Trichoderma* sp. suppressing fungal pathogens (Dawidziuk *et al.,* 2016). Species of Trichoderma *viz. Trichoderma asperellum, Trichoderma atroviride, Trichoderma harzianum, Trichoderma virens,* and *Trichoderma viride* are frequently used a biocontrol agents and are known as horticultural bio stimulants (López-Bucio *et al.*, 2015). Even De Connick *et al.*, 2015 reported synergistic impact of *Arbuscular Micorrhizal Fungi* (AMFs) and *Plant Growth Promoting Rhizobium* (PGPRs) on growth of horticultural plant and microbial diversity of soil.

C. Actinomycetes

Actinomycetes are microorganisms that belong to order Actinomycetes which are gram-positive and aerobic. They are known for their substrate and floating mycelium production. They belong to bacterial kingdom but share some features with fungi such as shape and branching properties, reproductive spore formation and production of metabolites. Actinomycetes form filaments which are thread-like in the soil. They exhibit a distinctive scent from freshly exposed moist soil that results from metabolic release of the nutrients. They also fix nitrogen in the soils which are then made available near vicinity of host and other plants through formation of associations with non-leguminous plants. Actinomycetes show optimal growth in alkaline pH.

Actinomycetes are known for decomposing the more resistant organic substances, such as polysaccharides, cellulose, fats, organic acid and protein. They are vibrant in breaking down different sources of humic acids in soils to form stable humus which then improve soil structure and upsurge soilwater retention capacity. Actinomycetes are those micro-organisms that exhibit freshly moist soil and its distinguishing “earthy” odour.

Role of Actinomycetes in soil

The rhizosphere of crop plants and enhances soil fertility and their health through solubilizing phosphate and salvaging organic matter. They form associations with non-leguminous plants and fix nitrogen, which is then available in close vicinity of the host and other plants.

D. Algae

Algae are defined as a large collection of photosynthetic, eukaryotic organisms. They are of varied groups of simple, usually autotrophic organisms. Algae can make their own nutrient through a process known as photosynthesis which converts light energy to chemical energy that can be stored as nutrients. For algae to grow, they must be exposed to light because photosynthesis requires light, so algae are typically distributed evenly wherever sunlight and moderate moisture is available. Reproduction in algae occurs in both asexual and sexual forms. Asexual reproduction occurs by spore formation. Algae do not need direct exposure to sunlight but can live below the soil surface under uniform temperature and moisture conditions. Algae are also capable of performing nitrogen fixation.

Types of algae

Algae can be divided into three groups as follows: the Cyanophyceae, the Chlorophyceae and the Bacillariaceae (Masbau and Ayindi, 2021). The Cyanophyceae also known as blue-green algae are chlorophyll-containing algae that absorb sunlight and uses that energy to synthesize carbohydrates from carbon dioxide and water. The Chlorophyceae usually have green colour pigment also known as chlorophyll and the Bacillariaceae contain chlorophyll and other pigments such as algal brown colour pigment. Cyanophyceae (Blue-green algae) are responsible for nitrogen fixation that depends on environmental and physiological factors. They include sunlight intensity, inorganic and organic nitrogen concentration, favorable temperature and soil stability.

Role of algae in soil

Algae also play a significant role in the soil. They are considered bio-fertilizers. They also help maintain the fertility of soil in tropical regions. Besides its role in controlling soil erosion, algae aid to recover the water potential in soils.

E. Protozoa

Protozoa are single-celled, eukaryotic microorganisms. They are grander than bacteria which differ from a few microns to millimetres and reproduce sexually with a unique evolutionary step from reduplication of spores. Protozoa can be classified into three categories viz. flagellates, amoebae and ciliates (Masbau and Ayindi, 2021).

a. Flagellates

Flagellates are non-chlorophyll-containing protozoa that are not capable of performing photosynthesis due to a lack of chlorophyll. They occur mostly in the soil. However, the chlorophyll-containing flagellates normally occur in aquatic environments. The chlorophyll-containing protozoa can be illustrated by their flagella, which are their locomotor organs (Stuart and Chapin, 2002). Some of the protozoa species bear numerous flagella, while the others only have a similitude of appendage.

b. Amoebae

Amoebae are protozoan classes that are bigger than flagellates with different locomotors mechanisms. They possess pseudopodia or 'false foot' which is a distinguishing feature of amoeba from the rest of the protozoan species. The pseudopodia are more of a slime-like dependability than a flagellum (Stuart and Chapin, 2002). It helps in the movement of food. However, amoeba bears temporary appendages.

c. Ciliates

Ciliates are the largest protozoa group which locomote through cilia, a short and numerous structures. They produce whipping reactions and resemble small and short hairs. Cilia can move in different directions, enhancing its mobility more than flagellates or amoebae (Stuart and Chapin, 2002).

Role of protozoa in soil

It is quite evident that the role of protozoan in regulating soil health is not that significant. However, more or less the yard sustains soil microbial equilibrium by feeding on bacteria. They grow profusely in surface soil. They are also found to employ in controlling diseases against various pathogenic species as biological control agents. Protozoa population in arable soil ranges from 10,000 to 100,000 per gram of soil.

F. Nematodes

Nematodes are tiny filiform roundworms also known as roundworms. They are phyto-parasites and reside at the surface of the living roots. These free-living nematodes feed on bacteria and fungi thereby control harmful microbial populations. They are bilaterally symmetrical and elongate with tapering ends. Nematodes range in size from microscopic to 7 meters. The average nematodes vary in size range of 0.15-5 mm long and 2-100 mm except mermithidae nematodes (20 cm) long commonly found in tropical soils (Musbau and Ayinde, 2021). The population of nematode species is about 20,000. Nematodes can only move through a film of soil moisture that surrounds the soil particles. Nematodes act as hydrobiont that fills spaces between soil particles and roots covers. They enter a dormant stage in hot and dry conditions. When the monsoons proceed, they return back to activity.

Nematodes are documented as key microbial feeder in soils. They are mostly assembled into four to five trophic classes based on their food habit, oesophagus and stomata structure and nutritional mechanism (Kiflu and Beyene, 2013): as bacterial feeders, fungal feeders, predatory feeders, omnivores, and plant feeders. The bacterial feeder's feed on bacteria *i.e.*, bacterivores which can invest up to 5000 cells/minute or 6.5 times their own weight daily. These activities help both the organic matter and the decomposers to disperse in the soil. Fungal and bacterial-feeding nematodes release a substantial amount of nitrogen while feeding on their prey and are accountable for most of the plant available nitrogen in the soils (Grayston *et al.,* 2004). The overall annual nematodes consumption may reach up to 800 kg of bacteria per hectare while the nitrogen turned over may be as high as 20-130 kg (Kiflu and Beyene, 2013). However, phytophagous nematodes impair plant roots which might affect economic returns in the future. They also possess a wide range of sizes and structure of styles. In fact, phytophagous nematodes are the most extensively studied group of soil nematodes. However, they hamper crop yield due to their pathogenic effect.

Role of nematode in soil

The most important role of nematodes is to enrich soil quality in four key aspects viz. regulation of soil microbial populations, mineralization of nutrients into inorganic forms, deliver of proper nutrient sources for various soil organisms and antagonistic effect on pathogenic organisms. They are dynamic nutrient-mineralizing microbes in soil. When nematodes ingest bacteria or fungi, they release a superfluous amount of ammonium ion (NH_4^+) while the harmless nematodes consume decaying plants, soil microbes and other nematodes and release nutrients from the bodies of their prey.

Evidence of role plays by microbial metabolites on soil aggregation

The most salient strategy projected for sustaining soil fertility is targeted through the the enhancement of soil's physical properties. So, soil aggregate stability is precarious for numerous soil functions: plant growth mechanisms, resistance to soil erosion, turnover of soil organic matter, abundance, activity and diversity of microorganisms, both mesofauna and microflora (Chotte, 2005). Soil microorganisms play a very significant role in the soil aggregate formation and stabilization processes through the production of microbial metabolites that hasten soil aggregation.

1. Polysaccharides

The polysaccharides show an active role in soil aggregate formation. They secrete bacterial metabolites and root exudates. These metabolites enable polysaccharides to adsorb on clay particles and to bind them together. Even polysaccharides strongly influenced the soil water retention capacity of clay (Chenu, 1993). However, the strength of retention depends on the types of polysaccharides and the properties of clay particles. The modifications of macro-molecular structures of clay particles are more significant in kaolinites than smectites which might be due to clay adsorption of metabolites. Puget *et al.* (1999) showed that plant carbohydrates are predominant in the largest aggregates of Typic Hapludalf soil. He also found that stable aggregates >50 highest microbial carbohydrate concentrations which might be due to the microbial production of the polysaccharides thereby resulting in decomposition of plant residues confined in the soil aggregates.

2. Glomalin

Glomalin is an insoluble organic compound secreted by the fungal hyphae. It was observed that *Arbuscular Mycorrhizal* (AM) fungi characterization has exhibited the occurrence of an enormous quantity of organic compounds (Wright and Upadhyaya, 1996). It plays a significant role in soil stabilization. Glomalin is a glycoprotein with N-linked oligosaccharides and strongly bound iron which is hydrophobic and insoluble (Wright *et al.,* 1996). The presence of glomalinon the hyphae and soil aggregates were detected using a monoclonal antibody produced from *Glomusintraradices* (Wright, 2000) which showed that glomalin is spotted on the mycorrhizal hyphae and the soil aggregates surface that help in stabilization of soil structures.

Conclusion:

The contributions of microorganisms to soil health are tremendous. The beneficial soil micro-organisms like bacteria, fungi, *actinomycete*s, algae, nematode and protozoa produce plant growth regulators and metabolites that affect their growth and development. Moreover, the microorganisms play a crucial role in maintaining an association between microbial densities and certain soil chemical characteristics in soil nutrient build up. Different microorganisms contribute to plant growth by providing essential elements and minerals. Soil microbes decomposed organic matter and recycled soil nutrients. They offer nutrients to crops, and enhance soil health and crop outputs. Overall, soil microbes play a substantial role in the lenience of plant diseases. Even long and persistent use of fertilizers can cause environmental damage. In order to maintain an optimum soil microbial population, a long-term strategy must come up along with research priority augmenting plant-soil microbe nutritional interactions as an indispensable need for sustainable agricultural systems.

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CHAPTER 3

IMPACT OF MACRO-ORGANISMS ON SUSTAINABLE SOIL HEALTH

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Introduction:

The soil is a complex system of inorganic and organic matter. The unconsolidated organic or mineral material on the earth's surface which serves as a medium for the natural growth of plants is known as soil (USDA). But there are many variations in defining of soil as it is dictated by its type of use like agriculture, engineering, or environment, how it is perceived to provide food, services, habitat, etc. It can be said that soil is a complex and dynamic system that exists at the intersection of atmosphere, hydrosphere, lithosphere, biosphere which is critical to food production. To a farmer, soil is a medium for food production, whereas a geologist will define it as a natural medium and unconsolidated material above bedrock. An engineer may define soil as a naturally occurring surface formed by complex weathering processes of biochemical and physical nature that consists of living matter whereas soil is considered capable of supporting human, animal and plant life by agronomists and pedologists (Brevik, 2005).

Later on, the concept of soil health emerged, due to an immense increase in soil degradation which led to the requirement of identification of methods to maintain soil fertility along with sustainability. The soil's capacity to function as an important living ecological system that sustains plants, animals and humans may be defined as soil health. According to the Natural Resource Service USDA, healthy soil gives us bountiful crops and forests, serene air and water, grazing lands, diverse wildlife, and breathtaking landscapes. These are achieved by performing five essential functions *viz.*, water regulation, plant and animal life sustenance, buffering pollutants and contaminant filtration, carbon, nitrogen and phosphorus cycling, etc. It also provides physical stability and support. In the 1990s, the term soil health comes from the context of soil quality which is the ability of soil to function for agriculture and its immediate environmental context (Doran and Parkin, 1994).

The interactions of soil organisms and plants are also considered an important part of soil health. These organisms inhabiting in soil play an important role in keeping the soil healthy and serve as a major component of soil sustainability. Some of these organisms are a friend while others are a foe to soil health. They are mainly grouped into two categories i.e., micro fauna or microorganisms and macro fauna or macroorganisms. The advantageous groups of micro and macro fauna play an important role in nutrient transfer, disease prevention, turnover of organic matter, improvement of soil structure, etc which in turn regulates soil health. Main microorganisms include bacteria, fungi and protozoa. Macro organisms comprise oligochaeta (earthworms), nematodes, spiders, crabs and mollusks. The beneficial roles of microorganisms are already clear in the fact that they convert nutrients into usable forms for plants, on top of that they also serve as a food source for most of the macroorganisms in the soil. None the less, macroorganisms also play a very important role in establishing soil health which has a direct impact on human health (Pepper, 2013). The invertebrates living in the soil are known to improve soil structure by increasing the pore space, decreasing bulk density, and integrating soil horizons. They also increase drainage of soil water and soil aeration aeration, improve water holding capacity, promote litter decomposition and improve the structure of soil aggregate (Abbott, 1989). Several studies on sustainable agriculture have also stated that soil macro-organisms can be used as an integrative measure of soil health as they help regulate soil components vital for the soil formation process and protect against soil degradation. The effects of some soil macro- organisms on soil health are discussed below.

Earthworms

Earthworms thrive in temperate climate area having mineral soils as well as in humid tropics with high organic matter soils (Curry and Good, 1992). Kladiviko (1997) described three types of earthworms: dwellers of shallow soil, litter-dwellers, and burrowers of deep soil. The litter-dwelling species like *Dendrobaenaoctaedra,* reside in the litter layer of forests. The shallow-dwelling species, such as *Lumbricusrubellus,* lives mainly in the upper soil part (12 inches). Earthworms having no permanently built burrows travel throughout the topsoil. The deep-burrowing worms are the night crawlers, for example, *Lumbricusterrestris*permanently burrows and can reach five to six feet deep inside the soil. Earthworms play a huge role in the maintenance of soil fertility and soil health which in turn enhances plant productivity. Their burrowing nature is mainly responsible for increased aeration in soil, water infiltration and root penetration.

Earthworms burrow through the soil and ingest plant materials and soil. Their excreta known as castings or cast are a mixture of partially digested plants and soil. This cast is the most beneficial part as it contains macro and micronutrients readily available which can be easily absorbed by the plants (Lake and Supak, 1996). Also, Edwards and Bater (1992) found that inoculation of earthworms in degraded soils increases the yields of plants. Some authors like Barois& Lavelle (1986) and Trigo *et al.* (1993) have also suggested a mutualistic relationship between soil microflora and earthworms in the exploitation of soil organic matter. Natural conditions in the anterior part of the earthworm gut like neutral pH, higher water content (100-150% of the dry weight of soil) and high content of readily assailable organic matter as intestinal mucus offer optimum conditions for the activities of soil-free microorganisms. A mixture of low molecular weight amino acids, glycoprotein and sugars are the main components of this mucus (Martin *et al.,* 1987).

Studies conducted by Gilot in 1990 revealed that in the middle part of the earthworm gut, microorganisms feed on the mucus and their metabolic activity increases sharply, which in turn gives them the ability to digest soil organic matter at a much higher rate than in bulk soil.

Another study conducted by Zhang *et al.* 1992 revealed that in the gut content of earthworm (*Pontoscolexcorethrurus*), the cellulase and mannanase found were produced by the ingested microflora as they were not found in isolated gut tissue cultures. Therefore, it may suggest that there may be mutualistic relationship between earthworms and the ingested microflora. Earthworms can also help in controlling plant pathogen present in soil to some extent. In avocado orchard soils, studies conducted by Van Zwieten*et al.* (2004) found that surface-feeding earthworm species horizontally and vertically disseminate microorganisms, pollen, seed and spores and can reduce plant pathogens by digesting the fungal spores.

Termites

Termites are considered a menace in many agricultural and non-agricultural lands but they are an important soil macroorganism group that helps in maintaining soil texture, increasing water infiltration and soil porosity **(**Curry and Good, 1992). They belong to the order Isoptera and are endogenic exopterygotous insect. Three nutritional categories include wood-feeding species, plant- and humus-feeding species, and fungus growers. They are found in tropical to sub-tropical climates with arid to semi-arid soils. Their most important role in maintaining soil health is the decomposition of litter on the ground. They build mounds of soil above the ground surface burrowing into the soil forming long tunnels known as galleries and in this process, they move soil and litter. They also consume a large amount of animal dung and litter which is significantly important to plant and soil health as dung has slow rate of decomposition. They also help in ecosystem productivity as the digested termite waste contains nutrients that are readily available for the plants (Whitford *et al.* 1995). Several taxa of mites also take the role of predators. Berg *et al.* (2004) stated that orders Mesostigmata and Prostigmata are voracious predators with agility having a broad feeding range on many organisms such as collembolans, leaf-miners, thrips, small flies, enchytraeids, and insect larvae and eggs. Under field conditions, predacious termites can reduce the density of eggs and larvae of *Diabrotica spp*., a pest of maize (Brust, 1990).

Ants

They belong to the order isoptera and are mainly decomposer organisms acting as ecosystem engineers which improve nutrient cycling and soil structure. Among the planet's animal biomass, ants are one of the dominant groups' accountings for almost 10% (Keller and Gordon, 2006). They are diverse and numerous with most wide distribution from the Arctic to tropical ecosystems. Ants build galleries while building their nests which helps increase soil porosity and aeration which in turn reduces the risk of potential soil erosion. They also provide agro-ecosystem services like soil bioturbation, regulation of crop pests, bioindication and plant pollination. The increased soil porosity is essential for key rhizosphere processes like gaseous diffusion, nutrient uptake and water uptake in the root-soil interface. Among different species of ants, the leaf-cutter ants modify soil fertility by affecting the soil structure, density and porosity while building their nests. Again they also add nutrient-rich organic waste through the collection and concentration of vegetative material inside their nest to maintain fungus growth, their main food source. These in turn have a positive effect on plants inhabiting their nest area.

Beetles

Beetles which belong to the order Coleoptera have extreme morphological, behavioral and ecological diversity. They live in humus and have a high diversity of feeding habits. They also decompose roots and logs, dung, leaf litter and rotting organic matter. They also feed on the fruiting bodies of many types of fungi, significantly contributing to decomposition process in soil (Ruiz *et al.*, 2008), which in turn helps in increasing soil fertility and maintaining soil health. The Beetle species of family Staphylinidae are largely predacious and have a big role as biological regulators of crop pests (Vignozzi *et al.*, 2019). On the other hand, many species of Carabidae and Staphylinidae are also taken as reliable indicators to assess soil health, especially as markers of environmental changes in orchard agro-systems. Carabid beetles can also be used as indicators of habitat alteration and degradation (Hedde *et al.*, 2015).

The main important roles of soil macro-organisms in maintaining soil health may be broadly stated as:

1. Regulation of the flow of nutrients through decomposition, immobilization and mineralization
2. Facilitates nutrient acquisition by plants
3. Maintenance of plant health by pathogenicity and parasitism
4. Modification of soil structure and mixing of organic matter in the soil profile
5. Improve water availability and aeration in soil
6. Stimulates microbial activity through direct supply of nutrients through their excreta

Soil macro-organisms as indicators of soil health

We have observed a tremendous increase in the rate of soil degradation which has given birth to the requirement for a holistic approach in maintaining soil health. Among many approaches, the use of soil macrofauna in terms of their abundance, biodiversity and functions can be a promising indicator of soil health. As soil macro-organisms are greatly affected by changes in chemical, physical and biological components of soil, a healthy, diversified and well-developed community of soil macroorganisms indicates a good quality soil. These indications are in turn useful in monitoring changes in soil health and provide early diagnostic practices or management. Moreover, farmers can easily observe and monitor these bioindicators i.e., soil microorganisms without any sophisticated technology. Therefore, they can be easily used for examining soil health and sustainability provided the correct techniques are used. Many macroorganisms are involved in soil processes such as decomposition, organic matter translocation, soil structure formation, nutrient cycling and water regulation. With rapid response to habitat fragmentation, forest cutting, fertilization and grazing, Coleopteran insects can be widely used as indicators (Rainio and Niemelä, 2003). Ground beetles predate on agricultural pests in grasslands and cereal fields, while those management practices that favor one spider species adversely affect another species hence diversity is decreased (Rushton *et al.*, 1989). Many alterations in the environment like post-fire recovery and pollution can also be indicated by (Fattorini, 2010). In Australia, ants have also been used as bioindicators of soil health (Andersen and Majer, 2004). Their abundance and microbial activity in the soil were correlated at mine sites which was undergoing land reclamation (Andersen and Sparling, 1997). They can also be potentially used as pollution, forest health and rangeland health bioindicators. In habitats with degraded soils having a concentration of nutrients and humidity changed by anthropogenic disturbances, it was evident that ant communities in that area differ from the ones in undisturbed habitats (Schmidt, 2008). By promoting the breakdown of dead organic matter and helping in nutrient cycling, larval stages of dipteran insects play an important role in the ecosystem and their population is highly dynamic and sensitive to environment changes (Hövemeyer, 2000). Indicator species of grasshoppers and locusts can be used as a shortcut in the identification of degrading communities and Jana *et al.,* 2006 revealed through their study that some species of orthopteran insects are susceptible mostly to industrial pollution while some are completely absent in industrial areas and thus can be used as a bioindicator group. Those that are absent include all three species of the Tettigoniidae family *viz*., *Euconocephalusincertus*, *Holochlora indica* and *Letana inflata*. Occasionally, spiders have been used as bioindicators. Pearce and Venier (2006) noted that spider assemblage provides evidence that natural disturbance like wildfire differs from anthropogenic disturbance like harvesting and silvicultural activities and can therefore be useful to determine the sustainability of forest management practices. Spider populations can also be affected by exposure to high concentration of heavy metals in the soil and habitat fragmentation mainly due to human disturbance (Maelfait and Hendrickx, 1998). They are also involved in biological magnification of a variety of soil contaminants, especially heavy metals. Another indication of habitat fragmentation due to intensive agriculture and urbanization can be seen through the loss or extinction of local populations of spiders. Diplopoda is a common group mostly present in woodlands, agricultural lands and grasslands. They are detrivores, can indicate vegetation structures and are associated with more stable environments, with a significant relationship between soil nutrient quality and microbial activity, helping to mineralize nutrients and making them available to plants (Lavelle, 1997). In many agroecosystems, terrestrial isopods also play an important role in the decomposition and mineralization of organic matter. They have also been used as bioindicators for biodiversity and soil quality for both environment protection and improvement of agricultural production.

Possible threats to soil macroorganisms

Soil fauna is imperative for sustaining soil health. But as agriculture starts inclining towards an intensive spectrum, some major threats to the survival and diversity of soil macroorganisms also emerge. Among these threats, climate change is also one of them. There are records of a high population spectrum of macroorganisms in sustainable organic farming as compared to high-input farming (Stromberger *et al.,* 2005). Desaeger*et al.,* 2004 also recorded deterioration in their population in high-input crop fields. Increasing temperatures due to climate change may lead to a more rapid breakdown of organic matter which may adversely impact the soil heterotrophic organisms. Most of the soil macro-organisms occurring in surface horizons may be most affected by this change in the environment. High input agriculture distresses the process of soil turnover and mineralization of nutrients and also disturbs the demographical and topographical properties. The use of chemicals like pesticides and insecticides also degrades the soil micro, meso and macroorganisms which lead to alteration in trophic structure and degradation of soil health.

Therefore, a search for low-input farming practices which improve soil health and decrease deterioration in ecosystem and soil microorganisms is necessary. Organic agriculture methods are believed to be more environmentally sound with higher carbon storage, less nutrient leaching, less soil erosion and lower soil and water pollution (Mäder*et al.*, 2002). In agricultural landscapes, organic farming is reported to improve diversity of carabid beetles (Pfinner and Niggli, 1996). Another study showed that in both organic farming and conservation farming systems, nematodes and macrofauna were more abundant in their biomass of soil organisms groups than that of microorganisms. This evidently suggests that conservation and organic agriculture can be practiced in order to ameliorate degraded macroorganism diversity, especially in agricultural lands which in turn conserves soil health.

Conclusion:

Nowadays, the main global interest lies in increasing the agricultural production with emphasis on sustainability. This requires conservation of the soil quality including soil health. Wagg *et al.* (2014) mentioned that loss in soil biodiversity and simplification of soil community composition leads to reduced plant diversity, plant decomposition, nutrient retention and nutrient recycling. This incurs that the preservation and maintenance of group of macroorganisms in soil community is a very important part of soil health. Their abundance and species diversity can be widely used to provide overall assessment of soil health as they are indicators of carbon and nutrient cycling in soil which will in turn help in persistence and sustainability of the ecosystem including agricultural systems. Because of their positive effects and contribution to agricultural ecosystem, developing and maintaining their diversity through sustainable agricultural practices is also recommended.

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CHAPTER 4

THE FUNCTIONAL AND ENVIRONMENTAL BENEFITS OF BIOENGINEERED MICROORGANISMS

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Introduction:

Soil is an important component for maintaining ecosystem balance on the earth. It made by biological and chemical weathering of underlying rocks and non-renewable resource. The term "soil health" refers to a soil's potential to retain a balanced ecosystem with great biodiversity both below and above the surface as well as its ecological functionality and equilibrium. Soil health were defined by Zeiss and Doran as “the capacity of a soil to function as a vital living system within ecosystem and land use boundaries to sustain plant and animal production, maintain or enhance water &air quality, and improve plant & animal health.

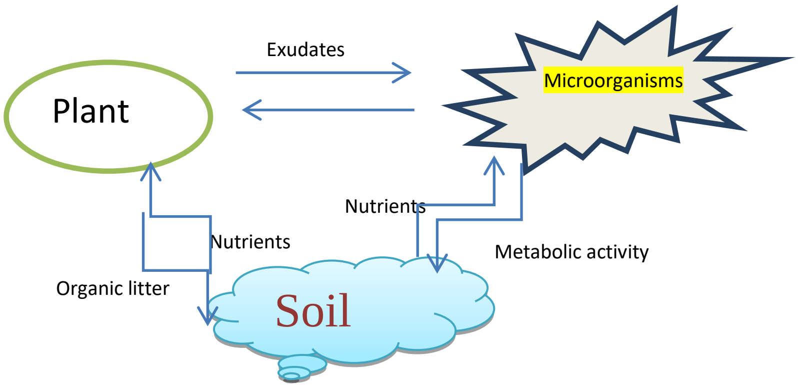

Fig. 1: Interactions between soil, microorganism and plants

The growing human population and the intensive use of majority of the cultivated land arethreatening of the soil quality. In soil ecosystem, there are interactions between plants, microorganisms, and micro-fauna that are present in the form of mutualistic, symbiotic, or suppressive. These interactions are a crucial phenomenon controls both the soil health as well as plant health (Nielsen *et al.*, 2002). As the beneficial microbes are engaged in numerous soil processes, they can be improving soil health. Many tasks carried out by soil organisms that are advantageous to plants might increase the soil's fertility. There are three main interacting components determine soil fertility: biological, physical, and chemical fertility. These are -

A. Biological fertility

The presence of microbes and organisms they areinteract with two other fertility components physical and chemicalin soil. Based on that interaction and fertility components thebiological fertility can be good or bad. These larger organisms within the soil (think worms), and on other organisms survive on soil particles of organic matter. In the soil, microorganisms influence many vital processes.

B. Physical fertility

Physical soil fertility is an indicator of characteristics of soil such as bulk density, texture, aggregate stability, and porosity. These characteristics related to hydrological processes like aeration, infiltration rate, erosion, runoff, and water holding capacity (Kumari *et al.*, 2016). These include the following:

1. Soil texture: The proportion of clay, silt, and sand particles determines the soil texture
2. Soil structure: Soil structure determined by how aggregates of soil particles (sand, silt, and clay) plus voids and other spaces arrangement
3. Water holding capacity &absorption: Water holding capacity &absorption component consists of four elements, one of which is a stopped gravitational flow (capillary action), and three of which are related to water movement (infiltration, permeability, and percolation)
4. Root penetration: The roots ability to spread out and travel around through the soil

C. Chemical fertility

Chemical conditions like acidity, alkalinity, and salinity in soil as well as nutrient levels referred as chemical fertility. Components are:

1. Macronutrients: Carbon, Oxygen, Nitrogen, Hydrogen, Phosphorous, Calcium, Magnesium, Potassium andSulphur
2. Micronutrients: Iron, Zinc, Boron, Manganese, Molybdenum, Copper, Chlorine andNickel
3. Toxic Heavy Metals: Aluminum, Chromium, Arsenic, Cadmium, Mercury and Lead
4. Nitrogen fixers: Nitrogen gas are extracted from the atmosphere by microorganism and transformed into forms that plants can utilize
5. Nitrifying: In forest soils, the nitrifying bacteria suppressed, that reason the majority of the nitrogen left in the form of ammonium, which changes to nitrite and then nitrate. Nitrate easily leached from the soil that is the reason farmers are usedinhibitors ofnitrification to reduce the activity of nitrifying bacteria
6. Denitrifying: Denitrifies are anaerobic, they convert nitrate to nitrogen or nitrous oxide gas

Soil microorganisms:

When microbes decompose organic matter, they use the nutrients and carbon for their own growth from organic matter and they release extra nutrients in the soil that may be absorbed by plants. Crop seeds coated with bacterial cultures (*Bacillus megaterium* or *Azotobacter chroococcum*) to boost growth and yield (Jacoby *et al.*, 2017). Typically, three theories are proposed to describe how microbial activity can boost plant growth: (1) Increase bioavailability of soilborne nutrients. (2) Repelling or outcompeting pathogenic microbial strains (3) the plant hormonal signalling manipulation.

In contrast, when organic matter added to soil with a carbon to nitrogen ratio greater than 22:1, microorganisms typically take up mineral nitrogen from the soil. If the organic matter is deficient in nutrients, microorganisms will suck nutrients from the soil to fulfil their requirements (Hoyle *et al.,* 2011). The term "beneficial microbes" or "disease suppressive soil microbes" refers to soil microbes that are helpful for plant growth and development by enhancing soil quality and soil health as well as supplying minerals and essential nutrients from soils that are typically unavailable to plants, such as *Pseudomonas, Bacillus, Trichoderma, Rhizobium, etc.* A teaspoon of fertile soil usually contains 100 million to 1 billion bacteria. Each acre may contain a tonne of microscopic microbes that are active. The biosphere is built on microbes, which make up 60% of all biomass and number astaggering 5 x 1031 cells, each weighing 50 quadrillion metric tonnes. Bacteria have also produced half the oxygen on the planet (Rao, 2007).

The soil microorganisms are involved in most of the essential nutrient cycles like:

Carbon cycle:

The main producers of organic carbon compounds, which provide nutrients for other organisms, are photosynthetic plants and microbes. These organisms utilize organic carbon and degrade organic matter through fermentation and respiration. Chemoorganotrophic microbes produce carbon dioxide by decomposing organic carbon compounds. In the dark, chemo-lithotrophic bacteria can transform inorganic carbon into organic matter.

Nitrogen cycle:

Nitrogen assimilation is a process in which inorganic nitrogen substances like nitrates, nitrites, and ammonia are transformed into biological nitrogen substances like proteins and nucleic acids. Theconversionof nitrites (NO_2^-) to nitrates (NO_3^-), further reducing the nitrites to ammoniais possible due to nitrate bacteria (*Nitrobacter spp.*). The nitrite bacteria (*Nitrosomonas spp.*) transform the ammonia into nitrites (NO_2^-). The biological oxidation of ammonia is carried out by nitrifying bacteria. A pH level above 7 or alkaline soil conditions are preferred by nitrifying bacteria. In plants, nitrogen can be found in the forms of nitrate and ammonia. The plant cell uses nitrogen to make amino acids. The nitrate must be converted into ammonia, which is the reason majority of plants favour ammonia.

Phosphorus cycle:

The health of the soil's microbial population and the growth of plants and animals both depend on phosphorus, which is gradually lost from the soil over time. The process by which phosphorus travels through the lithosphere, hydrosphere, and biosphere are known as phosphorus cycle. In the biological process of creating the nucleotides that make up DNA and RNA molecules, phosphorus is an essential component.

Sulphur cycle:

Desulfovibrio bacteria reduce SO_4 anaerobically to H_2S in the sulphur cycle, and *thiobacilli*turn H_2S into SO_4 through oxidation. The oceans, atmosphere, soil, and living things all participate in the sulphur cycle. The eight electron oxidation/reduction processes that make up the sulphur cycle go from the most reduced H_2S (-2) to the most oxidised SO_4^{2-} (+6).

However, soil microorganisms can be classified:

A) On the basis of microbial function:

(i) Decomposers:

(a) Microbial putrefaction (harmful fermentation): e. g. *Clostridium sp.*

(b) Microbial fermentation: e. g. *Saccharomyces sp.*

(ii) Synthetic microbes: e. g. *Azotobacter.*

B) On the basis of microbial activity:

(i) Disease-inducing soil:

The disease causing soils, which indicates that 5-20% of the total soil microflora is made up of pathogenic microbes. In this kind of soil, adding fresh organic matter causes the release of partially oxidised products that are essentialfor easily attacked by pathogens or insects and it dangerous for plants.

(ii) Disease suppressive soils:

Such soils are habitate for antagonistic microbes like *Actinomycetes*, *Trichoderma*, *Penicillium*, etc. that produce an adequate quantity of antibiotics that inhibits soil-borne pathogens like *Pythium*, *Fusarium,* etc. from growing. Based on their primary effects, beneficial rhizospheric microorganisms can be divided into two groups:

(a). Biocontrol agents: By preventing the spread of plant pathogens, they indirectly help to increase plant productivity. e. g. *Pseudomonas spp*., *Trichoderma spp.*

(b). Plant Growth Promoting Microorganisms (PGPM): They have a direct impact on promoting plant growth and development. e. g. *Glomus* and *Rhizobium spp*.

Importance of disease suppressive soil in plant health:

Disease suppression in soil is a complex mechanism:

1) When pasteurised (at 60°C wet heat for 30 minutes), some suppressive soils lose their suppressiveness.
2) Suppressiveness is transferable.
3) In some soils, several years of monoculture can induce disease suppression.

(iii) Zymogenic soils:

Zymogenic soils are those in which a process similar to fermentation or zymosis takes place (complex substances breakdown into simpler ones).

(iv) Synthetic soils:

These soils contain nitrogen and carbon fixers that enable them to break down complex organic materials into carbohydrates, amino acids, and proteins.

Soil Microorganisms and Their Types: Microflora (actinomycetes, fungus, bacteria, etc.) make up between 75 and 90 percent of the soil's living biomass and the primary decomposers of organic matter. Most of the time, these species are not working in isolation; instead, they engage in interactions with all other groups, which have an equal or higher influence on soil fertility than the particular activities of the organisms. Each set of soil microbes has distinctive traits that characterise the organisms and serve various purposes in the soil they inhabit. These are the fallowing organisms:

A. Fungi:

The microscopic cells that make up soil fungi can be single-celled (like yeast) or multicellular, and they can form hyphae (long, threadlike structures), which are referred to as a mycelium. They may have a symbiotic relationship with plant roots, which support the plant by providing required nutrients, and the plant may supply carbohydrates to the fungi for their survival. Fungi are typically beneficial to soil-dwelling organisms, but they can be occasionally harmful. On the plus side, fungi can form an advantageous association known as mycorrhizal with plant roots. However, fungus can also feed by attaching themselves to plants or other living things as parasites for destructive purposes.

B. Algae:

Most soils with access to moisture and sunlight also contain algae. Per gram of soil, they can be found in concentrations of 100 to 10,000. They have the capacity to generate their own food through a process known as photosynthesis, in which they absorb carbon dioxide from the environment and solar energy.

C. Bacteria:

The majority of soil microbes are single-celled, microscopic organisms called bacteria. The majority of bacteria are decomposers that consume organic waste and dead plant matter, releasing nutrients that can consumed by other organisms and a crucial element in the early phases of the nitrogen cycle. Decomposers play a crucial role in keeping nutrients immobilised in their cells and stopping nutrientsloss, like nitrogen. In some decomposers, pesticides and other contaminants in soil can be broken down.

D. Protozoa:

These organisms are single-celled, colourless, and animal-like. They are larger than bacteria, with sizes ranging between a few microns to a few millimetres. In surface soil, they are numerous and can found in concentrations of 10,000 to 100,000 per gram of fertile soil. Additionally, protozoa are more resilient to soil disturbances like ploughing than other bacteria.

E. Viruses:

The capacity of soil viruses to genes transfer from one host to other host and their potential role in microbial mortality make them of great significance for their potential to affect the ecology of soil biological communities. As a result, viruses play a significant role in global cycles by affecting the concentration and turnover of nutrients and gases. All viruses are parasitic, eating other plants and animals for food.

F. Nematodes:

Nematode worms are usually one millimetre long and 50 microns in diameter. Numerous levels of the soil on the food web which support by an incredible variety of nematodes. Nematodes are biological markers for determining the quality of soil because they support biodiversity and participate in the process of recycling nutrients (French *et al.*, 2020).

G. Lithotrophs:

Non-carbon-consuming microbes use the compounds of nitrogen, iron, sulphur, or hydrogen to obtain energy. Some species are crucial for the degradation of contaminants and the cycling of nitrogen. These microbes increase sulphur availability to plants in well-aerated soil, while decreasing its availability in soils with low oxygen levels.

H. Actinomycetes:

Humates and humic acids must broken-down by actinomycetes in order for the soil to increase water retention, enhance soil structure, and produce stable humus. The Actinomycetes are fifth functional group that usually grouped with bacteria. The more resistant organic compounds including protein fats, polysaccharides, cellulose, and organic acids, decompose or deteriorate.

Effect of absence of microorganism on soil health:

Everyone is aware of direct and indirect causes of soil damage in the absence of microorganisms, including a long list of natural causes like wind, water, and rainfall erosion as well as acidification, alkalinization, salinization, and oil spills, among many others (Hashim *et al.,* 1997; Fernandez *et al.,* 2007; Maximillian *et al.,* 2019). Due to the increasing demand for food, it is now necessary to use chemical inputs (such as fertilisers and herbicides) in agriculture (Saha *et al.,* 2016). Its depletion would lead to the generation of barren non-productive lands.

Characteristics of healthy soil:

A healthy soil should possess the following characteristics:

- Free of chemicals and toxins.
- Good soil tilth and structure
- Good water storage and good drainage
- High organic matter
- High soil biological activity
- Large population of beneficial organisms
- Resilience when unfavorable conditions occur
- Resistance to compaction
- Resistance to erosion
- Small population of weed, plant pathogens, and insect pests
- Sufficient supply of nutrients

Benefits / Role of microorganisms in soil health improvement:

1. Better quality, production and crop health.
2. Detoxifying hazardous heavy metals.
3. Sufficient nutrient Availability.
4. Sustainable productivity,
5. Maximize environmental quality, and animal health.
6. Improving soil structure
7. Controlling pathogens
8. Controlling and Degrading pesticides
9. Hydrocarbon degradation
10. Fixing atmospheric nitrogen
11. Root Colonization

12. Increasing phosphorus solubility
13. Siderophore production
14. Antibiotic production
15. Phyto-hormones production

1. Betterquality, production and crop health:

Main importance of soil microorganisms in improving soil fertility, Arbuscular mycorrhizae and plant growth-promoting microbes are both used to increase plant growth & development and crop yield. The advantageous microbial impacts of microbes are improving the production of sustainable crops. By direct and /or indirect ways, a number of diverse mechanisms, including plant growth regulators, the production of various metabolites, the conversion of atmospheric nitrogen into ammonia, etc., it enhances plant development on various physiological parameters (Kumar & Verma, 2019). They offer better soil nutrient availability, improved agricultural production & enhancement of crop nutrient, tolerance to biotic (insects and diseases) & abiotic stresses, and water uptake. Therefore, rhizobacteria that promote plant growth give a cost-effective and environment friendly method of raising crop production (Kumar & Verma, 2019). The bioengineered microbes used in the production of healthy and fertile soil. In an efficient way to soil health restoration will be provide by combinatorial initiatives that combine GMOs, plant growth-promoting rhizobacteria, and other soil amendments. This will result of bioengineered microbes in faster and greater effects of treatment for soil and soil health restoration (Rebello *et al.,* 2021). Rhizospheric microbial diversity of soil supported to health and productivity of soil. The biodiversity and health of an ecosystem that supports the existence of plants, animals, and people are directly influence by soil health (Maqsood *et al.*, 2023).

2. Detoxifying hazardous heavy metals:

The heavy metals from the polluted environment are eliminating through bioaccumulation and biosorption by soil microorganisms. Heavy metals are sorption and entrapped on the outer lipid membrane, and occasionally even on the exo-polysaccharide secretions of the live or dead heavy metal sequester, during the process of heavy metal biosorption (Diep *et al.,* 2003).

In order to remove heavy metals from the environment, genetically engineered microbes use as a different strategies, including the expression of different metal-binding proteins like ferritin, metallothionenin, polyphosphates, and phytoalexins that act as storage proteins for metals in the microbial cytoplasm (Diep *et al.,* 2003; Rebello *et al.*, 2021). Ferritins from the worm *Dendrorhynchus zhejiangensis* are useful for metal detoxification because they help store and transfer heavy metals (Li *et al.,* 2012).

3. Sufficient nutrient availability:

In addition to removing accumulated toxic chemicals, supplying nutrients to the soil can also improve soil health by allowing microbes to play a dual function in fertility-contributing nutrients to the soil and removing or neutralising the effects of toxic xenobiotics (Docherty & Gutknecht, 2019). P, K, Zn, Se, and Fe are made more available to plants by plant growth-promoting bacteria in the soil through biochemical processes such mineralization, chelation, solubilization, and oxidation and reduction reactions (Rouphael and Colla, 2020). The microbial inoculants (often employed as bioenhancersorbiofertilizers) comprising *Bacillus*, *Pseudomonas, Aspergillus*, *Azotobacter, Trichoderma, Rhizobia,* and *Glomus* species of single species or several strains.

4. Sustainable productivity:

The plant growth promoting microorganisms (PGPMs) are particular bacterial and fungal species group that stimulate plant growth and enhance soil productivity. They are an integral part of the agro-ecosystem (Santos *et al.*, 2019). Plant tolerance to biotic and abiotic stressors, biocontrol of pests and diseases, and improved water uptake are all responsibilities of PGPMs. They are also responsible for soil nutrient enrichment and crop nutritional improvement. Numerous direct mechanisms (phytostimulants, biofertilizers, rhizo mediators, or stress regulators) and indirect mechanisms primarily take the form of biocontrol of phytopathogens through nutrient competition, antibiosis, enzymatic lysis, volatile organic compound secretion, triggering of antioxidant defence mechanisms, and inducing systemic resistance (ISR) response in the host plant (Koskey *et al.*, 2021). To achieve sustainable plant growth, the use of rhizosphere bacteria to enhance soil fertility rather than chemical fertilizers has been promoted.

5. Maximize environmental quality, and animal health:

Improved understanding of microbe-based symbiosis in plants may be the key to creating sustainable farming practises that guarantee the provision of food for humans and animals with little danger to the environment. It is necessary to develop environmentally friendly pest and disease management solutions because the usage of synthetic chemical pesticides is considerably more detrimental for both humans and animals (such as teratogenic and carcinogenic effects) and the environment. It is possible to employ the bacteria to remove contaminants from uranium, copper, silver, and iron mines. Through multi-step processes involving both aerobic and anaerobic metabolism, certain bacteria help remove molecules containing carbon, nitrogen, and phosphorus, while others remove compounds including aromatic compounds, hazardous metals, pesticides, herbicides, and xenobiotics. Phosphates have been eliminating by the bacterium *Accumulibacterphosphatis*. Dodecanol, a degradatory intermediate produced by sodium dodeyl sulphate (SDS) degradation, can be biotransformed into rhamnolipids as a defence against SDS stress and destruction by the bioremediating bacterium. Rhizobacteria-mediated pollutant removal and soil health improvement offer a cost-efficient, secure, and environmentally friendly way to deal with hazardous substances in the soil (Rebello *et al.*, 2021).

6. Improving soil structure:

Structure of the soil can improve by biological activity. Some bacteria and fungi produce substances during the decomposition of organic materials that chemically and physically bind soil particles into micro-aggregates. Additionally, soil bacteria improve aggregation and porosity by tunnelling through and eating dirt. In order to create and sustain aggregates, fungus can cross-link soil particles with their hyphal filaments. In just one gramme of soil, fungus hyphae can spread over several miles. It has been proven that using native cyanobacterial strains as a bio-fertilizer significantly improves the physical, chemical, and biological characteristics of soil, leading to an increase in yield, especially in soils that are saline, dry, and contaminated (with heavy metals, Ni, Pb, Cr, and Cd).

Way of improving soil health:

- Using compost fertilizer.
- Reduced the use of more toxic pesticide.
- Use bio-fertilizer for crop production.
- Reduce the use of more concentrated chemical fertilizers.
- Proper water management
- Reduce erosion because soil organisms are mostly found in the topmost, most readily eroded layers.
- Keep or increase the amount of organic matter in the soil, as this is a vital source of nutrients, energy, and carbon for soil organisms.
- Employ diverse rotations because they produce a diverse organic matter inputs and a diverse soil microbial populations.
- Nitrogen fixing bacteria create unique relationships with legumes, choose nitrogen fixing bacteria that are compatible with the host plant and can withstand your soil's properties (such as pH).
- When choosing where to apply fertilizer, consider the release of nutrients from organic matter into soil.
- Utilize fertilizer inputs that support arbuscular mycorrhizal fungi's functions since they only help plants absorb more phosphorus from phosphorus-deficient soils.
- Choose crop rotation strategies and soil management techniques that reduce the soil's compatibility for plant diseases.
- Be patient as soil biological processes take time to develop.
- If soil is polluted, then use bio-remediation and phyto-remediation techniques for improving soil health.
- Utilization of genetically engineered organisms for improving soil health.

Bioengineering of microorganisms for soil health improvement:

Genetically modified microorganisms could be used in place of indigenous microbes ones because they have anextra time adapting to a new environment and degrading contaminants effectively. The majority of pollutants which are resistant to degradation by indigenous microbes can be effectively remedied by these engineered microorganisms. The indigenous microbe's ability to digest these contaminants is limited, and the process will take. As a result of their changed metabolic pathways, genetically modified organisms (GMOs) can catalyse the degradation process by causing the over-secretion of a variety of biomolecules that support the bioremediation process time (Maqsood *et al.,* 2023). GMOs can be created using a variety of molecular techniquesincluding biolistic electroporation, conjugation, transformation; horizontal transfer of bacterial DNA, protoplast transformation and molecular cloning. The transfer and synthesis of novel genes with high degrading capacity shorten the time required for cleanup.

Engineered microbes were able to eliminate a variety of pollutants, including toluene, octane, naphthalene, salicylate, and xylene, by expressing the genes found in the bacterial plasmid.

Engineering microbes by advanced gene-editing tools such as CRISPR/Cas 9 provides a cheap and easy method for xenobiotic remediation and plant growth promotion to restore soil health. The bottleneck to soil health restoration using genetically engineered microbes is the lower expression levels of proteins than confer properties of relevance such as toxic xenobiotic remediation, higher resistance and accumulation of heavy metals, and faster degradation of a diverse range of pesticides (Rebello *et al.*, 2021).

The researchers recommend the following four strategies:

a) Manipulating the specificity and affinity of the enzyme;
b) Construction of gene and regulatory pathway modifications;
c) Bioremediation process development, control, and supervision; and
d) Employing sensor-based bioaffinity reporters to sense pollutants, reduce toxicity, and predict the end points.

Advantages and challenges associated with bioengineering microbes:

Advantages:

- It is possible for contaminants to degrade more quickly.
- It is possible to create multifunctional microorganisms that can break down a range of xenobiotics.
- It is possible to screen and remove pollutants from soil using genetically altered organisms.
- The application is simple in-situ and ex-situ treatment.
- Different degradatory enzymes' expression levels can be controlled through induction.
- By boosting microbial resistance to xenobiotics, it is possible to prevent the stress and harm that high xenobiotic concentrations cause to native bacteria.
- One vector can link additional characteristics that could enhance xenobiotic breakdown and soil fertility.
- Engineering microorganisms can link the biosorption and bioaccumulation of heavy metals.

Challenges:

- Releases of GMOs raise environmental safety issues.
- GMOs must contend with an unstable environment compared to lab microcosms, which might sometimes limit their utility.
- The capacity for xenobiotic degradation of indigenous microbes could be significantly impacted by horizontal gene transfer between them.
- Recombinant plasmid stability might be compromised.
- Antibiotic resistance plasmids are employed in recombinant synthesis, which raises certain concerns.
- Before actual field implementation, a number of restrictions and legal difficulties must be resolved.

- Mutations may reduce the effectiveness of GMOs.
- Concerns about their interactions with other creatures and long-term impacts.

Solution to Genetic Engineering:

- Use chromosomal integration techniques instead of plasmids.
- Use mini transposons.
- Use response surface methodology techniques in media formulation and growth optimization.
- Utility advanced gene regulatory tools.
- Suicide genes may contribute to the controlled release of these GEMs since they become active in the absence of contaminants and cause the GEMs to die.

Conclusion:

The soil health is a major concern because it threatened by increasing human population that responsible for maintaining ecosystem balance on the earth. As they react fast to changes in the soil eco-system, microorganisms (fungi, bacteria, algae, protozoa, viruses, nematodes, etc.) seem to be effective indicators of soil health. The Interactions within the plants, microbes or microfauna, are present in the form of mutualistic, symbiotic or suppressive. The beneficial microbial effects are enhancing sustainable crop production. The soil microorganisms are involved in most of the essential nutrient cycles like nitrogen, sulphur, carbon, phosphorous *etc.* The soil microbes can be achieved disease control and better crop health through various activities like, siderophore production, antibiotic production, hydrolytic enzyme (chitinase, lipase, etc.) production, hydrocyanic acid (HCN) production, nitrogen assimilation, systemic acquired resistance and induced systemic resistance. The soil microorganisms have certain particular genes for eliminating heavy metals from polluted environments through biosorption and bioaccumulation. It is possible to use the bacteria to remove contaminants from uranium, copper, silver, and iron mines. There are many indigenous strains from oil-contaminated areas that can break down these hydrocarbons (Maqsood *et al.,* 2023). The likelihood of creating a GMO suited for the degradation of pesticides increases due to the large number of genes revealed with a high ability to degrade pesticides. A number of soil bacteria produce plant hormones such gibberellins, cytokinins, auxins, ethylene, and abscisic acid. A number of bacterial genera have been identified to produce the auxins indole-3-ethanol or indole-3-acetic acid (IAA). Rhizobacteria produce antibiotics, which helps in the prevention of disease. It has been demonstrated that using indigenous cyanobacteria strains as a bio-fertilizer considerably improves the physical, chemical, and biological properties of the soil, increasing yield. Arbuscular mycorrhizae and plant growth-promoting microorganisms both used to increase plant growth and crop yield.

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CHAPTER 5

INM: A KEY FOR SOIL HEALTH AND SUSTAINABLE AGRICULTURE

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Introduction:

In order to support soil fertility, health, and production, integrated nutrient supply, usage, or managing systems (INM) incorporate all of the major components of plant nutrient resources, including chemical fertilizers in addition to animal manure, organic matter, green manures, legumes with cropping systems, bio-Fertilizer residues from crops, or recyclable waste, as well as other locally accessible nutrient resources. It has been shown that using chemical-based fertilizers and organic matter together to provide and use plant nutrients results in higher crop yields than applying each one separately.This increase in crop productivity is the result of their complementary effects, which help to advance the chemical, physical, and biological soil constituents and, as a result, improve the soil's organic matter as well as nutrient status; to greatly expand well-adjust supply of nutrients with crops of cropping systems; and, if any, to have no or very little poisonous effects on the environment.The main goal of integrated nutrient delivery and controlling is to create a crop with a neutral nutrient supply that retains and also improves the health of the soil fertility for long-term, high productivity. The appropriate combination(s) to a manufacture approach for an ideal and equilibrium supply of nutrients depends on the land utilization, social, environmental, and economic situations because plant nutrient sources differ noticeably in terms of their nutrients substances, delivery effectiveness or fascination, positioning availability, crop specificity, producer's appropriateness, etc. (Meena and Reddy, 2021). Despite soil and agro-ecological zone, manure and fertilizer are the key contributions of improved technology that promote a 50–60% increase in the yield of food grains in India. However, greater production is not likely in the absence of an integrated supply and usage for nutrients for plants from chemical-based fertilizers and organic sources. By converting the chemical energy of manure and fertilizer into biomass with a higher grain: straw proportion, the HYV produce dramatically give higher yields. The best strategy for preserving land is to employ fertilizers in countries with little land, like India. But using this method, it would have been necessary to plant nearly 2-3 times more land in cereals in order to produce the same amount of food grains.

This emphasizes the importance of an integrated nutrient supply and use with a friendly combination of chemical fertilizers, organic manures, and bio-fertilizers to capitalize on nutrient use proficiency and reduce losses and seepage to achieve the goals of improving and sustaining (a) soil fertility in relation to factor productivity, (b) soil, water, and air excellence, and (c) farmers' socioeconomic status. However, there is no guarantee that even with a combined application of N, P, and K fertilizers and organic manures, some of the micronutrients will not become yield-limiting factors after a while, as organic manures may not be able to provide all of the micronutrients in the amounts required by HYV of a crop or cropping system(s). Because of the significant rise in with the world's population growing, the demand for efficient food for every individual has become a primary goal. With the rapid increase in population in the twenty-first century, there will be a demand for more than 250 million tons of food grains. To meet this demand for food products, most farmers have decided to use large quantities of inorganic chemical fertilizers, which increase production while harming soil health and indirectly causing stress to natural resources, making it difficult to meet future food security. Long-term food security necessitates striking a balance between crop output, soil health, and environmental sustainability.

Concept of INM

INM primarily refers to combining traditional and contemporary methods of managing nutrients into an environmentally friendly and sparingly optimal agricultural system that makes use of all available sources of inorganic, organic, and biological elements and substances in a wise, effective, and integrated way (Janssen, 1993). With the aim of synchronizing nutrients demands by the crop and its discharge in the atmosphere, it improves all facets of nutrient cycle, comprising N, P, K as well as other both macro- and micronutrients inputs and outputs. INM methods result in high nutrient-use efficiency while reducing losses from leaching, or the runoff, volatilization, emissions, and immobilization (Zhang *et al.,* 2012). Furthermore, it tries to improve soil conditions by improving its physical, chemical, biological, and hydrological assets in order to increase farm output and reduce land deprivation (Janssen, 1993). There is a growing recognition that INM can not only boost crop productivity but also, virtually gradually, protect soil resources. Farmyard manures, farm wastes, soil alterations, crop residues, natural and chemical fertilizers, green manures, cover crops, intercropping, crop rotations, fallows, conservation tillage, irrigation, and drainage are all used in its practices to increase available water and plant nutrients (Janssen, 1993).

A thorough INM approach includes several crucial elements, including the ones listed below:

- Determine agricultural plant nutritional deficiencies and the availability of nutrients in the soil. There are two broad techniques to identify nutrient shortages, even though sampling of soil and laboratory analyses are frequently employed to assess soil nutrient availability. First, through plant symptom evaluation and diagnosis, observable signs might reveal specific nutritional shortages. Second, post-harvest tissues and samples of soil can be examined in a lab and compared to a sample of reference from a plant in good health in cases when symptoms are not visible.

- Thoroughly evaluate the limitations and opportunities in the current methods for managing soil fertility and how these relate to nutrient diagnostics, such as the improper or excessive application of N fertilizers.
- Determine the farming techniques and technology that balance the nutrients required in various soil types and climates. The differential between fertilizer input and output can be used to compute the soil's nutrition budgets for a specific area and period. It will be possible to propose appropriate INM technology once these factors have been identified.
- Evaluate the sustainability and productivity of INM techniques.

The above-described overall INM management strategy focuses on streamlining the timing and rate of fertilizer application. A base fertilizer dose with respect to of N, P, and K requirements might be suggested based on the soil's capacity to deliver nutrients.

Need of INM

Crop production declines as a result of insufficient nutrient input and poor nutrient uptake by the crop.

- P, S, and Zn deficits occur more quickly and are linked to increased usage of N fertilizers.
- N treatment alone lowers plant growth in severely P-deficient soils.
- Soil Organic Matter decline brought on by ongoing nitrogen fertilizer application
- Constant application of fertilizers that cause acidification of the soil.
- Soil Organic Matter depletion and decreased soil fertility are caused by a shift in land use from the forest environment to the agro ecosystem. Effective nutrition management has been crucial in India in achieving the dramatic increase in food production.

However, using inorganic fertilizers alone is not sufficient to meet all of a crop's nutrient needs. Consequently, the concept of integrated nutritional management (INM) was successfully established by taking into account the aforementioned facts. INM has the potential to protect the surroundings and resource quality while simultaneously enhancing plant productivity and resource efficiency. Utilizing manures, chemical fertilizers, and biological agents are all part of integrated nutrient management (INM), which aims to promote soil health while achieving sustainable crop output. The finest method for making greater use of the resources at hand and producing crops on a budget is INM. The main factors limiting agricultural output in Indian soils are shortages in nitrogen, phosphorus, and sulfur. In order to deal with both of the concerns of nutrient excess and nutrient depletion, INM, that entails the maintenance of soil fertility to an ideal levels for the productivity of crops in order to get greatest amount of benefit from every potential source of plant nutrients, both organic and inorganic, in an integrated manner (Aulakh, *et al.* 2005 & 2010), is crucial. Marginal farmers that cannot afford to provide essential crop nutrients through pricey chemical fertilizations benefit from INM as well (Singh, *et al.*, 2014; Meena, *et al.*, 2013).

The main principles of INM

The overall goal of INM is to achieve maximum utilization of nutrients from the soil to improve crop yield and resource-use efficiency by utilizing every possible source of nutrients in order to maximize their input. Organic fertilizers can be made from leftover plant material, animal dung, and even waste that is recyclable and bio-fertilizers including fishery, municipal, and seaweed wastes. There are many advantages to using organic fertilizers. The soil's physical makeup and water-holding ability have both improved. Chemically speaking, organic fertilizers boost the soil's ability to buffer pH variations, increase cation exchange capacity, decrease phosphate fixation, and act as a reservoir for all nutrient types, including the micronutrients needed by crop plants. Rich organic matter increases soil fauna and microbes, which are the main factors influencing the breakdown of organic matter and the absorption of nutrients from minerals in ecosystems of soil (Janssen, 1993). As a result, INM methods ought to encourage the effective use of naturally derived fertilizers (Roy *et al.*, 2006). Inorganic N fertilizer requirements can be reduced by using INM techniques, and small farmers in underdeveloped nations can significantly reduce their use of expensive fertilizer nutrients by doing so (Chemonics, 2007).

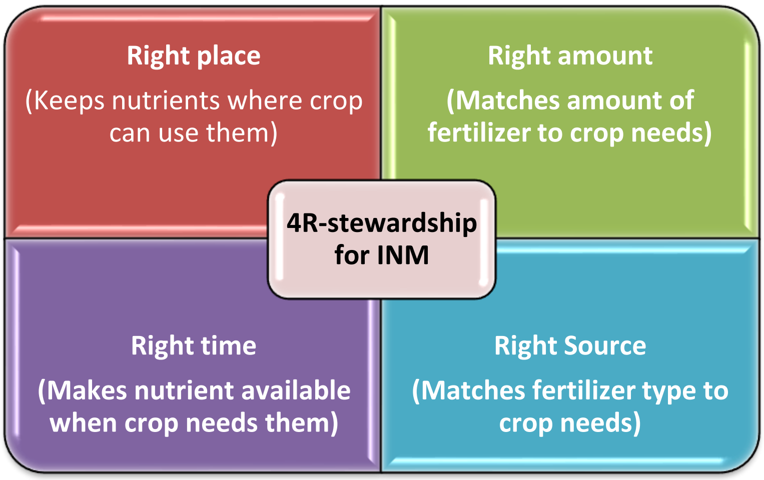
Steps of balanced fertilisation & INM:

- To asses on-farm and off-farm resource availability of the farmers
- Fixing of yield target
- Soil test based estimation of nutrient management
- Integration of all nutrient resources to finalise a probable best combination
- To determine time, method, mode of application
- To adopt efficient soil and water conservation measures
- Monitoring of soil fertility

Enhancing recovery of added nutrients

a. Balanced nutrition

a. Selection of crops and Cropping Systems
b. 4R-stewardship i.e. Right place, right time, right amount, right source

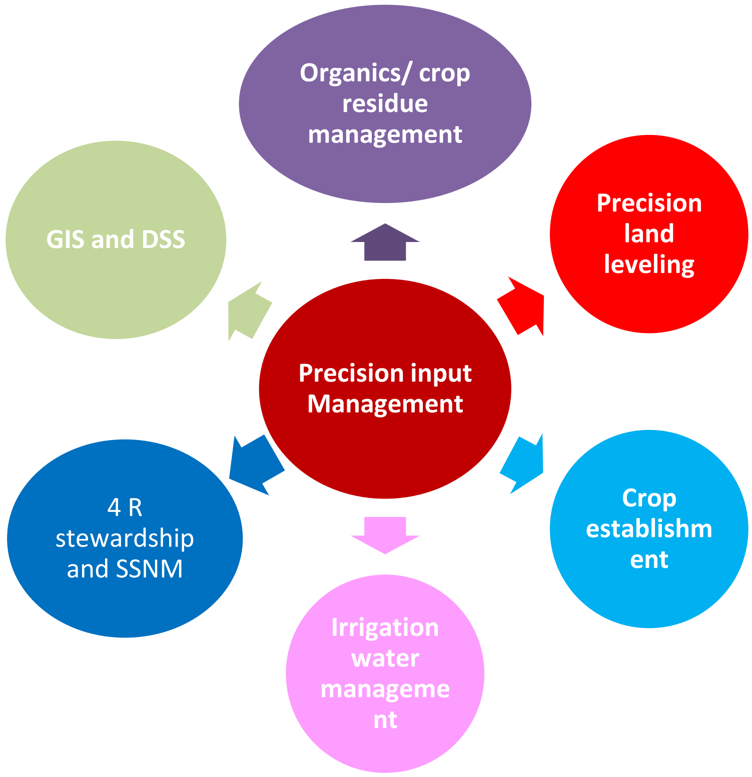


c. Specialty fertilizers (CRF (coated/encapsulated)/SRF (microbial activated)/SNF (Stabilised N Fert., enzyme activated), WSF, CF, NF, Bio formulation, Liquid fertilizerss, Agril. Micronutrients, Fortified Fertilizers (Zn-urea/ZNSSP), BSSP, ZnBSSP) - For soluble N-fertilizers like Urea, NH_4& NO_3 containing ones collectively called Enhanced-Efficiency Nitrogen Fertilizers (EFNFs)
d. Soil amelioration

e. Integrated Plant Nutrient management system (IPNS)/Site specific nutrient management (SSNM)
f. Real time Nitrogen management through Gadget based nitrogen management:
   - ➢ Chlorophyll meter or Soil Plant Analysis Development (SPAD) meter
   - ➢ Leaf Colour Chart (LCC)/ CLCC (Customized leaf colour chart)
   - ➢ Optical sensors (Green SeekerTM)
g. App use: can be a potential and non- destructive tool for real time nitogen management.
   - ➢ Nutrient Expert®
   - ➢ Crop Manager ®
   - ➢ Rice Expert ®

New approaches of INM

- Crop synergism
- Biodynamic interactions
- Agrometeorology
- Precision farming
- Rhizosphere management
- Carbon sequestration
- Nutrient use efficiency
- Water saving techniques particularly in rice: Direct seeded rice (DSR), System of rice intensification (SRI), Aerobic rice, Alternative wetting and drying method (AWD), Lesser land levelling



Precision input management for sustainable crop production

Components of INM:

The main components of INM can be divided into three categories: inorganic fertilizers, biofertilizers, and organic manures.

Manures made from plants, animals, and human waste is considered organic manures because they contain plant nutrients in complex organic forms. Manures, which are composed of farm waste, livestock shed waste, human housing waste, slaughterhouse waste, fish meal, and other byproducts of the agro-industry, are the main organic sources.

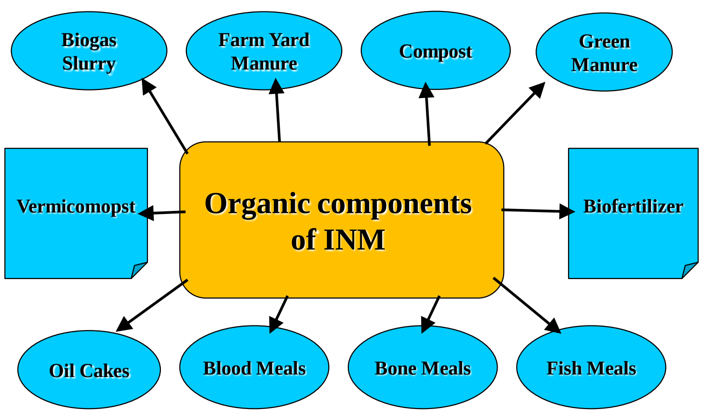
Inorganic fertilizer:

- Fertilizer is the "Kingpin" in the present system of agriculture and most important component of INM
- India is the third largest fertilizer user and the average rate of nutrient application is 128.6 kg/ha at present.
- The optimum desirable NPK consumption ratio is 4:2:1
    - India: 5.89:2.37:1
- Factors determining fertilizer needs of the crops
    - Crop, its variety and yield potential
    - Rooting system of a crop
    - Soil fertility status
    - Nutrient uptake pattern
    - Nutrient use efficiency

Profitable use of fertilizers

The answers to the following frequently asked questions will help you use fertilizers most profitably.

i. To use how much fertilizer? i.e. the proper dosage
ii. What type of fertilizer should we use? i.e., using the proper fertilizers
iii. How should fertilizer be used? i.e., the proper location
iv. When should we apply? i.e., at the appropriate moment (Yawalkar *et al.* 2002)



Manure classified as organic:

A. Organic manures that is bulky

(i) FYM: Cattle dung, sheep manure, and poultry manure are examples of animal manures.

(ii) Compost is an example of human waste. (a) Town/urban compost made from municipal waste

(iii) Wastewater and sludge

B. Organic manure concentrates

1. Oil cakes

(a) Edible oil cakes, which are used to feed cattle. These include mustard cakes, groundnut cakes, sesame cakes, and linseed cakes. (b) Cakes made of inedible oil that as manures. Castor cake, Neem cake, Sunflower cake, Mahua cake, and Karanja cake are among the options.

2. Bone meal and blood meal are two types of slaughterhouse waste.

3. Fish dinner

4. Guano is a product made from the waste and bodies of Dead Sea birds.

C. Green manures

(a) Leguminous plants (such as mung beans, cowpeas, guar, senji, and berseem), such as sun hemp and Sesbania species

(b) Non-leguminous plant (e.g., sunflower, maize, pearl millet)

D. Green leaf manures:

Neem, pungamia, glyricidia, and other green leaves of trees.

Biofertilizers are substances that contain living microorganisms with the capacity to biologically mobilize nutrients from inaccessible forms.

Advantages of green manuring:

Positive effect on physico-chemical properties

- Maintains soil OC
- Food and energy for soil microbes
- Builds up soil microbes population
- Nutrient pumping, biological plough
- Reduces soil erosion, soil temperature
- Fixes N for companion or succeeding crops, reduces N loss
- Increases solubility of native or applied P
- Solubulises/mobilises S, P, Si, Zn, Cu, Mn
- Ameliorates soil crusting, salinity and sodicity
- Exudates control nematodes
- Pest control (Karanja & Neem leaves)
- Weed suppression

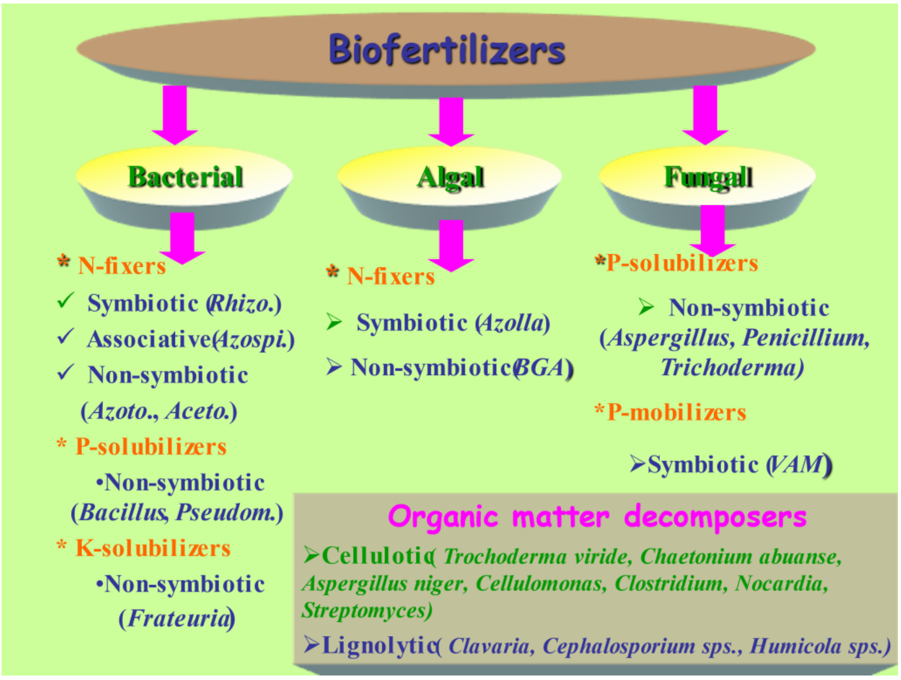
Nutritional value of different green manuring crops (Source: Sachan and Singh, 2002):

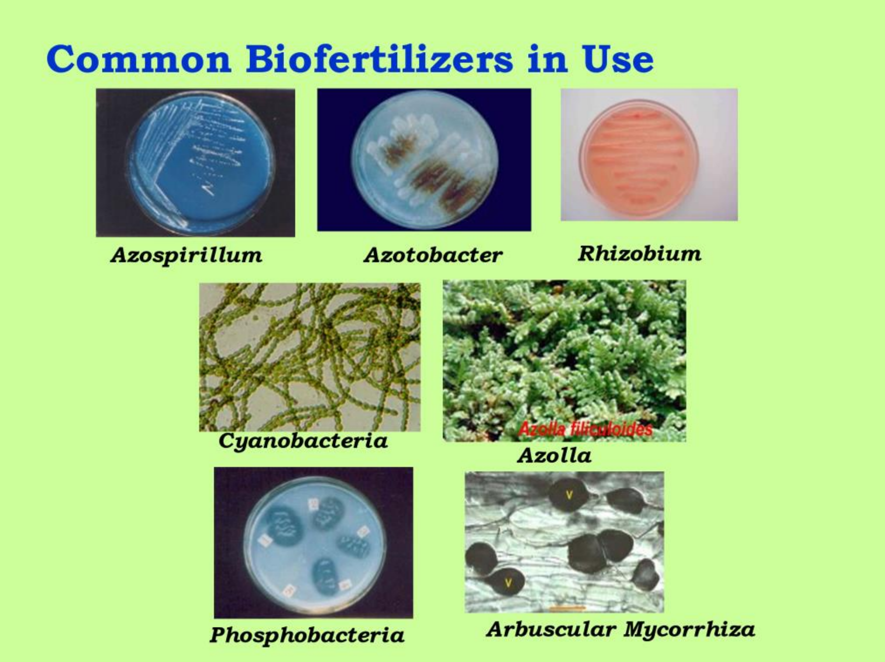
Crops	Time of sowing	Seed rate (Kg ha^{-1})	Green matter yield (t ha^{-1})	% N on green weight	Nitrogen available (Kg ha^{-1})
Sunhemp	April-July	50-60	18-28	0.43	60-100
Dhaincha	April-July	40-45	20-25	0.42	84-105
Lobia	April-July	45-55	15-18	0.49	74-88
Urd	June-July	20-22	10-12	0.41	40-49
Mung	June-July	20-22	8-10	0.48	38-48
Guar	April-July	30-40	20-25	0.34	65-68
Senji	Oct-Dec	25-30	26-29	0.51	120-135
Berseem	Oct-Nov	20-30	16	0.43	60
Pea	Oct-Nov	80-100	21	0.36	67

Biofertilizers:

Biofertilisers are organic product containing a biologically active and efficient strain of specific microorganisms or in combination which may play an important role when used for application to seed, soil or composting area to improve soil fertility and crop productivity due to their ability to

- Fix atmospheric nitrogen (symbiotic and asymbiotic),
- Transform native soil nutrients such as phosphorus, zinc, copper, iron, sulfur etc from the non-usable (fixed) to usable form
- Decompose organic waste.





Azotobacter:

Azotobacter is mainly used as an inoculant for vegetable crops, cotton, sugarcane, maize, sorghum, pearl millet and ornamental plants.

- They can add 10 to 30 Kg N/ha (by fixation) under optimum condition
- Increased yields with Azotobacter inoculation ranged from 2 to 45% in vegetables, 7-28% in cotton, 9 to 24% in sugarcane, 0 to 31% incase of wheat, maize, jowar, potato and mustard (Tilak and Singh 1996)
- Azotobacter can produce antibiotics and fungistic substances against pathogens like Fusarium, Alternaria and Trichoderma and this characteristic may prove advantageous to its action in improving health and growth of plants.

Azospirillum:

- It colonizes the root mass of cereals and grasses and is found mostly on rhizosphere root surfaces, root hairs, epidermal cells and vascular tissues.
- Produce plant growth promoting, antifungal, antibacterial substances
- Azospirillum inoculation increases yield by 3 to 17, 17.9, 15.4 and 17.7% of rice, sorghum, pearl millet, and ragi with a saving of 20 to 30 kg N ha-1

Phosphorous solubilizing bacteria (PSB):

- The major groups of microorganisms involved in the solubilisation of mineral and organic phosphorus sources are the soil bacteria particularly *Pseudomonas striate, Bacillus polymixa, B. circulans, Bacillus megaterium* and fungi *Aspergillus awamori, A. niger, A. flavus* and *Penicillium digitatium*.
- These soil microorganisms possess the ability to secrete organic acids, such as formic, acetic, propionic lactic and succinic acids etc. which in turn lowers the soil pH and bring about dissolution of immobile or bound form of phosphates. Some of the hydroxyacids may

chelate with Ca, Al, Fe and Mg resulting in effective solubilization of soil P and their by higher utilization of soil P by plants.

Phosphate absorber (VAM):

- The symbiotic association between plant roots and soil fugal mycelia is termed as mycorrhiza.
- Most species of crop plants are normally colonized by mycorrhizal fungi.
- These fungi belonging to the genera *Glomus, Gigaspora, Acaulospora, Scutellospora, Entrophosphora, Modicella*, and *Sclerocystis* are obligate symbionts and have not been cultured on nutrient media using standard microbiological techniques.
- They are multiplied in roots of host plants and the inoculum is prepared using infected roots and soil.

Azolla:

- The association of Azolla and Anabaena is a live, floating nitrogen factory using energy from photosynthesis to fix atmospheric nitrogen amount to 100 to 150 Kg ha-1 year-1 from about 40 to 60 tonnes of biomass.
- The increase in yield of rice due to Azolla inoculation has been reported to be varying from 18 to 47 % depending on the cultivar of rice used
- One crop of Azolla produces 10 to 20 tonnes of biomass within 20 to 25 days supplies 20 to 40 Kg N ha-1, which results in a saving of about 30 Kg N ha-1 as chemical fertilizer.
- It is a fast decomposing green manure in rice soil and its nitrogen is made quickly available to rice plant. Incorporated Azolla takes about 8 to 10 days to decompose and releases about 67% of it's nitrogen within 35 days.
- Besides nitrogen supply Azolla also contributes 15 to 20 Kg phosphorus and 25 to 30 Kg of potassium per hector as it contains 1.2% P and 4.5% K and adequate organic matter.

BGA:

- Composite nitrogen fixing cyanobacterial inoculums consisting of *Nostoc, Anabaena, Calothrix, Tolyporix, Plectonema, Aulosira, Cylindrospermum, Gloeocapsa, Aphanothece, Oscellathoria* and *Scytonema* have been used for inoculation in rice with better adaptability in wet land rice.
- Inoculation of BGA @10 to 15 Kg ha^{-1} a week after transplanting of rice provides 20 to 30 Kg biologically fixed N ha^{-1} seasons^{-1} which results in a savings of about 30 Kg N ha^{-1} as chemical fertilizer without affecting the crop yield

***Rhizobium* (for pulses):**

- Under most optimum condition, accepted contribution of Legume-*Rhizobium* symbiosis is 50 Kg N ha^{-1} season^{-1}
- Considering an average N fixation rate of 25 Kg N ha^{-1} per 500g application of *Rhizobium*, it is expected that 1 tonne of *Rhizobium* inoculant will be equivalent to 50 tonnes of nitrogen.

- The grain yield increase in pulses due to Rhizobium inoculation ranges between 10 to 30% at farmer's field condition.
- The residual effect of leguminous crops over succeeding cereal crops ranges from 20 to 123 Kg N ha^{-1}.

Objectivity of INM

In order to increase productivity and profitability, especially for low-income groups, sustainable agricultural production contains the idea that organic reserves should be used, without depleting the natural reserve base. Accordingly, INM protects soils as repositories of plant nutrients essential for vegetative growth. The goal of INM is combined and sensible use of all organic and inorganic plant nutrients in order to augment crop productivity in an efficient and environmentally friendly way without compromising soil productivity for future generations.

Good agricultural practices for nutrient management planning

A system for managing soil and crops must include nutrient management. Although the concept of nutrients management planning as a whole is relatively new, the underlying ideas are fundamentally sound and essential for good management. Site-specific nutrient management plans are required. They ought to be customized for the soils, crops, cultivars, landscapes, and farming practices of a certain farm (Singh *et al.* 2019). The following are crucial actions for nutrition management planning:

- ✓ To produce accurate soil fertility data for every field management unit, samples of soil should be collected and examined according to accepted standards soil fertility analytical protocols.
- ✓ Based on desired management and the estimated production potential for each field, a yield target should be established.
- ✓ Calculate the plant's nutritional requirements to reach the predetermined yield target. Data on intake of nutrients and removal by crops are accessible from a number of sources. It's critical to distinguish between the removal and intake of nutrients by the target crop and their actual physical displacement from the field during crop harvest.
- ✓ Determine the amount of the nutrients to be supplied separately through organic and inorganic available sources. The best method is to sample the manures to be used in the field and get analyzed accurately the nutrient contents of the manure and the nutrient release patterns.
- ✓ Doses of the nutrients to be supplied through fertilizers should be decided considering indigenous nutrient supply capacity. Record of the nutrient sources, their rate, method and time of application should be maintained.
- ✓ Use a combination of organic mulches and fertilizer to maintain the health of the crop.
- ✓ Promote use of locally available organic sources *viz.* compost, FYM and vermicompost etc. to minimize the need for inorganic chemical fertilizer application.
- ✓ Fertilizers guidelines must be followed, however always keep in mind how the crop is actually doing.

- ✓ Decide how much of each nutrient should be delivered from organic and inorganic sources, independently. The ideal approach is to take a sample of the manures that will be applied to the soil and have their nutrient composition and patterns of nutrient release accurately assessed.
- ✓ Decisions on the amounts of nutrients to be delivered by fertilizers should take local nutrient supply capacity into account. It is important to keep track of the sources, rates, methods, and timing of the nutrients.
- ✓ To keep the crop healthy, employ a mixture of organic mulches and fertilizer. Encourage the use of locally accessible organic sources, such as compost, FYM, and vermicompost, among others, to reduce the requirement for synthetic chemical fertilizer application.
- ✓ Follow fertilizer recommendations, but constantly keep in mind how the crop is actually doing.

Conclusion:

So long as agriculture continues a soil-based industry, there is no way that needed yield escalations of the major crops can be accomplished without safeguarding that plants have an satisfactory and steady supply of nutrients. The applicable environment must occur for nutrients to be accessible to a particular crop in the suitable right form, in the proper absolute and relative quantities, and at the right time for high yields to be appreciated in the short and long term. In this regard it is imperative that governments persuade analysis of “nutrient cycles” to have a clearer basis for deciding the flow of plant nutrients in and out of soils. Governments need to set up enough monitoring and testing systems to gather information on the cycle of nutrients and nutrient balance in designated regions across their rural economies. Governments should also support research into cutting-edge modern cultivars and appropriate integrated nutrition systems for arid climates like those in Sub-Saharan Africa. Additionally, biological nitrogen-fixation research should be encouraged as a low-cost "organic" means of increasing soil organic matter and nitrogen availability. The primary task for government agencies and extension services will be to encourage farmers to use nitrogen-fixing species and inoculants. The application of pursued, ample, and balanced quantities of inorganic fertilizers will be essential to make nutrients available for high yields without contaminating the environment. Governments should take the crucial steps to accelerate the widespread and responsible use of chemical fertilizers. At the same time, every endeavor should be made to develop the availability and use of secondary nutrients and micronutrients, organic fertilizers, and soil-conservation procedures. Farmers will need government support to set up an environment in which they will be able to choose the appropriate technologies for their surroundings. The environmental drawbacks of extensive fertilizer use are currently confined to a small number of emerging and wealthy nations. Applying fertilizers correctly and responsibly will help maintain production and reduce pollution. By contrast, the levels of fertilizers use in the majority of developing nations have become so low that there's little chance that its application will result in significant environmental problems. In reality, more extensive use of both inorganic and organic fertilizer in such locations could improve yields and benefit the environment.

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CHAPTER 6

ROLE OF ORGANIC MANURE FOR IMPROVING SOIL HEALTH

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Introduction:

Reduced soil quality, indicated by insufficient soil aggregation at the surface, increased bulk density, decreased porosity, and slow water infiltration, negatively impact agricultural productivity and exacerbates non-point source pollution of surface water due to runoff from farming activities. Improving soil organic matter content through the incorporation of organic amendments has proven to be a valuable strategy for preserving or restoring soil quality. Enhancing the soil's organic matter content through the incorporation of organic amendments has been acknowledged as a valuable approach for preserving or rejuvenating soil health (Evanylo*et al.*, 2008). Tropical soils face significant challenges, with soil acidity being a major problem. These soils have low pH levels, excessive aluminum content, insufficient calcium, and low organic matter, making them highly unproductive. Another issue is the strong fixation of phosphate in these soils, making phosphorus unavailable for plants. Addressing soil acidity and mineral deficiencies typically involves the application of lime and fertilizers. However, small and resource-poor farmers often face challenges in accessing these options. It is crucial to acknowledge that agriculture thrived for millennia without depending on synthetic chemicals. The introduction of new artificial fertilizers initially had positive effects in the short term. However, over time, it led to detrimental consequences such as erosion, soil compaction, and a decrease in overall soil fertility. Additionally, there were concerns about the potential health risks associated with toxic chemicals entering the food supply. Inorganic fertilizers are expensive and have harmful environmental effects when not properly managed (Sisay and Sisay, 2019).

Timeline of Indian agriculture:

Period	**Type of Agriculture**
I) Before Mid 1960s	Low input and low productivity, subsistence agriculture
II) Mid 1960s to 1990	High input and high productivity, production enhancement
III) 1990s to 2002	Over-exploitation of resources
IV) 2002 onwards	RUE, TFP, Cost of production
V) 21st century	Technology convergence, Commercialization, Smart agriculture

Effect of unscientific use of chemical inputs in green revolution

Component	Effect/ End result
Sustainability of yield	• Definite deceleration • Crop failure & losses
Soil degradation	• Nutrient exhaustion, deficiency, imbalance • Physico-chemical & biological properties affected • Salinity, sodicity, alkalinity • Reduced fertility & productivity • Soil health deterioration • Accumulations of toxic substances & heavy metals
Ground water	• Depletion & poor quality • Extra cost & energy consumption • Sea water ingress in coastal areas
Ecology	• Imbalance in soil flora & fauna & destruction • Loss of biodiversity & biological imbalance • Elimination of natural enemies of pests • Resistance in pests to chemicals
Environment	• Pollution of soil, water & air • Accumulation of heavy metals & non-biodegr. subs.
Social & economic	• Serious health hazards • Permanent or partial disability of farm workers • High inputs • Declining profitability • Export constraints affecting national economy • Rural economy ruined - over-dependence on off-farm inputs • Regional, crop & social-disparity

Need for INM in Sustainable soil health management:

- Depletion of soil organic matter
- Deterioration of soil fertility
- Decline in fertilizer use efficiency
- Negative nutrient balance in soil
- Deficiencies of nutrients such as S, Zn, and Mn
- Decrease in beneficial soil microbial population
- Increase in soil erosion, soil degradation, soil salinization, denitrification and volatilization of N and environmental pollution.
- The increasing cost of chemical fertilizers

- So, keeping these facts in mind, to sustain the food and nutritional demand along with environmental security and soil health in a broader sense there is an urgent need to adopt integrated nutrient management and Organic farming in the long run as Organic farming single headedly cannot meet the food and profit requirement of farmer. So Judicious use of fertilizer and organic manure along with crop residue, green manures, biofertilizers, and legumes in crop rotation at right time, right dose and right method can not only prove to be a sustainable method but also a profitable way of farming.

Why organic manure:

- All food & feed have pesticide residue.
- Pest resistance & resurgence.
- Pesticides & fertilizer costs are mounting.
- Increase in deficiency of micronutrients.
- Consumers' interest for organic food.

Organic manure

The word "manure" originated from the French language word "manoeuvrer," which means to manipulate, work, or produce a crop. In its general usage, "manure" refers to the excreta of animals that is used as fertilizer for crops. The term "bulky organic manure" typically refers to natural materials of organic origin that have a larger volume in relation to the nutrient content they contain. These materials are utilized to enhance the nutrient levels and organic matter content of soils. They are predominantly acquired as natural products. The substances encompassed within this category consist of farmyard manure, compost, sewage sludge, and green manure (icar/ecourses).

Manures refer to substances obtained from the wastes of plants and animals, providing important plant nutrients. Plants can access these nutrients as they undergo decomposition in the manure. The tradition of gathering and utilizing waste materials from animals, humans, and plants to improve crop yield has been an essential aspect of agriculture since ancient times. Manures comprise organic substances obtained from the remnants of animals, humans, and plants, containing intricate organic compositions with plant nutrients. Manures that contain a lower amount of nutrients per unit quantity exhibit a longer-lasting residual effect and play a significant importance in enhancing the physical properties of the soil, as opposed to fertilizers that have a higher nutrient content (TNAU).

Manures include a diverse range of organic materials made from many sources, including animals residue, plant residue and other organic remnants. They are widely used in agriculture to increase the physical and chemical properties of the soil and provide minerals and nutrients to plants. Depending on the source and processing techniques, manures can be bulky or concentrated, and their chemical contents might vary. These organic materials are important for plant growth because they are rich in micronutrients and necessary nutrients including nitrogen (N), potassium (K), and phosphorus (P). When manures are mixed into the soil, they gradually discharge these nutrients over time, guaranteeing a consistent supply for plant uptake. This nutrient release is typically more gradual compared to synthetic fertilizers, which can help prevent nutrient leaching and reduce the risk of nutrient runoff into water bodies. In addition to supplying nutrients, manures also improve the physical environment of the soil. They enhance soil structure by improving its water-holding capacity, drainage, and aeration. Manures contain organic matter that can increase soil organic carbon content, which promotes beneficial microbial activity and improves overall soil fertility (Singh, 2021).

Livestock manure remains a fundamental fertilizer in organic and sustainable soil management. It is most efficiently utilized in conjunction with other sustainable practices. These encompass green manuring; cover cropping, crop rotation, liming, and biologically friendly fertilizers or the incorporation of other natural and amendments. In organic farming, manure is typically administered to the field in either an unprocessed (fresh or dried) or composted form. The use of raw manure in organic farming is expressly forbidden. The National Organic Programme (NOP) Regulations, which govern the federal standard for organic agriculture, include a list of these limitations (Kuepper 2003).

Origins of organic fertilizers or manures

The primary sources of organic fertilizers included peat, animal byproducts (often from slaughterhouses), agricultural and sewage sludge, and plant waste. Naturally available organic fertilizers consist of animal byproducts from meat processing, peat, and liquid manure. Organic fertilizers are carbon-based substances that enhance plant productivity and improve the quality of growth. Unlike purified and simplified chemicals, organic fertilizers are complex compounds that provide various secondary and micronutrients. Manures, finely ground rocks (such as lime, rock phosphate, and green-sand), blood meal, bone meal, wood ash, and compost all possess vital micronutrients. Additionally, these organic fertilizers improve soil quality instead of degrading it by enhancing its texture (Sisay and Sisay, 2019).

The primary sources of manures include:

1. Poultry litter: Refers to the droppings of poultry, as well as the droppings of sheep and goats.
2. Crop residues: Encompasses sugarcane trash, stubbles, and similar agricultural by-products.
3. Cattle shelter residues: This includes dung, urine, and slurry obtained from biogas plants.
4. Cattle housing by-products: This comprises dung, urine, and slurry acquired from biogas plants.
5. Human habitation wastes: This category involves night soil, human urine, town refuse, sewage, sludge and sullage.
6. Byproducts of agricultural industries encompass oil cakes, bagasse, press mud as well as waste generated from fruit and vegetable processing among other examples.
7. Green cover crops and foliage-based manuring materials: Encompasses crops intentionally cultivated to enhance soil fertility through organic matter, as well as the utilization of green leaves as a natural source of nourishment.
8. Water hyacinth, weeds and tank silt: Refers to aquatic plants, weeds and sediment from tanks or ponds.

These sources provide a diverse range of organic materials that can be used as manures, contributing to the nutrient content and overall health of the soil.

- Organic materials are intrinsic and an essential component of all soils,
- Usually derived from plant and animal sources & Organic manures are considered as cheap and chief sources of plant nutrients and soil improvement

Residual effect of organic manure:

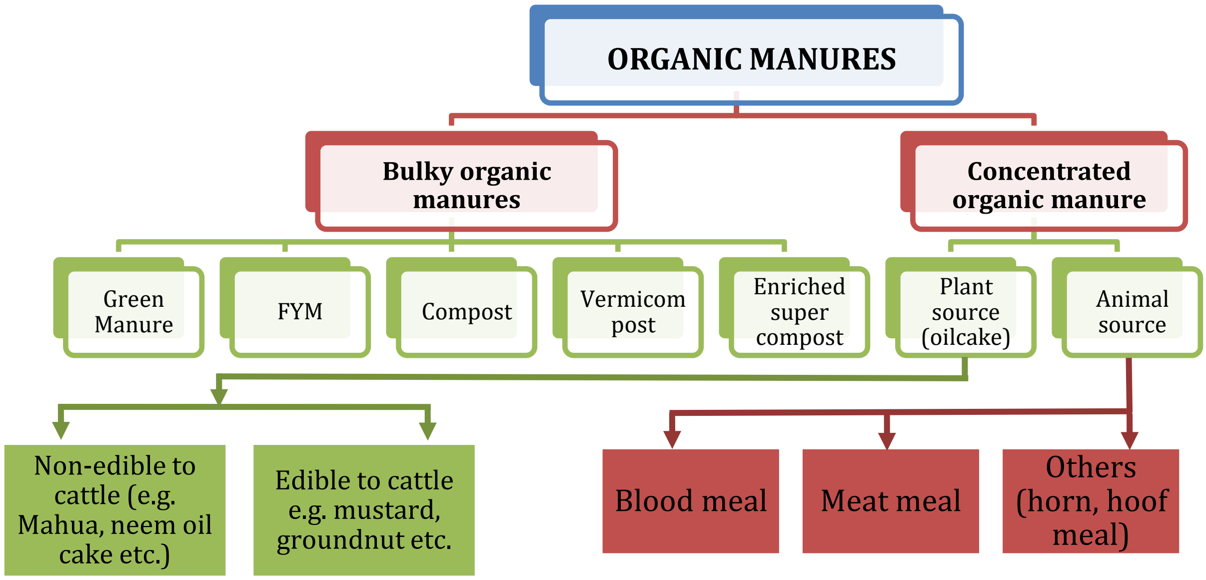
- OM builds up of secondary and micronutrient fertility of the soils, counter acting deleterious effects of soil acidity, salinity and alkalinity and sustenance of physical, chemical and biological soil health are the key benefits associated with continuous application of FYM
- Organic manures besides supplying nutrients to current crops very often leave substantial residual effects on succeeding crop in the system.
- It is reported that organic N is slowly mineralized and about 30% N, 60 to 70% P and 75% K is likely to become available to the first crop and rest to the succeeding crop

How to achieve sustainable livelihood?

Manures are plant and animal wastes that are used as sources of plant nutrients. They release nutrients after their decomposition. The art of collecting and using wastes from animal, human and vegetable sources for improving crop productivity is as old as agriculture. Manures are the organic materials derived from animal, human and plant residues that contain plant nutrients in complex organic forms. Naturally occurring or synthetic chemicals containing plant nutrients are called fertilizers. Manures with low nutrient, content per unit quantity have longer residual effects besides improving soil physical properties compared to fertilizer with high nutrient content. Major sources of manures are:

1. Cattle shed wastes-dung, urine and slurry from biogas plants
2. Human habitation wastes-night soil, human urine, town refuse, sewage, sludge and sullage
3. Poultry Jitter, droppings of sheep and goat
4. Slaughterhouse wastes-bone meal, meat meal, blood meal, horn and hoof meal, Fish wastes
5. Byproducts of agro industries-oil cakes, bagasse and press mud, fruit and vegetable processing wastes etc
6. Crop wastes-sugarcane trash, stubbles and other related material
7. Water hyacinth, weeds and tank silt, and
8. Green manure crops and green leaf manuring material

Manures can also be grouped, into bulky organic manures and concentrated organic manures based on concentration of the nutrients.



- They supply plant nutrients including micronutrients
- They improve soil physical properties like structure, water holding capacity etc.,
- They increase the availability of nutrients
- Carbon dioxide released during decomposition acts as a CO2 fertilizer and
- Plant parasitic nematodes and fungi are controlled to some extent by altering the balance of microorganisms in the soil.

Farmyard manure:

FYM or farmyard manure refers to the waste material derived from farm animals particularly sheep, cattle and poultry. It is revered for the many beneficial qualities it bestows on the soil and is one of the oldest types of manure. The FYM not only boosts the soil's organic matter and nutritional contents, but also its overall quality. A typical percentage of nitrogen (0.5%), potassium (0.5%), and phosphorus (0.2%) in farmyard manure with good decomposition. Urine typically contains 1% nitrogen (N) and 1.35 percent potassium (K_2O). The ratios of the nutrients may change depending on the food of the animals, how the manure is decomposed, and other variables. The majority of the nitrogen that exists in urine is present as urea, which is prone to volatilization losses. While it may be challenging to eliminate losses of nitrogen from urine during the preparation of farmyard manure; it is indeed possible to reduce these losses through improved methods. Trenches of varying sizes are dug:

Length: The length of the trench ranges from 6 meters to 7.5 meters. This measurement represents the separation between the ends of the trench.

Width: The trenches' width ranges from 1.5 to 2.0 meters. The space between the trench's two parallel sides is the subject of this assessment.

Depth: The depth of the trenches is 1.0 meters. This measurement refers to how deep the trench is dug from the ground level to the bottom.

All the presented litter and refuse are combined with soil and scattered throughout the shed to facilitate the absorption of urine. The following day, the urine-soaked refuse, along with dung, is gathered and deposited into the trench. A specific portion of the trench, starting from one end, is dedicated to accommodating the daily collection. As the daily collection accumulates, the section of the trench gradually reaches a height of 45 cm to 60 cm above the ground level. At this point, the top of the heap is formed into a dome shape and coated with slurry made from cow dung and earth.

This procedure continues until the first trench is filled completely at which point the preparation of a second trench begins. The manure reaches a state of readiness for use approximately four to five months after the plastering process. In situations where urine is not absorbed into the bedding, it can be collected together with the washings from the cattle shed and stored in a concrete pit. Later, it can be incorporated into the farmyard manure pit.

To minimize losses and enhance the nutrient content of the manure, chemical preservatives can be employed. Gypsum and super phosphate are commonly used chemicals for this purpose. Gypsum is applied within the cattle shed to absorb urine, inhibit urea volatilization losses and supply supplementary calcium and Sulphur. Likewise, superphosphate assists in minimizing losses and enhances the phosphorus content of the manure. Partially fermented farmyard manure should be applied three to four weeks before planting, while fully fermented manure can be applied immediately before planting. Generally, ten to twenty ton per hectare of farmyard manure is applied but for fodder grasses and vegetables, the application rate can exceed 20 t/ha. In such cases, it is recommended to apply farmyard manure should be 15 days in advance to prevent nitrogen immobilization. The conventional practice of leaving manure in small dispersed piles for a prolonged duration results in nutrient losses. These losses can be reduced by uniformly spreading the manure across the field and integrating it by ploughing immediately after application.

Concentrated organic manure:

Concentrated organic manures are organic materials that contain higher percentages of critical plant nutrients such as nitrogen, phosphorus, and potash than bulky organic manures. These concentrated manures are made from animal or plant-based basic materials. Aquatic weeds, oilcakes, blood-meal, fish meal, meat meal, and horn and hoof meal are some of the most often used concentrated organic manures. These is also known as organic nitrogen fertilizer. Before their organic nitrogen is used by the crops, it is converted through bacterial action into readily usable ammoniacal nitrogen and nitrate nitrogen. These organic fertilizers are, therefore, relatively slow acting, but they supply available nitrogen for a longer period.

1. Aquatic weeds: Many people still see aquatic weeds as a threat because they are unaware of the immense potential and economic value of these prolifically growing, unmanageable plants. These high-yielding plants outperform typical field crops in terms of yield. Important aquatic weeds utilised as organic manure include *Azolla pinnata, Eichhornia crassipes (small), E. crassipes (big), Lemna minor, Monochoria vaginalis, Pistia stratiotes, Salvinia sp., Spirodelapolyrhiza, and Spirogela and Lemna.*

Furthermore, when grown on trash, they do not compete for fertiliser, water, or land with conventional crops. They are a promising source of multipurpose raw material due to their natural profuse growth in the humid tropical and subtropical areas of the world, which does not necessitate rigorous cultivation. Indeed, these plants have shown to be an excellent source of animal feed, human food, fish feed, organic or biofertilizer, energy, fibre, and paper. By absorbing dissolved nitrogen, phosphorus, and undesired extra minerals, including heavy metals, aquatic weeds can also filter waste water. While it has been shown that organic manure is necessary to maintain soil productivity, it has also been documented that regular chemical fertiliser usage without the addition of organic manure has a negative impact on the physical characteristics of the soil. Given the issues of ecological imbalance, scientists have been asked to create organic and biological solutions to replace over use of artificial fertilisers and pesticides.

Aquatic weeds as a source of energy:

Even in modest amounts, fuel made from aquatic weeds has economic ramifications, particularly for rural areas in poor nations. Aquatic weeds can be used as organic manure and soil conditioners for biogas generation.

Aquatic weeds as organic manures:

It has been noted that aquatic weeds are a rich source of organic manure. Many aquatic weeds have high levels of nitrogen, phosphorus, and potassium. When composted aquatic weeds are sprayed on farmland, they have been shown to enhance field crops. Aquatic weeds not only offer nutrients to crops, but they also improve soil physical qualities such as texture and water holding capacity, which are critical in sandy, lateritic, and heavy clay soils common in developing nations. Azolla, a good source of biofertilizer, has the ability to reduce soil nitrogen demand. When aquatic weed compost is put into the soil, the residual effect is also noticeable.

2. Oilcakes: Oil cake is the residue left after the oil is extracted from oil bearing seeds

These can be grouped into two classes, namely:

(i) Edible oilcakes- suitable for feeding the cattle and

(ii) Non-edible oilcakes- not suitable for feeding the cattle.

After oil is extracted from oilseeds, the remaining solid portion is dried as cake which can, be used as manure. The oil cakes are of two types:

- Edible oil cakes which can be safely fed to livestock; e.g.: Groundnut cake, Coconut cake etc., and
- Non edible oil cakes which are not fit for feeding livestock; e.g.: Castor cake, Neem cake, Mahua cake etc.,

Both edible and non-edible oil cakes can be used as manures. However, edible oil cakes are fed to cattle and non-edible oil cakes are used as manures, especially for horticultural crops. Nutrients present in oil cakes, after mineralization, are made available to crops 7 to 10 days after application. Oilcakes need to be well powdered before application for even distribution and quicker decomposition. As concentrates, edible oil cakes are typically fed to cattle. Farmers do, however, also use part of the edible oil cakes to amend the soil. Depending on the type of oilcake, the nitrogen content varies. Mahua cake has 2.5% of it, whereas decorated safflower cake contains 7.9%. All oilcakes also contain minor amounts of potash (1.2 to 2.2%) and P2O5 (0.8 to 2.9%) in addition to nitrogen. Oilcakes are organic manures that work quickly. Despite being insoluble in water, their nitrogen becomes readily available to plants 7 to 10 days after application. The mahua cake, on the other hand, is an anomaly since its nitrogen is not available until around two months after application. As a result, if the soil is damp, mahua cake should be applied around two months before sowing. This cake is appropriate for use on fruit plants and plantation crops.

How to use oilcakes:

These should be thoroughly powdered before use so that they can be uniformly distributed and degraded by microbes. They can be applied a few days before or during sowing. Oilcakes, particularly groundnut cake, are also widely used as a topdressing for sugarcane. Depending on the crop, oilcakes are disseminated, drilled, or placed near the root zone while earthing up. Generally speaking, the nutritional content increases with increasing dry matter. For instance, the higher dry matter content of the poultry dung is primarily responsible for its higher nutrient content. Cattle slurry typically contains the same amount of nitrogen and potassium as phosphorus, which is typically 25% of the nitrogen and potassium level. The nitrogen and potassium concentration of pig manure is often comparable to that of bovine slurry, and the phosphorus content is typically around 25% of the nitrogen and potassium level. Pig dung contains almost the same amount of nitrogen as cattle manure, but it is greater in phosphorus and lower in potassium than cattle slurry. The phosphorus to potassium ratio differential between cattle and pig manure is primarily due to the diet of these animals. The relatively low potassium and high phosphorus content of pig slurry reflects primarily a cereal diet, whereas the high potassium level of bovine manure reflects the high potassium value of herbage, which often accounts for a large amount of the ruminant diet.

Characteristics:

1) Quick-acting organic manures as C: N (5 - 15)
2) Oil prevents rapid conversion of N
3) Nearly 50-80% of its N is made available in 2-3 months and varies with the type of cake and nature of the soil. Castor - Ricin, Mahuva -Saponin and Neem -Nimbidin which are responsible for the slow nitrification of their N due to the effects of alkaloids on soil microorganisms
5) Castor cake has also good vermicidal effect against white ants
6) Groundnut cake has the highest nitrification rate.
7) Mahua cake is very poor in N and takes a long time to nitrify, so applied to the soil two to three months before sowing/planting of the crop

Precautions in using oil cakes:

1. It should be powdered before use.
2. Apply during the last ploughing in short-duration crop.
3. It is best used as topdressing after the plants have established themselves.
4. Use only when there is sufficient moisture in the soil.

5. Mahua cake should be applied before 2-3 months before planting or decompose in a pit and then apply or treat with ammonium sulphate.

Oil cakes

Jatropha oil cakes Pongamia oil cakes Cotton seed oil cakes

The average nutrient content of different oil-cakes is presented in the following table.

Average nutrient content of oil cakes (Source: FAI (2012)

Oilcakes	**N (%)**	**P_2O_5 (%)**	**K_2O (%)**
Edible oilcake			
Ground nut	7.3	1.5	1.3
Rapeseed/ Muatrad	5.2	1.8	1.2
Linseed	4.9	1.4	1.3
Sesame	6.2	2.0	1.2
Coconut	3.0	1.9	1.8
Cotton seed	6.4	2.9	2.2
Saflower	7.9	2.2	1.9
Non-edible oilcake			
Castor	4.3	1.8	1.3
Mahua	2.5	0.8	1.8
Neem	5.2	1.0	1.4
Karanj	3.9	0.9	1.2
Cotton seed (undecorated)	3.9	1.8	1.6
Safflower (undecorated)	4.9	1.4	1.2

Poultry:

Chicken manure has a nutritional ratio that is somewhat similar to pig manure, which likely reflects the diets of both pigs and chickens. Compared to solid manures, slurry composition can vary more.

a. Litter Grown: The majority of poultry is raised on litter that collects moisture from the faeces. Vermiculite, wood shavings, sawdust, or other appropriate materials may be used as the litter. Depending on particular management techniques and field distribution, the spent litter is removed from the structures. Poultry waste management is strictly a solid waste handling issue.

b. Cage Grown: Some broilers and layers are reared in screened cages, which allow faeces to fall straight into a holding pit beneath the animals. In other circumstances, the pit holds water and functions as both a holding and treatment facility. The liquid waste can be pumped into a liquid spreader for use in the field or into a lagoon for further treatment.

c. In some systems, the pits are provided with air facilities to remove moisture from the manure, resulting in a dry end product. The dried manure can be transported and dispersed in the field, or it can be bagged and sold as commercial fertiliser. Grill manure contains about 17 kilogram of nitrogen, 8 kg of phosphate, and 12.5 kg of potassium every 1000 kg of dung. Layer manure contains around 13 kilogram of nitrogen, 12 kg of phosphorus, and 11 kg of potassium per 1000 kg.

3. Meat-Meal: After slaughter or death, a mature animal can provide 35 to 45 kg of meat. Meat meal is now produced on a modest basis in India. The manufacture of meat-meal is a pretty easy process. For two to three hours, the bones and meat are cooked or digested in a specific container. The meat is then removed from the bones. This meat is powdered after being dried on a sand bath until it is brittle.

The drying can be done in double-jacket trays heated with steam for an hour and the material dried over the steam. Mutton squeezers can also be used to remove the meat's water content before drying it. Meat-meal is a fast-acting manure.Meat-meal is fast-acting manure that is suitable for all crops and soil types. Its use is similar to that of oilcakes. Meat meal includes around 10.5% N and 2.5% P_2O_5.

Bloodmeal:

An adult cow produces approximately 14.0 kg of blood, while a goat or sheep produces approximately 1.40 kilogramme of blood. Slaughterhouse floors should be pucca or concrete, with a central drain leading into a blood storage tank. The blood is initially treated with 125 gramme of commercial copper sulphate per 100 kg of blood. On a sand bath, it is then evaporated to dryness.It is then laid on a concrete floor covered by a net and left to dry in the sun. It is powdered, bagged, and marketed as bloodmeal once completely dried. Bloodmeal is fast-acting manure that is suitable for all crops and soil types. It should be applied in the same way as oil cakes are. Bloodmeal contains 10% to 12% N and 1% to 2% P.

It contains varying quantities of oil, by treating the oil seed as shown below:

Process of manufacture	Oil (per cent)
Country ghani	10-15
Hydraulic press	8-10
Expeller	5-8
Solvent	1-2

Other concentrated organic manures:

Blood meal when dried and powdered can be used as manure. The meat of dead animals is dried and converted into meat meal which is a good source of nitrogen. Average nutrient content of animal based concentrated organic manures is given as follows.

Horn and hoof meal

Raw bone meal

Crushed bone meal

Nutrient contents of organic manures of animal origin (Source: FAI, 2012)

Material	**N (%)**	**P_2O_5 (%)**	**K_2O (%)**
Dried blood	10-12	1-1.5	0.6-0.8
Fish manure	4-10	2-9	0.3-1.5
Bird guano	7-8	11-14	2-3
Poultry manure	2.9	2.9	2.4
Hoof and horn meal	14	1	-
Activated sludge (dry)	5-6.5	3-3.5	0.5-0.7
Settled sludge (dry)	2-2.5	1-1.2	0.4-0.5
Raw bone	3-4	20-25	-
Steamed bone	1-2	25-30	-

Transformation Reactions of Organic Manures in Soils:

- It contains some amount of macro-and micro-nutrients, of which organic nitrogen content is likely to be dominant.
- The organic forms of soil nitrogen - amino acids, proteins, amino sugars etc, are added to the soil.
- Microbial attack results complete disappearance of the organic protein and changed into inorganic form of nitrogen through the process of mineralization.
- It may be absorbed directly by the plants.
- It may be utilized by hetero-trophic organisms in further decomposing organic carbon residues.
- It may be fixed in the lattice of certain expanding type of clay minerals.
- It could be slowly released back to the atmosphere as elemental nitrogen.
- Mineralization and immobilization of nitrogen or any other nutrient elements occur continuously. Normally organic manures are applied to the soil as a source of fertilizer nitrogen should contain about 1.5 to 2.0 per cent to meet the needs of the soil microorganisms.
- The carbon nitrogen ratio (C: N ratio) in the organic manures remaining in the soil after consumption by the soil microorganisms is approximately 10:1.
- Therefore, different organic manures organically bound nutrients like P, S, and other micro nutrients etc. are subject to transformation in soils similar to nitrogen and release inorganic forms of nutrients in soils that become available to plants.

Role of organic manure:

1. Organic manure binds soil particles into structural units called aggregates.
2. Water-holding capacity is increased by organic matter.
3. Surface runoff and erosion are reduced by organic matter as there is good infiltration.
4. Organic manure on the soil surface reduces losses of soil by wind erosion.
5. Surface mulching lowers soil temperatures in the summer and keeps soil warmer in winter.
6. The organic matter serves as a source of energy.
7. Organic matter serves as a reservoir of chemical in organic combination and supplies the nutrients needed by growing plants, as well as many hormones and antibiotics
8. Fresh organic matter has a special function in making soil phosphorus more readily available in acid soils.
9. Organic acids released by organic matter help to reduce alkalinity in soils.
10. Fresh organic matter supplies food for earthworms, ants and rodents. These micro-organisms improve drainage and aeration.
11. Organic matter on decomposition produces organic acids and carbon dioxide which help to dissolve minerals such as potassium and are available to growing plants.
12. Humus provides a storehouse for the exchangeable and available cations – potassium, calcium and magnesium.
13. Ammonium fertilizers are also prevented from leaching because humus holds ammonium in an exchangeable and available form.
14. It acts as a buffering agent.

Advantages of concentrated organic manures

- The soil becomes porous from concentrated organic manure, allowing gases to freely move across it.
- Concentrated organic manure fiber has been used to produce a wide range of specialized consumer items, such as plant growth media, seed starter pots, fertilizer garden sculptures, paper, and building materials.
- Additionally, the nutrients in concentrated organic manure can be used to develop worms, bug larvae, algae, and other living things.

Disadvantages of concentrated organic manures

- Regardless of its potential agricultural benefits, there is sufficient scientific evidence that this manure contains increasing numbers of pathogen organisms and veterinary drug residues, which may lead to the spread of antimicrobial resistant bacteria in soils.
- Nitrate levels in manure that exceed a particular threshold can be harmful to both cattle and humans.
- In rare circumstances, stored or applied manures or nitrogen fertilizers have resulted in high nitrate concentrations.
- Because nitrates freely drain down through the soil profile, nitrogen that is not used for crop or plant growth can swiftly reach groundwater part from additional consequences, they eventually poison the soil.

1. **Bulky organic manures**

Bulky organic manures are characterized by a relatively low percentage of nutrients and are applied in large quantities. The most prominent and frequently employed forms of bulky organic fertilizers comprise compost, green manure and farmyard manure (FYM).

2. Concentrated organic manures

Concentrated organic manures have a higher nutrient concentration compared to bulky organic manures. Significant examples of concentrated organic manures encompass blood meal, oil cakes and fish manure, commonly known as organic nitrogen fertilizers. The organic nitrogen present in these fertilizers is converted into readily usable ammonical nitrogen and nitrate nitrogen through bacterial activity before being utilized by crops. Due to this conversion process, these organic fertilizers have a relatively slow-release effect, providing available nitrogen to crops over an extended period.

Oil cakes: After the extraction of oil from oil seeds, the remaining solid portion is dried and referred to as "cake."

Oil-cake	**Nitrogen (%)**	**Phosphorus (%)**	**Potassium (%)**
Un-edible oil-cakes			
Cake of castor	4.30	1.80	1.30
Cake of cotton seed (un-decorticated)	3.90	1.80	1.60
Cake of karanj	3.90	0.90	1.20
Cake of mahua	2.50	0.80	1.20
Cake of safflower (un-decorticated)	4.90	1.40	1.20
Edible oil-cakes			
Cake of coconut	30	1.90	1.80
Cake of cotton seed(decorticated)	6.40	2.90	2.20
Cake of groundnut	7.30	1.50	1.30
Cake of linseed	4.90	1.40	1.30
Cake of niger	4.70	1.80	1.30
Cake of rape seed	5.20	1.80	1.20
Cake of safflower (decorticated)	7.90	2.20	1.90
Cake of sesamum	6.20	2.00	1.20

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Importance of organic fertilizer or manures

In numerous agricultural regions, groundwater contamination occurs due to the utilization of synthetic fertilizers and chemical pesticides. Organic fertilizers promote biodiversity, improve soil structure, and enhance water infiltration. Efficient management of organic systems, which exhibit excellent nutrient retention capabilities, considerably reduces the risk of groundwater pollution. Organic farming contributes to mitigating the greenhouse effect and addressing global warming by sequestering carbon in the soil through carbon capture. The diverse practices utilized in organic agriculture enhance carbon deposition into the soil, resulting in enhanced productivity and increased carbon sequestration. Soil organic matter undergoes mineralization, liberating significant amounts of nitrogen, phosphorus, sulfur, and trace amounts of micronutrients (Rahman *et al.,* 2013). Animal manure is regarded as a valuable source of nutrients when incorporated into the soil at rates that align with sound agronomic practices (Duffera *et al.,* 1999).

Effects of using organic manures on soil characteristics

The decrease in soil organic matter caused by farming practices and erosion has been a significant issue affecting the long-term sustainability of agriculture. As a result, implementing management practices that enhance the organic matter content has been recognized as crucial for improving soil quality and productivity. Continuously applying solid cattle manure results in a rise in soil organic matter. The quantity of soil organic matter relies on the amount of organic materials introduced into the soil, either through natural inputs like root residues, stubbles, root nodules sheddings, and root exudates or through synthetic application in the form of organic manures (Roy and Kashem, 2014).

Soil enzymes integrate the chemical, physical, and biological attributes of the soil and can be employed to monitor the impacts of soil management on sustained productivity. To some extent, enzymatic activities in the soil are influenced by physical and chemical conditions, although the principal restricting factors for microorganisms are temperature and moisture levels (Zhao *et al.,* 2009). The precise quantity of manure can be efficiently determined through accurate measurement of nutrient mineralization, ensuring no yield loss and reduced risk of environmental pollution. The appropriateness of organic materials as fertilizers largely depends on their rate of mineralization and the release of nutrients they contain (Weeraratna, 1979).

Alteration in pH of the soil

The impact of manure on pH of soil varies according to different conditions. The regular application of nitrogenous fertilizers may lead to soil acidification due to acidity produced during the nitrification process. However, the addition of organic matter through manure can help stabilize soil pH. It is important to note that manure with low organic matter content and high ammonium nitrogen can potentially lower pH when ammonium is converted to nitrate in the soil, producing acidity (Ukrainetz, 1996). The application of fresh cattle manure caused a rapid increase in pH for two acidic soils, indicating that the impact of manure on soil pH depends on the specific manure source and soil properties. Manures with high levels of organic matter and carbonate content are particularly effective in raising the pH of acidic soils and providing buffering capacity against pH fluctuations within the soil Whalen *et al.,* 2000).

Improve the structure of the soil

Organic amendments influence the soil's physical structure. Long-term and intensive cultivation causes the deterioration of soil structure, leading to diminished soil quality and productivity. Soil structure pertains to the organization of particles in three dimensions. Soil consists of clusters of particles referred to as aggregates, which are bound together by organic substances, microbially derived organic matter, and occasionally by chemical bonds between positively charged particles (cations) and silt and clay particles. Incorporating manure into the soil enhances the organic matter content, encouraging microbial activity and the synthesis of microbial polysaccharides that aid in the stabilization of soil aggregates. These resilient aggregates positively impact soil moisture, nutrient availability, soil preservation, and permeability. Enhanced permeability and aggregate stability also bolster other physical characteristics of the soil. These advantages encompass diminished soil density and compaction, heightened water holding capacity, enhanced water penetration and movement, and reduced surface crust formation and runoff (Haynes & Naidu, 1998).

Improve the microbes of the soil

The addition of manure leads to the accumulation of organic carbon, which not only increases microbial biomass but also brings changes to the structure of microbial communities and enhances functional diversity. Soils enriched with poultry litter demonstrated greater bacterial diversity concerning both the number of different species and their distribution evenness in comparison to soils treated with synthetic fertilizer (Jangid *et al.*, 2008).

Researchers found a direct and beneficial relationship between microbial diversity and soil organic carbon, indicating that the increased diversity of functions can be linked to the soil's increased carbon availability as a result of the addition of manure. Because microorganisms are so important to nutrient cycling, higher microbial biomass and diversity result in better soil quality. They help break breakdown organic materials and convert manure's organic nitrogen and phosphorus into forms that are readily available to plants (Gomez *et al.*, 2006).

Soil enzymes have a fundamental role in nutrient cycling and the degradation of soil organic matter. Microorganisms and enzymes collaborate to impact nutrient accessibility, organic matter characteristics and amount, and the potential for soil decomposition, ultimately governing soil quality and functionality. The majority of soil enzymes are synthesized by soil microorganisms and are situated extracellularly. Enzyme activities exhibit a robust reaction to manure applications, at times displaying a more significant effect than alterations in microbial biomass or soil community structure, with documented enhancements of two to fourfold. Not only does the carbon content in manure contribute to the escalation of enzyme activities; but soil nitrogen availability also plays a pivotal role in governing the competitive interactions among soil microorganisms, thereby influencing the synthesis of diverse soil enzymes. When manure is added to the soil, the increased availability of nitrogen (N) generally results in enhanced activity of soil enzymes involved in carbohydrate breakdown. Conversely, the activity of enzymes responsible for breaking down aromatic compounds like lignin tends to decrease (Graham *et al.*, 2012).

Improved large organisms of soil

Manure amendments have a significant impact on larger soil fauna, such as protozoa, nematodes, mites, and earthworms. In the immediate period, these organisms may respond to manure additions by increasing both in population size and level of activity owing to the additional organic matter. Furthermore, manure additions can also yield enduring indirect impacts on soil organisms over the long term. These consequences arise from alterations in soil pH, physical attributes like agglomeration and permeability, along with changes in productivity and the quantities of soil organic matter (Bunemann and Van, 2006).

Minute arthropods play a pivotal role in advancing decomposition and nutrient accessibility by consuming crop residues and other organic materials. This process is vital for crop production and maintaining healthy soils. The grazing activities of microarthropods and nematodes on microbes contribute to the release of nitrogen, which becomes accessible during the growing season (Graham *et al.,* 2012).

Reduces the incidence of diseases

Studies have revealed that the application of manure can diminish the abundance of detrimental organisms, encompassing disease-causing pathogens and plant pests. Manure amendments influence various pathogens belonging to bacteria, fungi, and nematode species. Organic amendments like manure have been demonstrated to modify soil's chemical, physical, and biological properties, which can have direct or indirect effects on pathogen survival and crop infection (Graham *et al.,* 2012). The reduction in Pythium spp., a prevalent pathogen responsible for root rot, was associated with the release of ammonia through volatilization from manure amendments (Scheuerell *et al.,* 2005).

Applying liquid swine manure to potato fields decreased the occurrence of common scab and wilt, as well as reduced the population of plant parasitic nematodes for three years following a single application (Conn and Lazarovits, 1999). Fields treated with compost made from poultry and dairy manure showed a significant reduction in red steel strawberry root disease compared to the control group (Millner *et al.,* 2004).

Environmental effects

Despite the fact that applying manure to soils has many positive impacts, it can unfortunately have negative consequences on the surrounding environment. Applying manure increases the transfer of dissolved nitrogen and phosphorus to runoff water, according to numerous studies. When manure is applied frequently in either large or small amounts, there is a risk of exceeding the system's capacity to absorb nutrients, which can result in the release of nitrogen (N) and phosphorus (P). Due to runoff from croplands fertilized with manure, nearby lakes, streams, and other bodies of water have higher concentrations of phosphate and nitrogen. These practises may have negative effects, including eutrophication, an increase in algae, and other unpleasant results.

The function of organic fertilizer in agriculture

The perception that organic produce is healthier and safer to eat than produce cultivated conventionally appears to be a major factor in the surge in consumer demand for it. Comparing organically managed soils to conventionally managed soils, the former often showed higher levels of microbial biomass and labile organic matter. Organic farming practices led to heightened organic matter content, nitrogen mineralization capacity, and microbial biomass when contrasted with plots that received synthetic fertilizers. Organically managed farms showed higher levels of total carbon (C) and nitrogen (N), microbial biomass, soil respiration, and mineralizable nitrogen compared to conventional farms (Liebig and Doran, 1999).

Conclusion:

Fertilizer use in India is inadequate, imbalanced, non-integrated and poorly managed. So, to achieve high crop yields, high and balanced nutrient application is a pre-requisite. To minimize the negative nutrient balance of about 8 to 10 mt of NPK, INM should be popularized in India. Organic manures supply primary (N, P, K), secondary (Ca, Mg and S) and micronutrients (Fe, Mn, Mo, B, Zn, Cu, Co etc.) to plants which are released in the available forms after mineralization, carried out by various micro-organisms present in the soil. Organic manures supply organic carbon in the form of organic matter to soil which influences soil physical properties like structure, aeration, water holding capacity and aggregate formation which will ultimately result higher grain yield. As we know Sustainable agriculture must meet four important criteria such as to produce adequate food of high quality, to environmentally safe, protect the resource base, and it should be profitable. Therefore, the use of concentrated organic manure along with other synthetic fertilizers in site specific dose, time and method can ease the problem of food crisis, marginal profit and poor soil health in long run.

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CHAPTER 7

COMPOSTING: AN EFFECTIVE APPROACH FOR SOIL HEALTH MANAGEMENT

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Introduction:

Soil health is a critical component of sustainable agriculture, environmental conservation, and overall ecosystem balance. However, modern agricultural practices, industrial activities, and urbanization have led to the degradation of soil quality, compromising its ability to support thriving plant life and maintain essential ecosystem services. In recent years, there has been growing concern about the need to restore and maintain soil health for the sake of current and future generations.

Composting has emerged as a powerful and effective approach to soil health management. It offers a natural and eco-friendly solution to improve soil fertility, structure, and resilience, while also addressing the problem of organic waste management. Composting involves the biological decomposition of organic materials, such as kitchen scraps, yard waste, crop residues, and animal manure, into a nutrient-rich, humus-like substance called compost.

Composting is advocated for recycling different types of biodegradable organic matter by converting them into valuable manure. Composting is largely a biological process in which aerobic and anaerobic microorganisms decompose organic matter and narrow down the C/N ratio of substrate used. The final product formed after composting is an amorphous, brown-to-dark brown humified material known as compost. It is a more stable, well–rotten material containing high organic matter and a relatively higher proportion of major nutrients compared to FYM. Composting is not only an effective approach for soil health management but also plays a crucial role in environmental conservation. By diverting organic waste from landfills and reducing greenhouse gas emissions associated with waste decomposition, composting aligns with sustainable practices and contributes to mitigating climate change.

Importance of soil health for sustainable agriculture and ecosystem balance:

Soil health is of paramount importance for achieving sustainable agriculture and maintaining a balanced ecosystem. It plays a crucial role in supporting various ecological processes and directly influences plant growth, food production, and environmental well-being. Understanding the significance of soil health is vital in fostering practices that preserve and enhance this valuable natural resource. Here are some key reasons why soil health is essential for sustainable agriculture and ecosystem balance:

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- **Nutrient cycling and plant nutrition:** Healthy soils are rich in essential nutrients, such as nitrogen, phosphorus, potassium, and micronutrients. These nutrients are crucial for plant growth and are obtained by crops from the soil through a process known as nutrient cycling. Balanced soil nutrition is necessary for high crop yields, improved crop quality, and sustainable food production.
- **Soil fertility and productivity:** Soil health directly affects its fertility and productivity. Fertile soils have a favorable nutrient balance, good soil structure, and an abundance of beneficial microorganisms. Maintaining soil fertility ensures long-term agricultural productivity, reducing the need for external inputs like chemical fertilizers.
- **Water retention and regulation:** Healthy soils have better water-holding capacity, which aids in water retention during periods of drought and improved drainage during heavy rainfall. Proper water regulation in soils reduces the risk of flooding, erosion, and nutrient leaching, promoting a stable and resilient ecosystem.
- **Carbon sequestration and climate regulation:** Soils are a significant reservoir of carbon. Healthy soils with abundant organic matter can store substantial amounts of carbon dioxide (CO_2) from the atmosphere, contributing to climate change mitigation. Sustainable land management practices that enhance soil health can play a role in reducing greenhouse gas emissions and stabilizing global climate patterns.
- **Biodiversity and habitat support:** Soil health is linked to biodiversity, as it provides a habitat for a diverse array of microorganisms, insects, and small animals. A thriving soil ecosystem is essential for supporting a broader ecological balance, including above-ground biodiversity and ecosystem services.
- **Soil erosion control:** Healthy soils with good structure and organic matter content are more resistant to erosion. Soil erosion can lead to the loss of fertile topsoil, reducing agricultural productivity and contributing to sedimentation in water bodies, impacting aquatic ecosystems.
- **Pesticide and fertilizer use efficiency:** Balanced and healthy soils can enhance the efficiency of pesticide and fertilizer usage. Improved soil structure and biological activity can reduce the need for chemical inputs, minimizing potential environmental impacts and reducing production costs.
- **Resistance to pest and disease outbreaks:** Soil health influences plant health and resilience to pests and diseases. Healthy plants grown in well-nourished soils are better equipped to resist and recover from pest infestations and disease outbreaks, reducing the reliance on chemical pesticides.
- **Sustainable land use and land restoration:** Soil health is a key consideration in sustainable land use planning. By adopting practices that promote soil health, such as crop rotation, cover cropping, and composting, degraded soils can be restored and made productive again.

What is composting?

Composting is a natural biological process that involves the decomposition of organic materials into a nutrient-rich, humus-like material called compost. It is a sustainable and eco-friendly method of recycling organic waste and transforming it into a valuable soil amendment. Composting is widely used in agriculture, gardening, and waste management to improve soil health, reduce organic waste sent to landfills, and support sustainable practices.

The composting process can be broken down into several stages:

- Collection of Organic Materials: The first step in composting is the collection of organic materials that will be used as feedstock. These materials can include kitchen scraps (e.g., fruit and vegetable peels, coffee grounds), yard waste (e.g., grass clippings, leaves), agricultural residues (e.g., crop stalks, straw), and other biodegradable waste.
- Shredding and Mixing: To accelerate the composting process and facilitate microbial activity, the collected organic materials are often shredded or chopped into smaller pieces. The materials are then mixed to create a balanced blend of carbon-rich (brown) and nitrogen-rich (green) materials. Achieving the right carbon-to-nitrogen (C/N) ratio is crucial for successful composting.
- Pile or Bin Construction: The mixed organic materials are placed in a compost pile, compost bin, or composting system. The size of the compost pile or bin can vary depending on the available space and the amount of compost being produced.
- Microbial Decomposition: The composting process is primarily driven by microorganisms, including bacteria, fungi, and actinomycetes. These microorganisms break down the organic matter into simpler compounds during their life cycles, consuming oxygen in the process (aerobic composting). In anaerobic composting, microorganisms break down organic matter in the absence of oxygen, but this process is typically slower and can lead to odors.
- Temperature and Moisture Management: As microorganisms decompose the organic matter, heat is generated as a byproduct. This heat raises the temperature inside the compost pile, which is beneficial for accelerating the composting process and killing weed seeds and pathogens. Proper moisture levels (typically around 40-60% moisture content) are essential to keep the composting microorganisms active and efficient.
- Turning and Aeration: To maintain oxygen levels and ensure uniform decomposition, the compost pile needs to be periodically turned or aerated. Turning the compost allows fresh air to reach the center of the pile, supporting aerobic microbial activity.
- Maturation and Curing: Once the composting process is complete, the compost needs to mature and cure for several weeks to several months. During this maturation period, any remaining raw materials further decompose, and the compost stabilizes, becoming mature and ready for use.
- Application and Use: Mature compost is used as a soil amendment, either by incorporating it into the soil before planting or as a top dressing around established

plants. Compost provides essential nutrients, improves soil structure, and enhances overall soil health, supporting healthy plant growth and sustainable agriculture.

Key components: organic matter, microorganisms, and environmental factors

The composting process relies on three key components: organic matter, microorganisms, and environmental factors. Each of these components plays a critical role in facilitating the breakdown of organic materials and transforming them into nutrient-rich compost. Let's explore each of these components in detail:

❖ **Organic matter:**

Organic matter is the primary feedstock for composting. It consists of biodegradable materials derived from plants and animals, such as kitchen scraps (e.g., fruit and vegetable peels, eggshells, coffee grounds), yard waste (e.g., grass clippings, leaves, twigs), agricultural residues (e.g., crop stalks, straw), and other organic materials. The organic matter provides a diverse array of nutrients, including carbon (C), nitrogen (N), phosphorus (P), potassium (K), and various micronutrients, which are essential for the growth and development of plants.

During composting, the organic matter is broken down into simpler compounds by microbial activity. The proper mix of carbon-rich (brown) and nitrogen-rich (green) materials is crucial for maintaining a balanced carbon-to-nitrogen (C/N) ratio, which allows microorganisms to efficiently decompose the organic matter.

❖ **Microorganisms:**

Microorganisms, such as bacteria, fungi, and actinomycetes, are the workhorses of the composting process. They are responsible for breaking down the organic matter into smaller compounds through a process called decomposition. These microorganisms feed on the carbon and nitrogen in the organic matter, releasing carbon dioxide (CO_2) and water as byproducts.

In aerobic composting (the most common type of composting), microorganisms require oxygen to carry out their metabolic processes effectively. Oxygen is vital for maintaining aerobic conditions, allowing the decomposition to occur efficiently and minimizing the production of foul-smelling anaerobic byproducts.

The microbial community in compost is diverse and dynamic, with different species of microorganisms dominating different stages of the composting process. Proper aeration, moisture levels, and a balanced C/N ratio are essential for fostering a healthy and active microbial population during composting.

❖ **Environmental factors:**

Several environmental factors influence the composting process and its effectiveness. These factors include:

Moisture: Adequate moisture is essential for the activity of composting microorganisms. The compost pile should be kept consistently moist, but not waterlogged, to support microbial growth and decomposition.

Temperature: The composting process generates heat as microorganisms break down the organic matter. Maintaining an optimal temperature range (usually between 130°F to 160°F and

55°C to 70°C) accelerates the composting process and helps in pathogen and weed seed destruction.

Aeration: Proper aeration ensures that composting microorganisms have access to sufficient oxygen. Regular turning or aeration of the compost pile allows fresh air to circulate, promoting aerobic decomposition.

pH: The pH of the composting materials can impact microbial activity. Most compost microorganisms function optimally in a near-neutral pH range.

Particle size: Shredding or chopping the organic materials into smaller pieces increases the surface area, aiding microbial access and decomposition.

Time: Composting is a time-dependent process that typically takes several weeks to several months to complete. Adequate time allows microorganisms to break down the organic matter fully and produce mature compost.

Different types of composting methods (aerobic, anaerobic, vermicomposting)

Composting methods can be classified into several types based on the presence or absence of oxygen and the involvement of specific organisms in the decomposition process. Here are three common types of composting methods:

Aerobic composting:

Aerobic composting is the most common and widely used composting method. It relies on the presence of oxygen to support the activity of aerobic microorganisms, such as bacteria and fungi, which break down organic materials into compost. The compost pile is regularly turned or aerated to provide fresh oxygen to the microorganisms and maintain aerobic conditions.

Advantages of aerobic composting:

Faster decomposition: Aerobic microorganisms work more efficiently and break down organic matter relatively quickly.

Reduced odors: Aerobic decomposition produces less foul-smelling byproducts compared to anaerobic methods.

Pathogen and weed seed reduction: The high temperatures generated in aerobic composting can help in killing pathogens and weed seeds, resulting in more sanitized compost.

Anaerobic composting:

Anaerobic composting occurs in the absence of oxygen. Anaerobic microorganisms, such as methanogens, break down organic materials through fermentation processes. This method typically involves compacting organic waste tightly to exclude air.

Advantages of anaerobic composting:

Suitable for certain types of waste: Anaerobic composting can handle certain types of waste, such as kitchen scraps and food waste, without the need for turning or aeration.

Reduced maintenance: Since the pile is not turned or aerated, anaerobic composting requires less frequent maintenance.

Disadvantages of anaerobic composting:

Slow decomposition: The absence of oxygen results in slower decomposition compared to aerobic composting.

Unpleasant odors: Anaerobic composting can produce strong odors due to the release of methane and other gases.

Vermicomposting:

Vermicomposting involves the use of earthworms to facilitate the composting process. Red worms (Eisenia fetida) and other composting worms consume organic materials and break them down through their digestive processes. Vermicomposting is typically done in containers or specialized worm bins.

Advantages of vermicomposting:

Faster composting: Earthworms can accelerate the decomposition process, leading to faster compost production.

High-quality compost: Vermicompost is rich in nutrients and microbial activity, making it an excellent soil amendment.

Disadvantages of vermicomposting:

Specific requirements: Vermicomposting requires a suitable environment for the worms, such as proper bedding and temperature control.

Limited capacity: Worm bins have a capacity limitation, and large-scale vermicomposting may require more space and management.

The role of composting in enhancing soil fertility and structure:

Composting plays a fundamental role in enhancing soil fertility and structure. As organic materials decompose during the composting process, they transform into a nutrient-rich, humus-like substance called compost. When added to the soil, compost provides a multitude of benefits that positively influence soil fertility and structure. Here's how composting contributes to these essential aspects of soil health:

- **Enriching soil with nutrients:** Compost is a valuable source of essential nutrients, including nitrogen, phosphorus, potassium, calcium, and many micronutrients. These nutrients are released slowly and made available to plants over time. By adding compost to the soil, nutrient deficiencies are addressed, promoting healthy plant growth and improving overall crop productivity.
- **Balancing soil pH:** Compost acts as a natural buffer, helping to regulate soil pH. It tends to be close to neutral pH, and when added to acidic or alkaline soils, it can help bring the pH closer to the optimal range for most plants, creating a more favorable environment for nutrient availability.
- **Increasing organic matter content:** Compost is rich in organic matter, which is crucial for soil health. Organic matter improves soil structure, water retention, and aeration. As compost is incorporated into the soil, it boosts the organic matter content, contributing to long-term soil fertility and resilience.
- **Enhancing soil structure:** Compost plays a significant role in improving soil structure. It promotes the formation of soil aggregates, creating a crumbly and well-structured soil. Improved soil structure allows for better root penetration, air circulation, and water infiltration, which are essential for healthy plant growth.

- **Improving water retention and drainage:** Compost enhances the soil's water-holding capacity, reducing water runoff and increasing water infiltration. This property is especially beneficial during dry periods, as it helps retain moisture in the root zone and reduces the risk of waterlogging during heavy rainfall.
- **Stimulating beneficial microorganisms:** Compost contains a diverse community of beneficial microorganisms, including bacteria, fungi, and actinomycetes. When added to the soil, compost provides a favorable habitat for these beneficial soil microbes, which play critical roles in nutrient cycling, decomposition of organic matter, and disease suppression.
- **Reducing soil erosion:** The improved soil structure and increased organic matter content resulting from compost application reduce soil erosion. Soil erosion, which can lead to the loss of topsoil and valuable nutrients, is mitigated by the protective properties of compost-amended soil.
- **Suppressing soil-borne diseases:** Compost has been shown to contain beneficial microorganisms that can help suppress certain soil-borne diseases. These microorganisms can compete with and inhibit the growth of harmful pathogens, reducing the risk of disease outbreaks in the soil.
- **Long-lasting benefits:** Compost's effects on soil fertility and structure are long-lasting. Unlike chemical fertilizers, which provide a quick nutrient boost but do not improve soil structure, compost continuously contributes to soil health over time.

Some of the finding which shows the overall benefits of compost on soil health:

Soil enzymes:

According to Garcia *et al.* (2017), compost appears to be a perfect substitute fertilizing material with a significant impact on soil organic matter and soil microorganisms. Enzymatic activities, which are crucial for mediating biochemical processes, are a good indicator of the ability of the soil to perform biochemical functions and reactions, whereas soil microbial diversity is considered to be a key factor for nutrient cycling and other biological processes in healthy soil (Bünemann *et al.,* 2018). When organic fertilizers were utilized, these enzymatic activity were boosted. For instance, it was discovered that the activity of the enzyme -glucosidase was increased by more than 200% in organically amended soil compared to unamended soil (Medina *et al.*, 2004). Additionally, manure treatment boosts soil organic C and enzymatic activity, and as a result, the increase in total organic C also increased the activity of the enzyme glucosidase (Lupwayi *et al.,* 2019). Microbial activities were improved, and microbial biomass C increased by up to 100%, according to analysis of enzymatic activities and microbial biomass (Bastida *et al.*, 2007). Additionally, it was discovered that applying compost to various soils was a successful way to influence the soil's microbial features (primarily biomass and respiration rate), which improved nearly all stages of plant growth, development, and overall yield (Dukare *et al.*, 2011). In fact, compost offers microorganisms (like bacteria and fungi) that can convert insoluble matter into plant nutrients and degrade harmful substances. This improves soil conditions and offers carbon to maintain the biodiversity of micro- and macro-fauna, including earthworms (Roman *et al.,* 2015). Additionally, it was documented that compost application promotes the activity of diverse groups of rhizospheric microorganisms that promote plant growth (Oehl *et al.,* 2004).

Soil physical properties:

Aggregate stability

Particularly in loam or clay soils where mineral-stabilizing agents are scarce, the dynamics and contents of organic matter have a significant role in the production of stable aggregates. Given that compost has a humus-like texture, adding compost to soil encourages the creation of stable aggregates by binding mineral particles (Duong *et al.*, 2014). Actually, changes in soil aggregates caused by the addition of compost are typically linked to a more active region that encourages intense interactions between soil fauna, microorganisms, and root hairs under ideal conditions (e.g., sufficient humidity). This, in turn, leads to optimal soil formation and has a positive impact on soil fertility while also enhancing the stability of soil aggregates and enhancing soil structure (Amlinger *et al.,* 2007).

Bulk density

Increased soil bulk density is linked to a number of issues, such as excessive soil strength, insufficient aeration, and low water infiltration. This would eventually have an impact on plant growth and would limit root penetration and elongation (Kranz *et al.*, 2020). To enhance soil structure and reduce bulk density, compost treatment is frequently employed, creating a healthy soil environment. This beneficial effect, which is brought on by interactions between organic and inorganic fractions that increase soil porosity (Amlinger *et al.,* 2007), has been seen in the majority of cases with a variety of soil types, application rates, incorporation depths, and compost feedstocks (Kranz *et al.,* 2020).

Infiltration rate and water-holding capacity

The main determinant of how effectively water is used in agriculture is the soil's capacity to hold water. Composting is a fantastic approach to increase soil organic matter because it has been demonstrated that doing so also impacts the soil's capacity to retain water (Richard, 2005). Organic matter in soil is primarily responsible for soil's ability to retain water. Compost is regarded as a water-saving sponge in soils with large granules, such as sandy soils, and it aids in adding porosity to clay soil to make it drain more readily so that it does not remain wet or dry out quickly (Adugna, 2016). Consequently, applying compost is the best and most promising natural fertilizer for addressing the difficulties of climate change and water scarcity, especially for farmers in dry areas semi-arid areas around the world, in which soils have low organic matter content and are subjected to erosion, deterioration and desertification processes (Garcia *et al.*, 2017).

Effect of compost on chemical properties of soil:

Enhancement of nutrient level

The amount of organic matter in the soil has a significant impact on the physical structure and biological activity of the soil, which in turn affects other qualities and establishes the appropriateness of the soil for various activities, primarily agricultural ones (Edwards & Hailu *et* *al.,* 2011). Compost and organic matter are directly related, as is widely known. In fact, applying compost increased soil fertility by enriching organic matter and, in turn, the amount of nutrients in the soil's dry matter (Adugna, 2016). However, each of these nutrients has a significant or modest part in the metabolism of plants. The macronutrients that are available in soil for plant health include N, P, K, Ca, S, Mg, C, O, and H. However, Fe, B, Cl, Mn, Zn, Cu, Mo, and Ni are also present in soil which are the trace elements that plants need in specific amounts (Johns, 1987).

Cation Exchange Capacity (CEC) and pH value

As it prevents cations from seeping into the groundwater, cation exchange capacity is one of the most crucial indicators for assessing soil fertility, specifically for nutrient retention. According to numerous studies, adding stabilized organic matter to the soil especially high dosages of compost increases CEC because it is rich in numerous functional groups. The accumulation of molecules with negative charges, such as lignin-derived products and carboxyl and/or phenolic hydroxyl groups in the soil, is thought to be the cause of this rise in CEC, which is related to the exchangeable base cations (Diacono & Montemurro, 2010). In a study by Liu *et al.* (Liu *et al.,* 2019), compost treatments increased nutrient content, organic carbon content, and cation exchange capacity. With regard to pH, it was found that the initial pH of compost has a direct effect on the change in soil pH. The initial pH of the compost was discovered to directly influence the pH shift in the soil. Accordingly, depending on the original pH of the compost, soil pH is either raised or lowered (Zebarth *et al.,* 1999). Acid soils typically have their pH raised by composts with a near-neutral or slightly alkaline pH and a strong buffering capacity. For instance, adding compost made from municipal solid waste raises the pH of acidic soils. The pH did, however, drop after the application of compost, according to other investigations (Amlinger *et al.,* 2007). These studies attributed this pH drop to the creation of organic acids during the mineralization of organic matter. High-pH soils should be given special consideration since they result in a reduction in the availability of nutrients. Fortunately, the application of stable composts to soils rarely shows a substantial increase in soil pH due to the low buffering capacity of the compost (Taylor *et al.,* 2016).

Compost application as bioremediation agent for contaminated soil

Numerous human activities have resulted in a wide range of contaminants, including but not limited to Pesticides and chlorophenols are continuously making their way into the soil due to petroleum and its byproducts, posing a serious threat to human health and the health of natural ecosystems. It is noteworthy that in certain instances, compost applications in combination with phytoremediation produced positive outcomes (Visconti *et al.,* 2020). For the bioremediation of soils contaminated with polycyclic aromatic hydrocarbons (PAHs), compost application to contaminated soils has been shown to be a practical and ecologically beneficial method (Sayara& Sanchez, 2020). Additionally, as organic matter tends to form powerful complexes with heavy metals, the addition of compost reduced the amounts of heavy metals in soil solution as a result of precipitates or increased metal sorption (immobilization). With heavy metals (Khan *et al.,* 2000). Accordingly, increasing organic matter content resulted in lower Cd and Ni concentrations in soil solution (Arnesen & Singh, 1998). Additionally, according to studies by Angelova *et al.* (2013), the application of compost and vermicompost typically reduced levels of extractable heavy metals in the soil due to the immobilization of heavy metals by humic compounds. When various kinds of organic amendment were utilized, the same tendency was shown with lead and cadmium (Wong & Lau, 1985).

Conclusion:

In conclusion, composting proves to be a remarkable and effective approach for enhancing soil health and fostering sustainable agriculture and environmental conservation. Through the natural process of converting organic waste into nutrient-rich compost, composting offers a multitude of benefits for the soil and the broader ecosystem. By enriching the soil with essential nutrients and organic matter, composting creates an optimal environment for plant growth, promoting healthy crop development, and increasing agricultural productivity. The improved soil structure resulting from compost application allows for better root penetration, enhanced water retention, and improved aeration, supporting plants in accessing vital nutrients and water. Compost also plays a vital role in enhancing the soil's resilience to environmental stresses. It improves water retention, reducing the impact of droughts, while also enhancing drainage, preventing water logging and erosion during heavy rainfall. The addition of compost fosters a thriving soil ecosystem, supporting diverse populations of beneficial microorganisms that aid in nutrient cycling, decomposition, and disease suppression, thus contributing to a more balanced and sustainable environment. Moreover, composting serves as an eco-friendly waste management solution, diverting organic waste from landfills, reducing greenhouse gas emissions, and contributing to climate change mitigation by sequestering carbon in the soil. Composting represents a tangible step towards building a more sustainable future. By adopting composting practices on individual, community, and agricultural scales, we can actively contribute to conserving natural resources, promoting biodiversity, and mitigating the impacts of climate change. As we continue to face global challenges like population growth, food security concerns, and environmental degradation, composting stands as a practical and accessible solution to foster soil health and address these pressing issues. By recognizing the importance of composting and its far-reaching benefits, we can empower ourselves and future generations to cultivate a healthier, more resilient, and sustainable planet. In this pursuit, education, awareness, and active participation are key. Governments, organizations, and individuals must collaborate to support composting initiatives, develop sustainable waste management practices, and promote responsible land use. Together, we can harness the potential of composting to nourish the soil, nurture biodiversity, and create a more harmonious and thriving coexistence with the natural world. In the journey towards a greener and more sustainable future, the composting serves as a beacon of hope, guiding us towards a healthier and more resilient planet for generations to come. Embracing composting practices is not only an investment in the soil's well-being but also a testament to our commitment to preserving the beauty and abundance of the Earth's natural ecosystems. Let us sow the seeds of composting today, reaping the bountiful rewards of a thriving and sustainable tomorrow.

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CHAPTER 8

VERMICOMPOST: A VIABLE RESOURCE IN ORGANIC FARMING

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Introduction:

Climatic changes occurred due to natural events such as solar radiation and continental drift as well as human activities, broad deterioration of the environment has occurred and increase in the world's population is posing a significant challenge to agriculturalists. Chemical fertilizers are used to provide nutrients to plants and maximize crop yield in a short period of time but their widespread use contributes significantly to environmental degradation through the depletion of fossil fuels, the production of carbon dioxide (CO_2), the contamination of water resources and the deterioration of soil fertility (Nagavallemma *et al.* 2004). One of the key concerns is the adoption of environment friendly approaches to reverse the long-term and diminishing effects on global production. Organic farming which works in harmony with nature and produces high-quality food without the use of hazardous chemicals is becoming increasingly popular around the world. Seeking out microbes-based preparations such as organic manures, biofertilizers and so on is one of the most viable, pollution-free, ecofriendly, biodegradable, inexpensive and renewable alternatives for use in organic farming systems for sustainable agriculture. (Brahmaprakash and Sahu, 2012; Geetanjly *et al.* 2015). Vermicompost as organic manure is being popularized for producing high quality organic fertilizers because importance of organically grown products is in demand at present due to health awareness. Aristotle referred to worms as the "intestines of the Earth," and Charles Darwin wrote a book on worms and their activities in which he noted that there may not be any other species that has played such an essential role in the history of life on Earth and referred to them as 'unheralded soldiers of mankind' and 'friends of farmers' (Neelima *et al.*, 2020). Vermiculture is a sustainable method that involves the breakdown of organic waste by particular species of earthworms into nutrient-rich liquid substances known as vermicasts. (Quaik *et al.* 2012). Earthworms consume organic waste and their gut serves as the bioreactor in which vermicasts are produced (Manyuchi and Phiri, 2013). Vermicasts are also termed vermicompost and are rich in macronutrients viz nitrogen (N), phosphorous (P), potassium (K) and micronutrients such as copper, iron, manganese and magnesium etc. depending on the kind of feedstock used (Palanichamy *et al.*, 2011). Below are the key steps involved in vermicompost production:

Selection of suitable earthworm

Earthworms that can be found nearby are also utilized for vermicomposting, but they feed extremely slowly and are not good for making vermicompost because they dwell underground. African earthworms (*Eudrilus eugeniae*), red wigglers (*Lumbricus rubellus*) and red worms

(*Eisenia foetida*) are promising worms used to produce vermicompostdue to their efficient composting abilities and tolerance to environmental conditions.

1. African Night crawlers (*Eudrilus euginae*): They are hermaphrodites (male and female reproductive organs are present in each worm. They get mature in 6 weeks and their population doubles in about a month. The temperature requirement is about 25°-29°C under shade conditions.

2. The compost worm (*Eisenia foetida*): The cocoons of E. foetida can survive in an unprotected freezing and remain viablefor several weeks. This species has ability to combine with very high and fast reproduction rates that allows these surface-dwellers and non-burrowing worms to thrive in regions with long and cold winters. All these worms can be used singly or in combination of two or more.

Nature of worm

1. *Eisenia foetida* is mostly used for vermi-composting, because this worm is heavy feeder and turns compost within a short period compared with other worms.
2. *Eudrilus eugenae* is used for vermiculture due to its rapid multiplication.
3. Life cycle of these species is almost one year.
4. It casts/lays 2 eggs or cocoons/ worm once a month within its life cycle.
5. Its cocoon contains at least 2 worms. Compost worms are heavy feeders. Under ideal conditions, they are able to consume in excess of their body weight each day, although the general rule-of-thumb is ½ of their body weight per day.

Selection of site

Vermicompost can be produced in any place with shade, high humidity and cool conditions. Abandoned cattle shed or poultry shed or unused buildings can be used. If it is to be produced in open area, shady place is selected. A thatched roof may be provided to protect the process from direct sunlight and rain. The waste heaped for vermicompost production should be covered with moist gunny bags.

Different structures for vermicompost production

A cement tub may be constructed to a height of2.0- 2.5 feet and a breadth of 3 feet. The length may be fixed to any level depending upon the size of the room. The bottom of the tub is made to slope like structure to drain the excess water from vermicompost unit. A small tank is necessary to collect the drain liquid. Vermicompost can also be prepared in wooden boxes, plastic bin or in any containers (except metal) with a drain hole at the bottom.

Materials required

1. Vermi bin/cemented tank	4. Waste materials	7. Gunny bags
2. Thatch roof	5. Cow dung	8. Plastic net (Happa)
3. Polythene sheet (black)	6. Water	9. Vermi worm

Procedure for vermicomposting

1. The compost can be prepared in concrete tank (size should depend upon the availability of raw materials) to be used.

2. Collect and heap the weed biomass under sun for about 7-10 days or until well decomposed. Chop the hard materials required.
3. Sprinkle cow dung slurry on the heap for quick decomposition.
4. Place a thin layer of surface soil/sand (1-2 inch) at the bottom of the tank.
5. Place fine bedding material such as partially decomposed cow dung/dried leaves etc. over the soil or sand layer.
6. Place the chopped bio-waste and partially decomposed cow dung layer-wise in the tank up to adepth of 0.5-1.0 ft.
7. Release about 1000-2000 worms/m^2 of any of the above earthworm species over the mixture. 8. Cover the compost mixture with dry straw or thatch or gunny bag.
8. Sprinkle water as and when necessary to maintain 70-80% moisture content.
9. Provide shade over the compost mixture to protect from rain water and direct sunshine.
10. Stop sprinkling of water when 80-98% bio waste is decomposed. Maturity could be judged visually by observing the formation of granular structure of the compost at the surface of the tank.
11. Collect the vermicompost by scrapping layer-wise from the top of the tank and keep it under shade.

Separation techniques

1. Heap the harvested vermicompost for 6-12 hrs. Under shade for separation of the worm.
2. Make small balls of cow dung are kept inside the heap for 2-3 days.
3. Remove the balls and earthworm can separate from the whole compost for reuse.
4. Sieve gently the vermicompost and pack it for further use or sale.
5. Dry vermicompost (if necessary) under shade to keep the moisture content below 20 per cent.

Chemical composition

Nutrients	**Percent**
Nitrogen	1.5-3.0
Phosphorus	1.2-1.8
Potassium	1.5-2.4
Calcium	0.5-1.0
Magnesium	0.2-0.3
Sulphur	0.4-0.5
Iron	0.8-1.5
Copper	22-36
Zinc	500-1000 ppm
Manganese	1000-2000 ppm

Characteristics of vermicompost

1. Nutrient content of vermicompost is higher than traditional composts.
2. Vermicompost harbors certain microbial populations that help in N fixation and P solubilization.
3. Its application enhances nodulation in legumes and symbiotic mycorrhizal associations with the roots.
4. Superiority of vermicompost over other synthetic growth media is more pronounced in plant nurseries.
5. It can be used as rooting medium and for establishment of saplings in nurseries.
6. It improves taste, lustre and keeping quality of the produce.
7. It has immobilized enzymes like protease, lipase. amylase, cellulase and chitinase which keep on their function of biodegradation of agricultural residues in the soil so that further microbial attack is speeded up.
8. It does not have foul odour as is associated with manures and decaying organic wastes.

Benefits

1. Improving soil biological properties: It helps in soil enrichment of micro-organisms, addition of plant hormones such as auxins and gibberellic acid and addition of enzymes, such as phosphates, cellulase etc.
2. It attracts deep-burrowing earthworms already present in the soil.
3. Nutrient-rich soil amendment: Vermicompost is an excellent source of essential plant nutrients such as nitrogen, phosphorus, potassium, calcium, and magnesium. These nutrients are released slowly and in a form, readily available to plants promoting healthy growth and development.
4. Improved soil structure: The organic matter in vermicompost helps improve soil structure by enhancing soil aggregation and water retention capacity. It also increases soil porosity, allowing better aeration and root penetration, thus creating a healthier environment for plant roots.
5. Enhanced plant growth and yield: The balanced nutrient content and beneficial microorganisms in vermicompost support robust plant growth and higher crop yields. It enhances seed germination rates, increases fruit and flower production and improves overall crop health.
6. Suppresses plant diseases and pests: Vermicompost contains beneficial microbes, such as bacteria and fungi that can help suppress harmful pathogens and pests. These beneficial microorganisms create a more resilient and disease-resistant ecosystem.
7. Soil pH balance: Vermicompost acts as a natural pH buffer helping to balance the soil pH levels. It prevents extreme acidity or alkalinity, creating a more neutral and suitable environment for various plants.
8. Environment friendly: Vermicomposting is a sustainable and eco-friendly method of waste recycling. It converts kitchen scraps and organic waste into a valuable resource, reducing the amount of waste sent to landfills and minimizing greenhouse gas emissions.

9. Reduced dependence on synthetic fertilizers: By using vermicompost, organic farmers can reduce their reliance on synthetic fertilizers, which often come with environmental concerns and potential negative impacts on soil health in the long term.
10. Carbon sequestration: Vermicomposting promotes carbon sequestration in the soil, helping to mitigate climate change by capturing carbon dioxide and storing it in the soil as stable organic matter.
11. Soil biodiversity and microbial activity: Vermicompost supports soil biodiversity by providing a habitat for beneficial microorganisms. These microorganisms contribute to nutrient cycling, decomposition of organic matter, and overall soil health.
12. Safe and non-toxic: Vermicompost is safe to handle and use, making it suitable for organic farming practices. It does not contain harmful chemicals or synthetic additives that could potentially harm plants, animals or humans.

Application rate (Source: KVK, Patan, Gujarat)

It can be applied in any crop at any stage, but it would be more beneficial if mixed in soil after broadcasting. The rate of application is as-

- ✓ Field crops : 5-6 t/ha
- ✓ Vegetables : 10-12 t/ha
- ✓ Floweringplants : 100-200 g/sq ft
- ✓ Fruit trees : 5-10 kg/tree

Vermicompost as a resource in organic farming

In essence, vermicompost serves as a natural and renewable resource that aligns with the principles of organic farmingThe principles of organic farming aligns closely with the use of vermicompost, a nutrient-rich and biologically active soil amendment produced through the decomposition of organic matter by earthworms in the following terms:

1. **Health:** Organic farming prioritizes the health of both the environment and consumers. Vermicompost enhances soil health by providing a balanced and natural source of nutrients, fostering healthier plant growth. This translates to healthier crops that can contribute to a more nutritious and safe food supply.
2. **Ecology:** The use of vermicompost embodies ecological principles by recycling organic waste materials and converting them into a valuable resource. This reduces waste in landfills, promotes nutrient cycling, and supports the health of soil organisms and beneficial microorganisms in the soil ecosystem.
3. **Fairness:** Vermicomposting contributes to fairness by reducing the reliance on external inputs like synthetic fertilizers, which can have economic and social implications. Additionally, the practice of vermicomposting can be integrated into local and community-based initiatives, fostering fair trade and equitable access to resources.
4. **Care:** Vermicomposting exemplifies care for the environment by transforming organic waste into a beneficial soil amendment, reducing pollution and promoting sustainable waste management practices. It also cares for the soil by improving its structure, water-holding capacity, and nutrient availability.

5. **Prevention:** The use of vermicompost aligns with the prevention principle by enhancing soil health and fertility, which reduces the need for synthetic fertilizers and chemical pesticides. Healthy soils are more resilient to pests and diseases, minimizing the need for external interventions.
6. **Substitution:** Vermicompost serves as a natural substitute for synthetic fertilizers, providing essential nutrients in a form that is released slowly and in sync with plant needs. This minimizes the risk of nutrient runoff and pollution while maintaining soil fertility.
7. **Diversity:** Organic farming encourages biodiversity, and vermicompost contributes to this principle by promoting the growth of diverse soil organisms. Earthworms and microorganisms thrive in vermicompost-amended soils, enhancing soil biodiversity and improving nutrient cycling.
8. **Recycling:** Vermicomposting embodies the recycling principle by converting organic waste materials (such as kitchen scraps and agricultural residues) into a valuable resource for soil improvement. This closed-loop system reduces the need for external inputs and minimizes waste.
9. **Renewable resources:** Vermicompost is derived from renewable resources i.e., organic matter from plants and animals, which aligns with the organic farming principle of using sustainable, renewable inputs to support soil fertility and plant growth.
10. **Local adaptation:** Vermicomposting can be adapted to local conditions and resources, making it a versatile and customizable practice within organic farming systems. It can be implemented on small or large scales, in rural or urban environments, contributing to the resilience and adaptability of local agricultural systems.

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CHAPTER 9

APPLICATION OF BIOCHAR: AN EFFECTIVE WAY OF IMPROVING SOIL FERTILITY

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Introduction:

Biochar is defined as the carbon formed by slow pyrolysis biomass under an oxygen-free or stressful environment. Charcoal is good e.g. biochar is produced from biomass. Using of as soil amendment. Agro Ecosystems all over the world are severely stressed. According to Mueller *et al.* (2012), agricultural and forestry production systems have grown increasingly reliant on chemical products and technological inputs as a result of the challenge of feeding the expanding population and meeting the constantly rising demands for fiber and other natural products. According to a report, biochar and compost mixtures are growing in popularity for enhancing soil fertility, soil health, and plant growth by Schulz & Glaser, 2012. Prost *et al.*, 2013, suggested by Godlewsk*et al.* (2017) have discovered that the characteristics of the feedstock influence biochar's impact on composting. According to some research studies, the formation of functional groups in O_2 during the composting process improves nutrient retention (Schulz *et al.*, 2014). The procedure enables the biomass to retain more nutrients, raising the value of the finished good. As research done by Wu *et al.* (2017) in another recent review, biochar & composting would alter the physico-chemical properties of both materials. An intriguing alternative to inorganic fertiliser and source of the amendment is the combination of biochar and compost. Black carbon, which makes up a sizeable portion of the organic carbon in the soil, is produced when biomass is burned. Black carbon is resistant and can potentially sequester carbon over an extended period in soil because of its aromatic structure. There are numerous locations where the Amazon Basin's soils have **"dark earth of the Indians"** Amazonian Dark Earths exist. The mineral elements with the levels of the parts can be directly correlated with biochar of the feedstock before burning as suggested by Lehmann *et al.* 2011. The significance of incorporating biochar into soil mycorrhizal fungi has also been reported a fungal-free physical niche is provided by biochar. However, this use of biochar is not new since it was used long before, unknowingly. It was used because it increases the productivity. Some of the practices are followed in the northeastern states of India.

Food stocks for preparing food char

Biochar obtained by slow pyrolysis from ware has the goal of soil improvement. Nature & quality of biochar depends upon the type of feedstock used. Most biological sources can be conveniently used production of biochar. The biochar formed should not contain any hazardous materials. Biomass is regarded as a complex solid material, composed of biological, organic, or inorganic material which was derived from living or living organisms. Biomass is characterized into two types

(i) Woody biomass

(ii) Non-woody biomass

Woody biomass essentially includes tree residues and forestry residues. The moisture in the biomass can exist in different forms such as water, water vapor and adsorbed within the pores of biomass. Higher moisture content in biomass majorly inhibits the formation of char and raises the amount of energy needed to attain the pyrolysis temperature. Low moisture content in the biomass is preferable for biochar formation because of the impressive decrease in the energy & the reduction of time needed for the pyrolysis process which makes biochar formation feasible when compared with biomass with high moisture content.

Applications of biochar

Fertility of the soil

Biochar can improve soil fertility stimulating plant growth, and nutrient availability which then consumes more carbon-dioxide in a positive effect.

Fertilizer inputs are reduced

Biochar will reduce the chemicals and fertilisers, which decrease greenhouse gas emissions from fertiliser manufacture

Decreased nitrous oxide and methane emissions

Nitrous oxide & methane, two potent greenhouse gases produced by agricultural soils, can be reduced through the use of biochar. Dangerous gases are present in nature.

Increase microbial life in the soil

Biochar can increase soil microbial life causing increased soil carbon storage.

Decrease emissions from raw materials

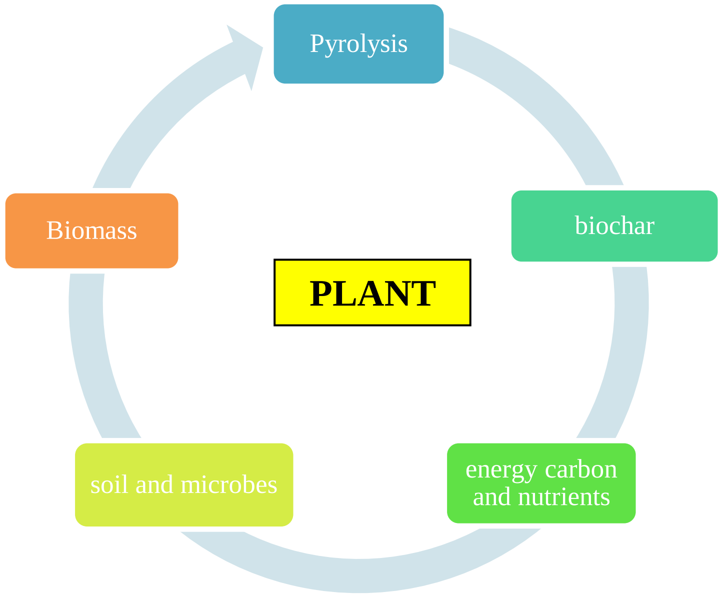
Converting agricultural & and forestry waste into biochar, carbon dioxide and methane emissions that would otherwise be produced by the waste's natural decomposition or burning are avoided.

Energy generation

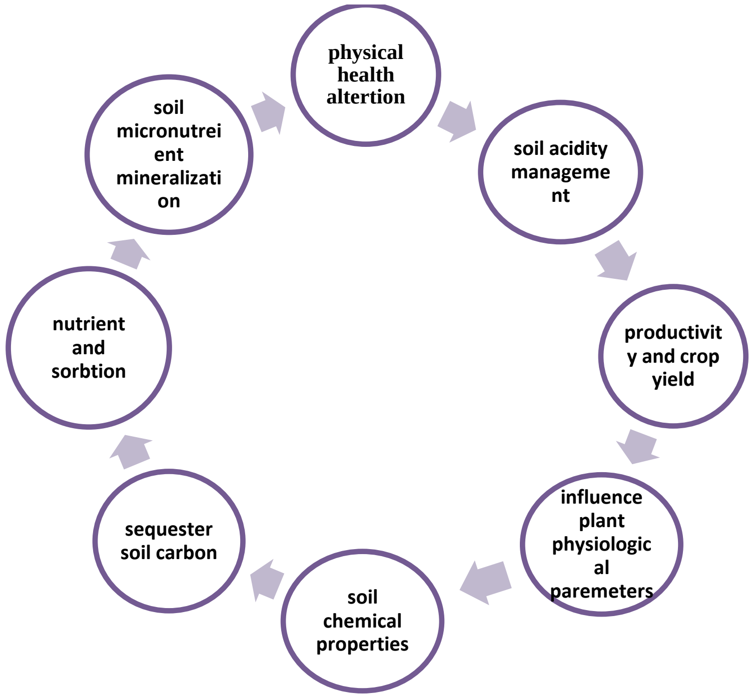
Heat energy & also the bio-oils & Synthesis gas emissions from the production of the biochar also be used to replace carbon-positive energy from fossil fuels.

Mechanism of biochar

As the plant's biomass is produced. In the pyrolysis process biochar is produced at the temperature is about 300–600°C. Due to this energy of carbon and nutrients will be an uprising in the soil as a result the nutrients will be increased the soil & soil-microbes will be increased due to this soil health & recycling of nutrients in the Takes place so the nutrients in the soil will be available and nutrients will be greater absorbed by the plants.



Functions of low-cost biochar amendment in agro-environment



Biochar's chemical composition

The application of biochar led to an improvement in soil pH. The biochar made from chicken litter makes it easier to lime soil, which raises pH of neutral soils. This capability is connected to the biochar's liming value. When biochar made from paper mill sludge was applied to acidic soil at a rate of 10 tonnes per ha however not to an impartial soil, wheat height increased by almost 30 - 40 percent. The obstinate character of the carbon in the biochar, which is highly resistant to decomposition may have contributed to an increase in soil organic carbon by the application of biochar. It was also reported that soil carbon increased noticeably compared to control. Applying the adding biochar and organic matter to forest soils or synthetic fertilisers has been discovered to improve bioavailability of available N, P, and K. The bio char made from chicken litter makes it easier to lime soil, which increases the pH of neutral or acidic soils.

Studies have shown that high application rates of biochar (10% or 20%, w/w) significantly decreased ammonium volatilization due to its high cation exchange capacity, and the skill is connected to the weathering of biochar in soil, which accelerates the immobilisation of nitrogen on its surface.

Biological activity

The addition of carbon to the soil, basal respiration of the microbial biomass increases. The amount of soil bacteria in the biochar is not directly connected to the quantity. Therefore, biochar with a higher porosity makes soil more favorable conditions for microorganisms to establish a home. According to scientific theory, biochar helps microbial communities by creating environments that are suitable for micro-organisms that guard them against predators. Most types of bacteria, fungi, lichens, and algae are found in microbial cells, which typically come in sizes between 0.5 and 5 meters. Pietikäinen *et al.*, 2000

Biochar applications in organic pollutants

In recent times the contamination of soil and water resources by organic contaminants has been a significant issue in areas of high population and modernization. The pore network of biochar is typically made up of micropores 2 nm, mesopores 2–50 nm, & macropores > 50 nm. However, the majority of the surface area and high adsorption capacity of biochar are provided by micropores and small mesopores (2–20 nm)

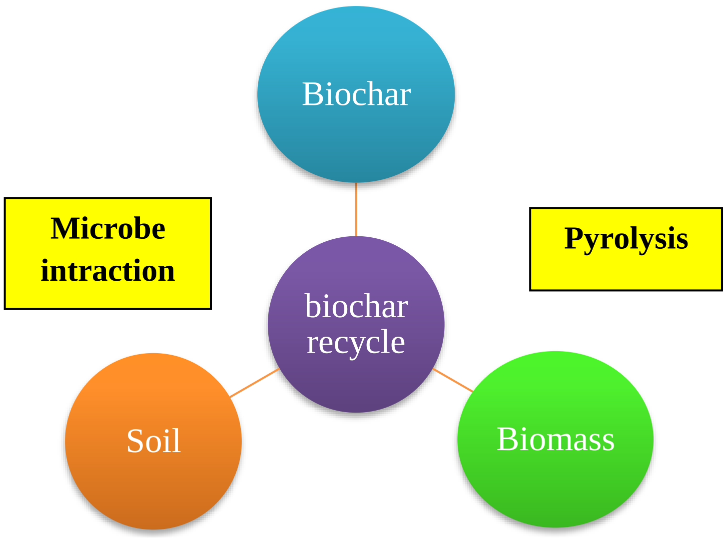
Applications of biochar for capturing carbon in soil & mitigate green house gases emissions

Biomass in India availability estimated (2010–2011) with a 500 Mtpa. The annual production of bio-manure is 32,582 tonnes. Farmers themselves are consuming the potential 61.1 MMT of fuel crop residue (241.7) MMT of fodder crop residue. 17,500 MW of biomass energy can be in India. Currently, 2665 MW of power are being produced, including 1666 MW from cogeneration. According to studies funded by the Ministry of New & Renewable Energy, the government's surplus biomass availability is estimated to be between (120 and) 150 Mtpa. About 93 Mt. of crop residues are burned annually from this. The highest crop residue production occurs in Punjab 50 Mt & Uttar Pradesh 60 Mt. One strategy to control soil quality, fertility, and reduce GHG emissions is to effectively utilise this biomass by turning it into a valuable source of soil amendment. Srinivasarao *et al.* 2010.

A stable solid with high carbon content and an aromatic structure, biochar is known for being extremely resistant to microbial decomposition. Lehmann *et al.* (2010) reported that biochar application has attracted increasing interest as a sustainable technology to enhance severely weathered/degraded tropical soils. Inhibiting either the stage of nitrification or denitrification or encouraging the reduction of nitrous oxide, biochar can reduce nitrous oxide emission from the soil. These effects may take place simultaneously in soil. A number of workers have stated that adding biochar to soils has improved the yield of a number of crops. Similar to this, it has been discovered that biochar interacts favorably with rhizobacteria that encourage plant growth.

Biochar prospects and essential research

Possibilities of biochar reach far beyond slash & char the majority of biochar research was confined to the humid tropics and was inspired by the recreation of Terra Preta. More details are required regarding the agronomic and physiological function of biochar, the potential to use alternative biomass sources crop residues & the production of by-products to evaluate the opportunities for adopting a biochar system on a global scale. Now the majority of biochar research was confined to the humid tropics and was inspired by the recreation of Terra Preta. More details are required regarding the agronomic biochar as a by-product might offer an opportunity to address these problems. Biochar can be produced by incomplete combustion from any biomass, and it is a by-product of the pyrolysis technology used for biofuel & ammonia production. The biochar as a carbon sink would facilitate Carbon trading mechanisms. The scientists agree the half-life of biochar is in the range of centuries, better knowledge of the use of biochar's durability in different ecosystems is important to achieve the goal.



Recyclcling of biochar

Application rate & frequency

Biochar has great potential in production & climate change mitigation In horticulture crops biochar should be applied near the root zone Many researchers found that 5-20 t/ ha. Making use of biochar even to tune that 50 t/ha was attempted by the researchers. If the biochar is applied when FYM, compost, slurry, vermicompost, lime, etc. the efficiency of biochar will be improved

Conclusion:

Energy derived from crop wastes and residues reduces the consumption of fossil fuels, such as carbon dioxide, carbon monoxide, and other harmful gases. It also provides agricultural farmers & rural areas with a brand-new source of income. According to a global analysis, replacing slash & burn with slash & char could annually offset 12 percent of the total anthropogenic/human activities Carbon emissions by changing land use (0.21 Pg C). Waste from forestry and agriculture is thought to contribute 0.16 Pg C annually. Biochar sequestration could surpass current emissions from fossil fuels (5.4 Pg C year) if the demand for renewable fuels in 2100 were to be satisfied through the pyrolysis method. The combination of driving forces & technologies may allow the use of leftover waste carbon. rich residues to reshape agriculture, balance carbon & address nutrient depletion.

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CHAPTER 10

SOIL HEALTH MANAGEMENT IN DRYLAND AREAS

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Introduction:

Drylands cover approximately 41% of the world's land area comprises of drylands, which supports two billion people. Drylands have an aridity index of less than 0.65. Drylands are characterized as places of water scarcity, wherein the rainfall may be limited or may only be abundant for a short span of time. They experience high mean temperatures resulting in high rates of water loss through evaporation and transpiration. Climatic variations and devastating human activities like deforestation, overgrazing and unsustainable agricultural practices make drylands vulnerable to land degradation. As a result of such activities soil erosion, soil nutrient loss, changes in salt concentration in the soil and disequilibrium in the carbon, nitrogen and water cycles occur. Limited agricultural productivity and water scarcity are the result of low precipitation and prolonged dry spells in such areas. An environmental extreme of hot and cold temperatures along with low water availability constrains the soil fertility in dryland areas. These soils thus have low soil organic matter (0.1 to 3%), low availability of nitrogen and phosphorus, low water-holding capacity, high pH, shallowness, stoniness, and other specific problems. The biological activity of such soil is much lower compared to humid areas. The organic carbon content of such soil is also low, often less than 1% of the soil mass. Nutrient cycling is disturbed by low and erratic rainfall, wide temperature extremes, alkalinity and/or salinity, wind erosion, etc. All these constraints lead to low production and therefore, adopting measures to increase production becomes necessary. Conservation agriculture makes efficient use of the resources available for agricultural production. Crop rotation has a beneficial effect on soil fertility. Leguminous trees often grown in hedgerows or intercropped with annual crop improves the water and nitrogen content of soil. The use of low-cost organic inputs (animal manure and crop residues) improves the structural and chemical properties of soil and thereby replenishes macro- and micronutrients. In order to improve crop yield, management of weeds and diseases is an integral part. Thus, to minimize losses and maximize recycling of nutrients integrated management of rangeland, feeding systems, manure management, and composting is required which optimally sustains soil fertility thereby improving crop yield. Moreover, conservation of soil moisture and water harvesting is of the utmost need in dryland areas in order to improve crop yields.

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Dryland:

Drylands are areas characterized by low overall amounts of precipitation in the form of rainfall or snow. According to modern concept, Dryland areas are those areas where the balance of moisture is always on the deficit side. In other words, the annual evapotranspiration in such areas exceeds the precipitation. Drylands covering 41% of the earth's land surface is known to provide 44% of the world's cultivated systems and 50% of the world's livestock. Drylands are found on all continents and include grasslands, savannahs, shrublands and woodlands. They are most commonly found in Africa and Asia. The Sahel region in Africa and almost all of the Middle East are drylands. Dryland is designated by the aridity index. The aridity index is the ratio between average annual precipitation and total annual potential evapotranspiration.

Based on the aridity index, Drylands has been subdivided into four categories:

1. Hyper-arid deserts (aridity index < 0.05)
2. Arid (aridity index 0.05-0.20)
3. Semiarid (aridity index 0.2-0.50)
4. Dry sub-humid (aridity index 0.5-0.65)

Drylands are characterized as places of water scarcity, wherein the rainfall may be limited or may only be abundant for a short span of time and extremely high levels of climatic uncertainty, they experience high mean temperatures resulting in high rates of water loss through evaporation and transpiration. Many areas can experience varying amounts of annual precipitation for several years.

Climatic variations and devastating human activities like deforestation, overgrazing and unsustainable agricultural practices makes dryland vulnerable to land degradations. As a result of such activities soil erosion, soil nutrients loss, changes in salt concentration in the soil and disequilibrium to the carbon, nitrogen and water cycles occurs. Limited agricultural productivity and water scarcity are the result of low precipitation and prolonged dry spells in such areas.

Biological or economic productivity suffers loss and the complexity of land is reduced due to land degradation. 25-35% of drylands are already degraded, directly affecting over 250 million people and further risking about one billion people in over one hundred countries.

Desertification is the land degradation in drylands, *i.e.,* the loss of the biological or economic productivity of land. Desertification reduces agricultural output which in turn contributes to droughts and increases vulnerability of humans to climate change. One of the major causes and outcomes of land degradation is the loss of biodiversity in drylands, including bacteria, fungi and insects living in the soil. Restoring rangelands and sustainable land management practices is a must in order to preserve dryland biodiversity, restore ecosystem functions and halt land degradation.

Drylands are known to support an impressive array of biodiversity which includes wild endemic species, such as the Saiga Antelope in the Asian steppe and American bison in the North American grasslands that do not occur anywhere else on earth and cultivated plants and livestock varieties. Biodiversity in drylands also includes organisms inhabitating soil, such as bacteria, fungi and insects (soil biodiversity) which are uniquely adapted to the conditions. Soil biodiversity comprises the largest variety of species in drylands, thus, determining carbon, nitrogen and water cycles and thereby, the productivity and resilience of land. One of the major cause and outcome of land degradation is the loss of biodiversity in drylands.

In drylands low precipitation and prolonged dry seasons can lead to water scarcity and limit agricultural productivity. Soil fertility and moisture are maintained by dryland biodiversity which ensures agricultural growth, and reduces the risk of drought and other environmental hazards. For instance, vegetation is decomposed in the gut of large herbivores in the drylands, after which the dung is transformed into nutrients by the soil bacteria, which are then absorbed by plants. Plants and animals are also decomposed by microbes in soil thereby converting them to soil organic matter which helps the soil to easily absorb rainwater and retain moisture. Each gram of organic matter increases soil moisture by 10-20 grams. It is a known fact that each millimeter of additional infiltration of water into the soil equals one million additional litres of water per square kilometer.

The ability of drylands biodiversity to perform nutrient recycling, and water storage and filtration services are undermined by poor crop-soil management, and habitat destruction activities. On severely degraded land such as devoid of biodiversity, as little as 5% of total rainfall may be used productively. According to an estimated report, every year 20 million hectares of fertile land is degraded and in the following 25 years, global food production could decline up to 12% as a consequence of land degradation, thereby threatening the food and water security of the increasing human population.

Soil types in dryland areas:

Five types of soils are commonly found in dryland areas. The laterites and lateritic soils predominate in high-rainfall regions and coastal areas.

a. **Black soils**

   The black soils are characterized as deeper soil, clay to clay loam in texture, low permeability and high water holding capacity. They have a slioght alkaline reaction, calcareous in nature, have a low infiltration rate, high plasticity and stickiness, low organic matter content, high CEC, therefore pose problems of management practices, e.g., Vertisols when kept fallow during Kharif become vulnerable to soil erosion hazards.

b. **Red soils**

   The red soils are light textured, shallow to medium in depth, and failrly porous. The soils have low water holding capacity because of compact subsoil and are prone to erosion and surface crusting. Crusting just after seeding leads to poor emergence of seedlings, particularly in small seeded crops like finger millet and pearl millet.

c. **Alluvial soils**

   These soils are deep, fairly level, light to medium textured having favorable physical characteristics and good permeability. Small showers are useful and there is efficient utilization of most of the water held by the soil due to low moisture content at wilting point.

d. Sierozemic soils

These soils are alluvial sandy loams in texture and structure, very deep having low soil moisture storage, instability of soil structure and poor soil fertility. Moreover, high wind velocity leads to severe wind erosion. Soil drifting results in soil and nutrient losses. Desirable crop stand is limited by surface crust formation after sowing following light showers.

e. Submontane soils

Distributed in the dry sub-humid environment of Hosiarpur in Punjab and RakhDhiansar in Jammu and Kashmir and the humid tract of Dehradun, the soils range from loamy sands to sandy loams, silty loams and clay loams in texture with soil moisture storage capacity improving in that order. These soils of dry and sub-humid regions are seen to be affected by soil crusting.

Soil fertility status and factors affecting soil fertility in dryland areas:

Drylands are considered to be areas where average rainfall is less than the potential moisture loss through evaporation and transpiration. About 47 percent of the surface of the earth can be classified as dryland (UNEP, 1992). These areas are characterized by a low mean annual precipitation to potential evapotranspiration ratio ranging from 0.05 to 0.65. Due to climatic limitations, the soils of these areas have an inherent low organic carbon stock. However, they contain a significant amount of inorganic C in the form of soil carbonates which is of a persistent nature.

An environmental extreme of hot and cold temperatures and low water availability constrains soil fertility in drylands. These soils have inherently low fertility, low availability of nitrogen and phosphorus, low water-holding capacity, high pH, low soil organic matter (0.1 to 3%), shallowness, stoniness, and other specific problems (Matar *et al.*, 1992). These areas occupy around 30–40% of the world's terrestrial surface.

Most of the dryland soil varies from sandy, shallow, low fertility soils to highly productive, medium to fine textured and deep soils. The climate strongly influences the soil characteristics. Many of the upland soils in the tropical dryland areas are sandy, often gravelly and shallow, with low water holding capacity, thus having difficulty in dealing with the detrimental effects of erratic and limited precipitation, Yet another problem of these areas is soil erosion. In dryland areas, soil hardening and crusting are very common, resulting in large amounts of runoff. Furthermore, dryland soils have toxic levels of aluminum which has resulted in soil acidity. Lower organic matter levels and periods of extreme dryness have resulted in low biological activity in drylands. Furthermore, low and erratic rainfall affects nutrient cycling in drylands. The areas have wide temperature extremes, alkalinity and/or salinity. In extremely dry areas where vascular plants are absent, nutrient cycling through microbial organisms predominates. For example, microbiotic crusts composed of nitrogen-fixing cyanobacteria, often found on desert surfaces can survive long periods of desiccation with very rapid responses to rehydration as they conserve and cycle water as well as nutrients, thereby increasing water infiltration, slowing evapotranspiration, and reducing wind erosion. Under certain conditions, repeated rainfall events followed by mineralization of litter and nitrification can accumulate nitrate in dry soils. This usually occurs in the absence of vascular plants. Also, spots of higher fertility can occur in the soil, which can be exploited temporarily by fodder plants, for example, plants growing in arid and semiarid areas have most of the nitrogen in the plants' biomass with efficient internal plant recycling. Due to less biological turnover of organic matter, the organic matter present in dryland soils is chemically and biologically less stable.

As plants invest more of their energy and photosynthate into developing more extensive and deeper rooting systems to acquire water rather than into forming root nodules, therefore, the possibilities for enhancing nitrogen in dryland soils by use of legumes are restricted wherever water rather than nitrogen is the most limiting factor (Sprent, 1985). This may be a reason for having little evidence regarding native dryland legumes fixing significant amounts of nitrogen.

Moreover, plant productivity is constrained by the scarcity of water in drylands, which ultimately affects soil organic matter (SOM) and soil organic carbon (SOC) accumulation in soils. Therefore, dryland soils typically have low organic carbon content, often less than 1% of the soil mass. In grassland or forest soils, SOC may be as high as 4-5% but cultivation of the soil releases its stored carbon and in temperate zones SOC is around 1-2% in cultivated soils.

Droughts are characteristic of drylands and can be defined as periods (1–2 years) where the rainfall is below the average. Lack of water is the main characteristic of drylands. The problem is further aggravated because rainfall is not only low but also erratic thereby affecting the accumulation of soil carbon. The SOC pool tends to decrease exponentially with temperature (Lal, 2002). As a result, soils of drylands contain small amounts of C (1% - less than 0.5%). The SOC pool generally increases with the addition of biomass to the soil when the pool has been depleted due to land use. Dryland soils are prone to degradation and desertification, which lead to further reductions in the SOC pool.

Thus, the factors affecting soil fertility in dryland areas can be summarized into the following:

1. Rainfall.
2. Climate.
3. Vegetation.
4. Soil erosion.
5. Crop production practices.

Management strategies for improving soil health & crop yield in dryland areas:

The management strategies to improve crop yield in dryland areas can be categorized into the following points:

1. **Conservation Agriculture (CA)**

Conservation agriculture aims to conserve and improve the natural resource base while using the resources available for agricultural production more efficiently. It avoids or minimizes soil tillage, maintains a permanent soil cover of crops and/or residues, and utilizes efficient crop rotations (FAO, 2002). Even though it has been successful in many parts of the world, in the dry areas with very low organic matter production CA has been the least successful to date.

However, even a small amount of crop residue can reduce wind erosion considerably and increase soil water storage. Under arid conditions, wind and water erosion leads to significant quantities of soil and nutrient loss as the soil remains bare for most of the year, so even small savings are worth pursuing. Soil nutrients and water interactions are different in conservation tillage and conventional tillage systems. For example, nitrogen use efficiently is more under no-till as compared to conventional tillage because no-till reduces water loss due to residue cover in dry years and improves water infiltration during wet years. In this regard, Stewart and Koohafkan (2004) stated that no dramatic increase in production and soil fertility can be expected in dry areas in the short term, and on the other hand without adequate incentives farmers are unlikely to commit themselves to long-term solutions.

2. Legume rotations and crop mixtures

In recent years, there has been an encouraging trend away from mainly cereal-based systems in drylands toward cereal–legume and cereal–legume–livestock systems that not only bring economic benefits but also improve soil and benefit yield of crops. Examples are found in the drylands of West Asia, Australia and the dry savannas of West Africa. Biological nitrogen fixation is the cheapest and most effective management tool for maintaining sustainable yields in low-input agriculture. Furthermore, this is often the only available source of nitrogen supply for plants in smallholder systems in less developed countries. An alternative to the widely practiced cereal–fallow or cereal monoculture systems is the introduction of nitrogen-fixing legume crops into a rotation with cereals. The beneficial effects of legumes in crop rotation on soil fertility and subsequently on cereal productivity are well documented (Pierce and Rice, 1988; Robson *et al.*, 2002). There is evidence, for example, that wheat grown in rotations with other plants such as legumes in dry areas gives more efficient water and nitrogen use than does the cropping system of grain followed by bare fallow. In dry areas, long-term trials undertaken by ICARDA researchers in Northern Syria under rainfed conditions (annual rainfall 250–320 mm) have shown an increase in residual soil nitrogen content, higher wheat and barley yields, and higher water-use efficiency after the legume phase. Legume crops differ in their nitrogen-fixing capacity and yields. ICARDA's long-term trials have shown that fava bean (*Vicia fava*) and lathyrus (*Vicia lathyrus*) can fix more nitrogen than chickpeas and lentils. Peoples *et al.* (1998) reported that perennial pastures containing alfalfa (*Medicago sativa*) provide consistently greater annual vegetative production and can fix up to 50% more nitrogen than subterranean clover pastures, especially under drought conditions in Australia. In West Africa, Sanginga *et al.* (2003) have reported the success of maize–soybean systems as a result of the introduction of promiscuously nodulating soybean varieties in dry savanna areas.

An important additional benefit of the introduction of crop and forage legumes into dryland systems is their apparent ability to utilize relatively inaccessible pools of soil phosphorus. After nitrogen, phosphorus is usually the second most limiting major nutrient in dryland soils. Lupins were the first crop identified as having a mechanism for enhancing phosphorus availability by the exudation of citric acid. Later chickpeas were found to be able to utilize phosphorus from apatites (calcium phosphates) by the exudation of citric acid (Ae, *et al.*, 1991). Other beneficial soil fauna, such as fungi and plant growth-promoting rhizobacteria, should be considered in addition to rhizobium, in efforts to achieve economically sound sustainable cropping systems for the dry areas. A recent study conducted in Southern Australia identified new isolates of Penicillium fungi associated with wheat roots having a high potential to mobilize phosphorus originating from phosphate rocks (Wakelin *et al.,* 2004). These fungi are being investigated for their ability to increase crop production on strong phosphorus-retaining soils in dry areas.

3. **Adopting nitrogen-fixing trees**

Leguminous trees can survive with arid soils' low levels of nitrogen due to their nitrogen-fixing capacity. This is why they can be characterized as "fertilizer trees". Nitrogen-fixing trees such as Acacia and Prosopis are some of the best sources of this fertilization in arid regions, which are inexpensive and already in situ. Acacias are also well adapted to low rainfall and extreme temperatures due to their extremely deep root systems. They include about 1250 species of deciduous or evergreen trees and shrubs widely distributed in the tropics and warmer temperate areas, especially in Australia (Fagg and Stewart, 1994). In addition to their nitrogen-fixing capacity, such species in agroforestry systems are beneficial for maintaining soil fertility due to their efficient nutrient cycling of tree biomass and their uptake of nutrients from deep soil layers (Kang *et al.,* 1990). Leaf pruning of these trees is an important component of sustainability in agroforestry and soil fertility, adding to the biomass available from leaf fall. *Prosopis spp*. is a deciduous, thorny shrub or small tree. Their deep rooting systems give them significant tolerance to water stress. This depth allows the roots to achieve good nodulation even under drought conditions, enabling them to survive and contribute to biomass maintenance in the soil. Nutrient levels (N, P, and K), moisture content, and organic carbon of soil are all higher under the canopy of Prosopis cineraria compared to the open area. The beneficial effects of tree legumes can also be estimated indirectly through their effect on a neighboring or following crop. In the Sahelian region with annual rainfall of 400–600 mm, the yields of millet, peanuts, and sorghum increased from 500 to 900 kg ha21 when grown under the canopy of *A. albida*. Leguminous trees, which can be grown in hedgerows or intercropped with annual crops, improve soil water conditions as well as enhance soil nitrogen supplies. However, optimum spacing and related considerations need to be factored into such management decisions.

4. **Combining inorganic and organic nutrient sources**

Nutrient cycling through the use of low-cost organic inputs such as animal manure and crop residues is known to improve the structural and chemical properties of soil and to replenish macro- and micronutrients. These changes increase soil water-holding capacity and allow for better root penetration and aeration, protecting nutrients against loss by leaching or erosion and enriching soil flora and fauna. Increasing nutrient use and uptake efficiencies is important to maximize the use of applied organic and inorganic inputs and to reduce production costs. Careful management of the methods and timing of fertilizer application will synchronize nutrient release with peak nutrient uptake by crops, offsetting deficiencies in nutrient availability and depletion of soil nutrient stocks (Woomer and Swift, 1994). Proper management of other low-cost sources

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of organic inputs, such as the collection and composting of household organic waste, as well as the use of agro-industrial waste such as oil mill wastes or sawdust, can further contribute to efficient nutrient cycling, depending on how much immobilization of nutrients accompanies the process, thereby improving the yield of crops grown. For resource-poor farmers on drylands, this option is likely to be more feasible than direct interventions such as introducing and/or manipulating particular beneficial soil fauna.

5. **Pest and disease management**

To improve crop yield, the management of weeds and diseases is an integral part. Failure in this can result in crop failure which endangers food security. Manipulating soil microorganisms, soil fauna and plant pathogens as bioherbicides has been proposed for effective control of parasitic weeds and other crop pests and diseases. Crop rotations can play an important role in pest control Intercropping is also emerging as an effective management strategy for pest control.

6. **Management of rangelands and crop–livestock interactions**

Rangelands covering vast areas of arid and semi-arid regions are characterized by low levels of productivity, and most are undergoing some degree of degradation as a result of uncontrolled grazing of communal lands and the removal of shrubs and trees for fuel wood. Extensive grazing is a system that facilitates the exploitation of nutrients dispersed over wide areas that could not otherwise be profitably used. While there may be some merit in promoting nitrogen-fixing species in rangelands, it is unlikely that they will receive enough other inputs to significantly increase nutrient cycling and accumulation in useful plant or animal products. Water harvesting in rangelands can lead to the increased production of forage shrubs and herbs, followed by a more general improvement in soil fertility, and maybe the most feasible option for these large areas. The interactions between livestock and crops can be competitive. For example, the grazing of crop residues that help replenish soil nutrients or protect bare soils against erosion can result in range deterioration and land degradation if the manure is not returned to the field or there is uncontrolled grazing. Integrated management of rangeland, feeding systems, manure management, composting, and application is needed to minimize losses and maximize recycling of nutrients, optimally sustaining soil fertility over time thereby improving crop yield in such areas.

7. **Soil moisture conservation measures**

Conservation of soil moisture is of the utmost need in dryland areas in order to improve crop yields. Various mechanical measures like contour bunding, graded bunds, branded-border stripes, and bench terracing (Leveled, inward-slopping, outward-sloping, California type and compartmental bench terracing) are used to conserve moisture.

Bunding system is the most effective & widely practiced field measure for controlling soil erosion & moisture conservation. Bunds are constructed on a contour with a cross-section of 0.54 m^2 where the annual rainfall is < 700 mm. Contour bunding is a series of mechanical barriers across the land slope to break the slope of the land on a contour. It can be adopted in light and medium-textured soils. It can be laid up to 6% slopes. It helps to retain moisture in the field. Graded bunding, on the other hand, is bunded across the slope with a cross-section of 0.34 - 0.8 m^2 at a vertical interval of 0.7 m with a channel on the upstream side. It is highly suitable in areas with AR > 800 mm and also suitable for areas with less rainfall under clay soil conditions. Graded border strips are bunds across the slope with a small cross-section of 0.2 m^2 to conserve rainwater in situ in alfisols regions. Contour border strips increased the crop yield at different locations. The yield of black gram was increased by 18.4 percent (Bidar) by 38 and 41.6 percent in sunflowers and *rabi* sorghum (Bijapur) over traditional bunding practices. Bench terraces are one of the most widely adopted mechanical measures of SMC suitable for hilly areas with a slope of 6 – 33%. It consisted of the construction of step-like fields along contours by half-cutting & filling. Cultivation is carried out in these leveled fields. Another option can be a dead (Conservation) furrow opened for capturing rainwater. It is normally followed in the intercropping system. All these mechanical measures help in improving crop yield by managing soil quality.

Conclusion:

41% of the world's land area is covered by drylands, thereby supporting two billion human populations, 90% of whom live in developing countries. Drylands are found on all continents. They are however most prevalent in Africa and Asia. Drylands are the foundation for both rural and urban communities, including some of the world's biggest cities *viz.*, Cairo, Mexico City and New Delhi. Around one billion people directly depend on dryland ecosystem services for their daily survival, whether through rainfed or irrigated farming or widespread pastoralism. The Dryland areas of the country contribute about 44 percent of the total food grain production, supporting 40% human & 60 % livestock of India. Coarse grains like sorghum, pearl millet, finger millet, etc. are grown in drylands only. The potential productivity of food grain is about 2 t/ha in rainfed and about 4 t/ha in irrigated conditions. But presently the production is only 0.8–1.0 t/ha. Soils in dryland areas are characterized by low soil organic matter levels due to rapid mineralization, and inherently low fertility. Nitrogen is universally deficient, followed by phosphorus and zinc deficiency. However, potassium deficiency is rare in semi-arid areas. Soils of drylands contain small amounts of carbon (1 % - less than 0.5%). Nutrient cycling in drylands is affected by low and erratic rainfall, wide temperature extremes, alkalinity and/or salinity, and occasionally by relatively high rates of dry deposition of nutrient-enriched soil particles from wind erosion. The biological activity is much lower in dryland as compared to humid areas. To improve the crop yield, measures must be taken beforehand in dryland areas. However, farmers have to commit themselves to long-term solutions in order to obtain an increased yield. Measures like conservation agriculture, intercropping practices including legume rotation, adoption of nitrogen-fixing trees, combining organic and inorganic sources of nutrients, management of pest and diseases, rangeland management and crop-livestock interactions and soil moisture conservation are undoubtedly to be an integral part of dryland agriculture, thereby improving soil fertility, productivity and above all crop yield.

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CHAPTER 11

ORGANIC PLANT NUTRIENTFOR MAXIMIZING NUTRIENT USE EFFICIENCY

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Introduction:

The demand for food and agricultural commodities is rising faster than their production capacity due to the growing global population, which is projected to reach 9 billion by 2050 (FAO, 2017). Therefore, we must enhance productivity per area of farmed land in order to close this disparity. To overcome these obstacles, we must improve soil fertility by using alternative fertilizers like organic and biofertilizers in addition to chemical nutrients. With the continued growth in global population, food resources become scarcer due to increased food consumption. When utilized in greater quantities, nitrogen fertilizers, which are inorganic in origin and inflict significant harm to soil and the environment, as well as to human health. The majority of nations in the 21st century advanced in their search for a natural substitute that might take the place of the usage of chemically generated fertilizers or pesticides, reducing environmental pollution as well as the expense of agricultural output (Alalaf, 2019). The utilization of organic inputs is one of the greatest alternatives. Regarding sustained production, better quality produce, and a reduction in hazard-free produce, organic farming has a number of advantages over conventional agricultural techniques. The price of inorganic fertilizers is rising dramatically to the point where small and marginal farmers cannot afford them. Similar to inorganic fertilizers, organic fertilizers provide nutritional needs for crops, control populations of plant pests, and boost crop output and quality. All crops require proper nutrient management, and among organic and bio-fertilizers like compost, farmyard manure, biochar, vermicompost, and humic substances, *Azotobacter*, *Azospirillum*, *Vascular ArbuscularMycorrhiza* (VAM), and *Plant Growth-Promoting Rhizobacteria* (PGPR) are crucial. By changing the rhizosphere zone and the microclimate around the plants, these organic foods increase soil biodiversity, preserving soil health and promoting root growth. The integrated pest management system may also call for a substitute for pesticides in the case of these organic goods. Because they are environmentally friendly, economical, improve fruit quality, and aid to withstand various stress circumstances, biofertilizers boost the supplementation of various nutrients (Ortas, 2012).

Why do we need organic and biofertilizers in agriculture?

For maintaining soil health, the environment, and sustainable crop output, organic farming serves as an alternate nutrient management practice. Biofertilizers, which are crucial to organic farming, mobilize fixed macro- and micronutrients to improve their availability and efficiency while also fixing atmospheric nitrogen, which is vital for renewing soil fertility.

Organic farming is beneficial to the environment, financially successful, and offers a number of health advantages. Organic foods also have a large market potential and might be a significant step towards sustainable farming. Numerous initiatives are being made to maximize the use of organic and biofertilizers in agricultural cultivations, including enhancing plant productivity and development as well as boosting plant resistance to abiotic stresses including salinity, high temperatures, and drought (Morugan-Coronado *et al.* 2020).

History of organic farming:

The terminology of "organic farming" was originally used by a scientist named Lord Northbourne in 1939. The phrase comes from his definition of "the farm as organism" in his 1940 book "Look to the Land." He described a comprehensive, ecologically sound method of farming. Additionally, he contrasts "chemical farming versus organic farming". In 1940, another scientist Sir Albert Howard published his first book with the term "organic" in the title. "An Agricultural Testament" by Sir Albert Howard has a significant impact on the promotion of organic farming methods. Terminology from Lord Northbourne's 1947 book "The Soil and Health, a Study of Organic Agriculture" was used. Another scientist Lady Eve Balfour wrote a book titled "The Living Soil" in 1943. Based on preliminary results of the Haughley Experiment, which is the first comparison of organic vs. conventional farming, Lady Eve Balfour released the book. As a result, the Soil Association is established. In the United States, J.I. Rodale started to popularize the phrase and techniques of organic farming, especially among consumers through the promotion of organic gardening, in 1950. "Silent Spring" by Rachel Carson was published in 1962. The impacts of DDT and other pesticides on the ecosystem are discussed in her book. The book is a worldwide best-seller in numerous nations. The book is thought to have played a significant role in the federal government of the United States outlawing the use of DDT in 1972.

International Federation of Organic Agriculture Movements (IFOAM)

The international organic movement IFOAM was founded in 1972. The International Federation of Organic Agriculture Movements (IFOAM) was founded in Versailles, France, by five groups from Sweden, the United States, South Africa, France, and England.

According to IFOAM, the definition of organic agriculture is *"Organic Agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved."*

Organic farming society or organization in India:

Organizations	Goal
All India Organic Farmers Society (AIOFS)	Establish in 2007 According to AIOFS, Every farmer should grow organic food for his family consumption
Organic Farming Association of India (OFAI)	To promote farming methods and systems that are environmentally benign, scientific, profitable, and energy efficient
National Project on Organic Farming (NPOF)	NPOF promotes organic farming in the country through technical capacity building of all the stakeholders including human resource development, transfer of technology, promotion and production of quality organic.
WWOOF	It is a network that enables volunteers to reside on organic estates or farms and learn there. It brings together Hosts and Volunteers (WWOOFers) who support one another in creating a healthier world. India launched WWOOF on August 15, 2007.

Why nitrogen and phosphorus are needed for plant growth?

As crucial nutrients for plant development, nitrogen and phosphorus are required for plant growth. Chlorophyll formation in plants depends on nitrogen, whereas energy production in plants depends on phosphorus. For plants to grow and develop properly these two nutrients are essential. The growth and production of plants depend on nitrogen. Plant cells contain nitrogen, which is necessary for their division as well as the growth of their growth tips. It is necessary for the synthesis of compounds like proteins and DNA. If plants have access to sufficient amounts of these elements, they will grow and develop more effectively. The growth and development of the plants can be impeded if they are not available. Nitrogen and phosphorus must be present in adequate amounts for plants to continue to develop and produce. If these components are unavailable, this type of plant may suffer damage.

1. Nitrogen

Nitrogen is one of the plant nutrients that are crucial for crop growth. According to Mosier *et al.* (2001), nitrogen is the nutrient that frequently restricts crop output reported by Mosier *et al.* (2001). Due to its high need, its crucial participation in nearly all metabolic processes of plants, and its significant losses in soil-plant systems, nitrogen occupies a special position in crop production systems (Ladha *et al.,* 2003). Nitrogenous fertilizer around 120 million metric tons is used annually by farmers worldwide to meet the high nitrogen needs of agricultural plants (FAO, 2014). Nitrogen fertilizer has a lower recovery rate around 30–50% because of various losses from the soil-plant system; farmers must apply enormous amounts of nitrogen fertilizer to crops as reported by Fageria, 2002. Mohan *et al.* (2015) reported that practically all agricultural soils and cropping systems around the world are nitrogen deficient, it is imperative to use external nitrogen inputs (N fertilizers) to produce the crops necessary to meet the continuously rising demands of human populations (Mohan *et al.,* 2015). Although N_2 gas makes up roughly 78% of the atmospheric gaseous composition, agricultural plants cannot utilize this element directly unless it is converted into forms that are useful to plants (Barbieri *et al.,* 2000). The first and most important step in adding nitrogen to the soil-plant system is to use organic or inorganic sources. Because chemical fertilizers quickly become available to plants, they are typically used in higher quantities in crop production systems than organic sources like crop residues, organic manure, biological N fixation, and organic manures (Manning *et al.* 2001). The following are some examples of organic nitrogen sources:

Horn meal, blood meal, bat guano, crab waste, fish meal (dry), green manure, prawn waste, organic manure, farm yard manure, organic manure, fish waste and bacterial nitrogen fixation.

Available forms of Nitrogen:

Nitrogen exists as a gas (N_2) in the atmosphere whereas in the soil it exists as Nitrogen oxide (NO) and Nitrogen dioxide (NO_2). When nitrogen is utilized as fertilizer, it can also be found in various forms such as ammonia (NH_3), which can then be converted into other fertilizers, and ammonium nitrate, or NH_4NO_3.

Transformation of nitrogen in soil:

Nitrogen in crop residue becomes available only after mineralization. Available nitrogen includes NH_4^+ and NO_3^-. The mineralization process includes the conversion of complex organic nitrogen into simpler inorganic forms by different microorganisms. The important factor that affects mineralization is the C: N ratio, if the C: N ratio is more than 20 then it lead to the mineralization process. Mineralization increases with an increase in temperature. For the mineralization of organic manure, three basic steps are included and they are aminization, ammonification and nitrification.

$$\text{Organic nitrogen (Many forms)} \xrightarrow{\text{Mineralization}} \text{Inorganic nitrogen Ammonium } (NH_4^+)$$

$$\text{Organic nitrogen (Many forms)} \xleftarrow{\text{Immobilization}} \text{Inorganic nitrogen Ammonium } (NH_4^+) \text{ \& Nitrate } (NO_3^-)$$

a) Aminization

Conversion of proteins and allied compounds to amines and amino acids by heterotrophic (bacteria like *Bacillus*, *Pseudomonas*) in the absence of O_2

$$\text{Organic matter} \xrightarrow{\text{Hydrolysis}} \text{Polypeptide/Protein}$$

$$\text{Polypeptide/protein} \xrightarrow[\text{Bacteria}]{\text{Heterotrophic}} R\text{-}NH_2 + CO_2 + \text{Energy} + \text{Other Compounds}$$

b) Ammonification

The reduction of amines to ammonical compounds by some other group of heterotrophic microorganisms is known as ammonification.

$$R\text{-}NH_2 + H\text{-}OH \xrightarrow[\text{Absence of oxygen}]{\text{Heterotrophic Bacteria}} NH_3 + NR\text{-}OH + \text{Energy}$$

$$\xrightarrow{H_2O} NH_4^+ + OH^-$$

c) Nitrification

The microbial process of nitrification involves the successive oxidation of reduced nitrogen molecules, typically ammonia, to nitrite and nitrate. The bacteria that live in soil and other nitrifying bacteria convert ammonia to nitrate. The nitrification process is mostly carried out by the Nitrosomonas and Nitrobacter families of autotrophic nitrifying bacteria.

i. $$NH_3\ (\text{or } NH_4^+) \xrightarrow[\text{Nitrosomonous}]{[O]} NO_2^- \text{ Nitrite}$$

$$NO_2^- \xrightarrow[\text{Nitrobacter}]{[O]} NO_3^- \text{ Nitrate}$$

2. Phosphorus

Phosphorus is an essential macronutrient for all living things. In the creation of ATP, nucleic acids (DNA and RNA), and phospholipids in cell membranes, it is crucial. Phosphorus and phosphorus-based compounds cannot be found in air in the gaseous state since they are normally solids at the common ranges of temperature and pressure observed on Earth. Phosphorus (symbol: P) is progressively lost via runoff, which only happens in specific, local conditions, making it steadily less available to plants over thousands of years on earth.

Organic sources of phosphorus

Fig. 1: Organic Sources of Phosphorus

Uptake and transport of phosphorus

Phosphorus (P) is one of the few macronutrients that is essential for the growth and development of all organisms. It serves as a crucial building block for many diverse reactions, including those involving the phospholipids that make up membranes, DNA, RNA, sugar-phosphate intermediates for glycolysis, respiration, and photosynthesis, and numerous phosphorylated compounds (Raghothama 1999). The primary supply of P for plants is inorganic phosphate (Pi), but because it is frequently complex with metal ions in the soil, it can be difficult for plants to absorb. Plants have therefore evolved sophisticated defenses against Pi deficiency, including biochemical and metabolic adjustments that increase the availability of both internal and external Pi (Puga*et al.* 2017). Pi is absorbed into root cells, loaded into the xylem through symplastic or apoplastic channels, transferred to the shoot via xylem flow driven by transpiration, and distributed across diverse shoot tissues through the phloem, according to Poirier and Bucher (2002). These operations call for specific Pi transporters. Before soil bacteria transform organic molecules into straightforward inorganic phosphate, phosphorus that is present in soil organic matter is not accessible to plants. Inorganic orthophosphate ions (HPO_4^{2-} or $H_2PO_4^-$) are the most common form of phosphorus that plant roots absorb.

Transformation of phosphorus within soil

The following are some examples of how phosphorus in soil changes: mineralization, assimilation, microbial solubilization of in soluble form of phosphorus, precipitation of phosphorus compounds, and assimilation of phosphorus compounds.

i. Mineralization

Phosphatase enzymes are present in all species, but only bacteria, fungi, and some algae can manufacture them outside of their cells. They serve as exoenzymes in the environment, dissolving and mineralizing organic phosphate complexes. Numerous microorganisms, including bacteria (like *B. subtilis*, *Arthrobacter*), actinomycetes (like *Streptomyces*), and fungi (like *Aspergillus*, *Penicillium*), mineralize organic phosphorus compounds to orthophosphate, including phytin, inositol phosphates, nucleic acids, and phospholipids. The enzymes phosphatases are in charge of breaking down phosphorus molecules.

ii. Microbial solubilization of insoluble forms of phosphorus and assimilation

A few heterotrophic microbes may also dissolve phosphate that has been coupled with calcium or magnesium. These soluble forms are now easily digested into organic biological components (DNA, RNA, ATP, etc.) by plants, algae, cyanobacteria, and autotrophic bacteria. The metabolic processes involving enzymes are among the solubilization mechanisms. Succinic acid, oxalic acid, nitric acid, and sulfuric acid are just a few examples of the organic and inorganic acids that microorganisms can create. They are capable of producing CO_2, which brings pH down. Moreover, they produced H_2S, which may react with iron phosphate to liberate orthophosphate, and the manufacture of chelators, which can complex Ca, Fe, or Al.

iii. Compounds containing phosphorus precipitate

The pH of the aquatic environment and the amount of Mg^{2+}, Ca^{2+}, Fe^{3+}, and Al^{3+} regulate how soluble orthophosphate is. When precipitation takes place, insoluble substances such as hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2,8H_2O$) and variscite ($AlPO_4.2H_2O$) are formed.

Improvements in nitrogen use efficiency in plants

The effectiveness of nitrogen utilization can be increased through conservation agriculture (CA). Long-term adoption of CA techniques can enhance the soil's capacity to supply nutrients since healthier soil increases the availability of nutrients to plants (Fageria, 2002). The next strategy is residue management. According to Malhi*et al.* (2011), residue is the crop parts that are still present after harvesting. Due to their impact on the amount of nutrients available to crops, crop leftovers are crucial to plant growth and development (Mohanty and Mishra, 2014). Growing green manuring crops is another way to increase the effectiveness of the nitrogen cycle. Leguminous crops have a lot of potential as green manuring crops. Legumes have the capacity to fix atmospheric free N in the soil, making them superior green manure crops versus non-leguminous crops (Vyn*et al.*, 2000). Crop recovery of N in crops is also improved by using crop rotation techniques. Hirel*et al.* (2007) claim that by employing genetic engineering tools or breeding techniques, new kinds can be created that absorb more organic or inorganic nitrogen (N) from the soil and use it more effectively.

Improvements of phosphorus use efficiency in plants:

Phosphorus diffusion is made possible by the use of phosphate-solubilizing bacteria and effective irrigation management. Through the use of crop and variety types that are efficient in removing less soluble or insoluble forms of phosphorus from soil (Lungmuana *et al.*, 2015). Rock phosphate is the sole ingredient used to make phosphatic fertilizer. 80% of the world's rock phosphate reserves are located in Africa. According to the report by Rao *et al.* (2015) about 20% or less of the mined P is thought to end up in food products for families.

It is necessary to increase the efficiency with which plants absorb phosphorus (P) fertilizer from the soil (P-acquisition efficiency) and utilize it in processes that encourage quicker development and larger biomass allocation to the harvestable sections. Increasing P acquisition has the potential to produce large increases in efficiency because crops only absorb 15–30% of the fertilizer P in the year of application (Syers *et al.*, 2008). Recent studies on this aspect of P efficiency (White & Hammond, 2008; Ramaekers*et al.*, 2010; Richardson *et al.*, 2011) have attracted a lot of attention and highlighted opportunities for improved crop features and agronomic methods. Contrarily, the confounding effects of variation in P-acquisition efficiency have frequently hampered comparative studies of PUE, and physiological PUE has received far less attention (Rose *et al.*, 2011). If P absorption is enhanced, yields will rise, but more P will also be exported from the field as a whole. In order to avoid long-term soil P depletion, increased P exports must be replaced with more fertilizer. This is because they may cause serious off-site environmental problems (Tiessen, 2008; Childers *et al.*, 2011). High yields per unit of phosphorus consumed, or high PUE, and a balance between phosphorus inputs and exports are characteristics of agricultural systems that are both sustainable and productive. In this review, we identify plant traits that, from the level of the whole plant to the biochemical level, enable a plant to efficiently use internal P once it has been acquired. We assess agricultural plant efficacy from a broader perspective as well as potential areas for improvement.

Benefits of organic farming

The increased interest among consumers and producers in the nutritional content of foods grown organically and conventionally has been noted by Magnusson *et al.* (2003) and Brandt and Magnusson *et al.* (2003) and Brandt and Mlgaord (2001) have both noticed the rise in interest among consumers and manufacturers in the nutritional value of foods farmed both organically and conventionally. A 2003 AFSSA study discovered that foods grown organically have higher dry matter than foods grown conventionally, especially green vegetables and tubers. Fruits and vegetables include a variety of phytochemicals, which are frequently secondary metabolites of plants and include polyphenols, resveratrol, pro-vitamin C, and carotenoids. Fruits and vegetables cultivated organically have 27% more vitamin C than those grown conventionally, according to a study by Lairon (2010). Due to their strong cellular regulatory effects at the cellular level, these secondary metabolites are discovered to be protective against a number of diseases, including cancer, chronic inflammation, and other diseases (Lairon, 2010).

Future aspects:

It has been established that organic farming is a long-standing Indian tradition, one that has been practiced on countless farms and in rural areas for centuries. The introduction of modern agricultural techniques and the expanding population have led to a preference for conventional farming, which makes use of synthetic fertilizers, chemical pesticides, genetic modification techniques, etc. Since people are more concerned with the safety and quality of their food and because the organic method employs no chemical pesticides, there is an increasing demand for products grown organically, even in developing countries like India. Organic farming has a huge potential for financial gain (Bhardwaj and Dhiman, 2019). Deshmukh and Babar (2015) claim that the soil in India is rich in a variety of organic nutrients that occur naturally and enable organic farming. India is a country with a long history of traditional farming, inventive farmers, huge drylands, and little use of synthetic fertilizers and pesticides. In addition, the hilly northeast of the country produces naturally organic soils because there aren't many small chemicals utilized there for a long time (Gour, 2016).

The field of organic farming has seen the development of a number of newer technologies, such as the incorporation of mycorrhizal fungi and nanobiostimulants (to increase agricultural productivity in an environmentally friendly manner), more conscious mapping of cultivation areas using sensor technology and spatial geodata, 3D printers (to aid the nation's smallholder), production from side streams and waste along with main commodities, and promotion and improvement of sustainable agriculture (Nova-Institut GmbH, 2018).

Conclusions:

Organic farming results in the production of more healthy and safe food. Organic foods are becoming more and more popular as a result of consumer demand because they are thought to be safer and healthier. Therefore, eating organic food may ensure food safety from farm to plate. Compared to conventional farming, organic farming is more environmentally friendly. By preserving the integrity of the environment and the soil, organic farming benefits consumer health. The organic produce market is also currently the one with the fastest growth rates globally, except India. By producing money in an all-encompassing way, organic farming promotes a country's ecological health, consumer health, and economic progress.We may draw the conclusion that by encouraging organic farming in India, which is presently the world's top producer of organic food (Willer and Lernoud, 2019), we can help the country flourish in a way that is economically, environmentally, and nutritionally sound.

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CHAPTER 12

CLIMATE SMART CROPPING SYSTEMS: LEADING THE WAY IN SOIL HEALTH MANAGEMENT

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Introduction:

The agriculture sector is shaped and driven by numerous variables. Among them, the key factors are changes in the market, management practices, agricultural policies, types and accessibility of technology and extension, land-use rules, availability of water resources, soil quality, carrying capacity of soil and environment, pests and diseases, etc. Agriculture output is subject to uncertainties brought on by climatic change, particularly disastrous events like flooding and drought, because of its innate connection to natural resources. The last ten years or so have seen a gradual acknowledgment of climate change as an additional factor that, when combined with other conventional pressures, will significantly impact the spatial and temporal impact on agricultural productivity. This includes long-term changes in average temperature or precipitation norms as well as a rise in the frequency of extreme climate effects. Long-term scarcities of water and other resources, worsening soil conditions, drought and desertification, disease and insect outbreaks on crops and livestock, sea-level rise, and other effects are predicted as a result of climate change. Yield losses are anticipated in vulnerable areas, mostly as a result of poor fruit setting and flower drops (Rosenzweig and others 2002). The impact of climate change on Indian agriculture was studied in detail under National Innovations in Climate Resilient Agriculture (NICRA) and the data shows that Rainfed rice yields in India are projected to marginally decline (<2.5%) in 2050 as a result of climate change and irrigated rice yields may decrease by 7% in 2050 and 10% in 2080. Further, wheat yield is likely to diminish by 6-25% in 2100 and maize yields by 18-23%.

Climate Smart Agriculture (CSA) – Concept and objectives

Climate Smart Agriculture (CSA) is a method that focuses on creating the technological, strategic, and financial conditions necessary for sustainable agricultural growth to ensure food security in the face of climate change. Due to the severity of climate change and its subsequent effect on agricultural systems, it is imperative to ensure that these consequences are kept in mind while formulating national agricultural plans, investments, and programs. CSA is an integrated strategy to manage landscapes, horticulture, crops, livestock, forests, and fisheries and it tackles the interconnected issues of food security and accelerated climate change (World Bank Group Climate Change Action Plan 2016- 2020).

CSA seeks to accomplish three goals at once:

- **Augmented productivity:** To raise incomes and improve nutrition security, especially for the 75% of the world's poor who reside in rural areas and rely mostly on agriculture, more food of better quality must be produced consistently.
- **Greater resilience:** Improved ability to adapt and flourish in the face of long-term challenges like shortened crop growing seasons and unpredictable weather patterns is the need of the hour.
- **Reduced emissions:** The efforts necessary to maintain climate resilience of farming systems include persuading producers to emit less emissions per calorie or kg of food produced, preventing deforestation caused by agriculture, and developing methods to extract carbon from the atmosphere.

Climate smart approaches:

A. Strengthening the capacity of farmers and relevant stakeholders:

Developing the skills and knowledge of farmers to help them better adapt to and safeguard their communities against extreme climatic circumstances, such as heat or cold waves, elevated salinity levels, flooding, and other difficulties arising due to changing climate. Providing training to farmers on soil improvement, use of organic manures e.g., animal manure, green manure, FYM, vermicompost, and the knowledge of when and how to employ chemical fertilizers to increase land productivity.

B. Introducing climate smart agricultural technologies

Practicing conservation agriculture which includes reduced soil disturbance (minimum tillage), crop rotation and sustainable crop residue management.Spreading awareness and encouraging the use of water management technologies and practices, such as on-farm water management, rainwater harvesting, alternate wetting and drying (AWD) and drip and sprinkler irrigation with mulch in crop fields, use of covered drains and underground pipelines, cultivation of cover crops to prevent water loss, and including less water-demanding crops in crop rotations.Introduction of agricultural insurance programmes to protect against crop losses caused by climatic catastrophes, such as drought, flood, hailstorm etc. Promoting fertilizer applications based on soil tests, use of precision agriculture technologies, leaf color charts, and cultivation of legume crops. Increasing the use of ICT in agriculture by building databases on different parameters of soil, climate and crop management, early warning systems, agricultural technology compendiums, mobile-based e-agriculture assistance and services, and community radio in remote, drought-prone areas.

C. Promoting climate resilience crop/livestock varieties

Introduction of stress (e.g., flood, drought, salinity and cold) tolerant, nutrient-rich and short-duration crop varieties. Promotion of disease and pest-resistant crop varieties and livestock breeds.

D. **Documenting and disseminating best practices and learnings and engage in policy advocacy**

i. Compiling best practices that help foster climate resilience.
ii. Sharing the knowledge of best practices and knowledge with farming communities and decision-makers.

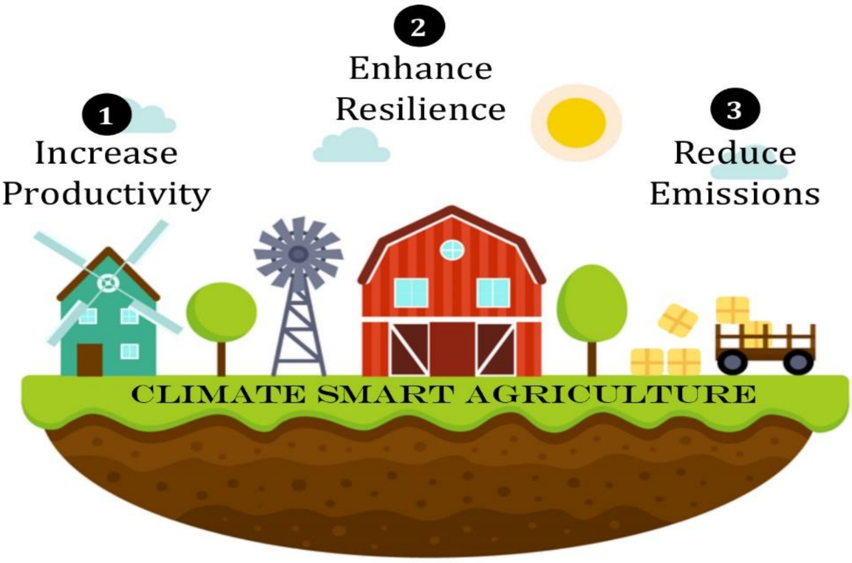

Fig. 1: Benefits of Climate smart agriculture (Source: https://minnesota.agclassroom.org)

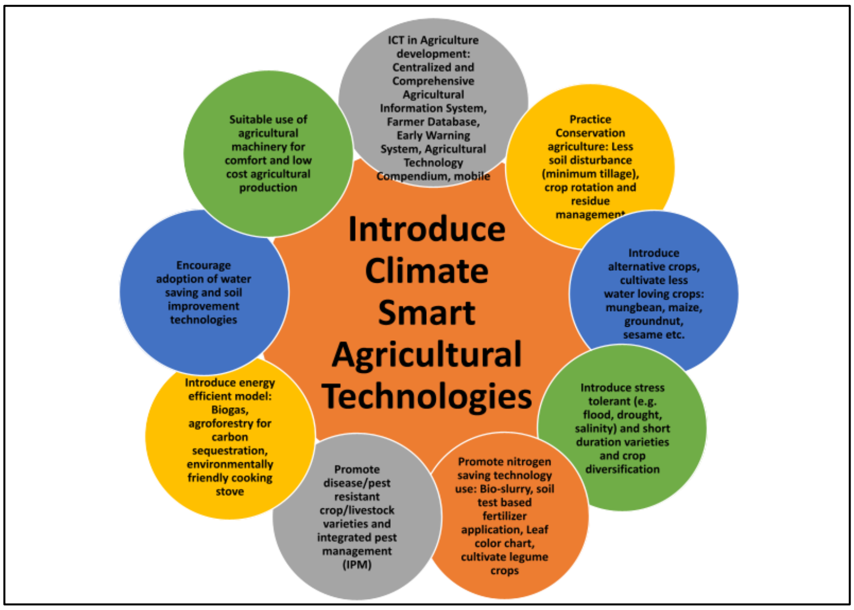

Fig. 2: Climate Smart Agricultural Technologies (BRAC-International-Climate-Smart-Agriculture-Strategy, 2021)

Climate-smart cropping systems:

Characteristics of Climate-resilient cropping system may include:

a. Maintaining and enhancing soil fertility by promoting nutrient restorer crops instead of soil-exhausting crops
b. Ability to enhance crop growth by providing shared benefits to each other, for example, reducing lodging, improving winter survival, and acting as cover crops and windbreaks to enhance crop growth
c. Minimizing the spread of disease and insect pest

d. Controlling weeds, as crops planted at various periods of the year are associated with various weed species

The prospective cropping systems, such as monocropping, intercropping, and double cropping systems, along with their climate change vulnerabilities across the country, based on the length of effective crop growing seasons determined from climatological data have been presented in Table 1.

Table 1: Potential cropping Systems and agricultural drought vulnerability based on rainfall and soil types (CRIDA, 1997; Chary *et al.*, 2016)

Mean annual rainfall (mm)	Soil order	Growing season (weeks)	Suitable Cropping	Agricultural drought system (frequency)
350- 650	Alfisol, Vertisol (Shallow), Aridisol, Entisol	15	Single rainy season	Severe drought
350- 650	Aridisol (Deep), Inceptisol	20	Rainy season/ Post monsoon season	Moderate drought
350- 650	Vertisol (Deep)	20	Post monsoon crop	Moderate drought
650- 800	Alfisol, Vertisol, Inceptisols	20 – 30	Intercropping	Less prone to drought
800- 1100	Vertisols, Alfisols and Entisols	30	Double cropping	Less prone to drought
>1100	Deep Alfisols, Oxisols etc.	30 +	Double cropping	Nil or less prone to drought

Table 2: Climate-smart cropping systems based on crops (modified from CRIDA http://icar-crida.res.in/CRIDA% 20 new/Technology 2.html)

Name of the cropping system	Technology involved	Performance
Farming of Hybrid Napier Grass for feeding livestock	Improved variety, Vertical planting, Use of organic manure	40% higher yield of hybrid Napier
Fodder cultivars to tackle fodder scarcity	Short duration varieties of finger millet (ML – 365), GPU – 48), Sorghum (Pusa Chari hybrid 106, CSH 14, CSH 23, CSV 17), Pearlmillet (CO 8, Avika Bajra Chari 19), Maize (African tall, APFM 8), Berseem (Wardan, UPB 110), Lucerne (CO 1, LLC 3, RL 88)	Average yield increase of 33%, good fodder quality, improved milk productivity in milch animals.

Cultivation of Elephant Foot Yam (EEY)	Better varieties with spreading rooting patterns that increase microclimate and soil moisture retention	Average yield of 60 q/ ha as against 31 q/ ha with local variety.
Different agricultural crops in broad bed and furrow system	Adequatedrainage techniques and in-situ soil and water conservation, especially in deep black soils	Increase in crop productivity (5-10%), needs 20 – 25% lower seed rate, water saving up to 25 – 30 %, Reduces crop lodging
Zero till drill wheat	Sowing of wheat with zero till drill	68 % saving in time and 85 % reduction in cost of operation compared to the conventional practice, average yield advantage in the range of 16 to 64 %
Flood tolerant varieties of rice	Flood tolerant rice varieties Swarna-sub 1, MTU – 1010, MTU – 1001, MTU – 1140 to impart resilience to farmers in flood – prone areas	Tolerance to submergence up to two weeks, lodging resistance, increased grain, and straw yield upto 40 % as compared to traditional varieties
Drought tolerant paddy cultivars	Sahbhagidhan for plain areas and uplands, Naveen (for cultivation in Odisha), Anjali (for cultivation in Jharkhand), Birsa Vikas Dhan 109 for eastern states	Yield advantage of 20 – 40 % against traditional varieties in dryland regions and deficit monsoon conditions
Direct Seeded Rice	Direct seeding of rice instead of transplanting	Less consumption of water, less labour and energy requirement
Crop diversification with millets and pulses	Intercropping of Setaria (Foxtail millet, variety: SIA – 3085) with pigeon pea in 5: 1 ratio or pearl millet and pigeon pea (3:3) instead of pigeon pea sole cropping.	Higher benefit cost ratio despite prolonged dry spell up to 25 days.
Short duration crop varieties appropriate for late sowing	Green gram varieties (TARM – 1, K-851) of 60 -70 days, Black gram varieties (Azad urd – 1) of 65 days, short duration groundnut varieties (GG – 5), short duration soybean varieties (JS- 335)	Improved yield in late planting conditions, tolerance to terminal dry spells.

Examples of Climate smart cropping systems based on Horticultural crops:

A. **Growing Fruit crops on marginal lands:**

Intervention:

By diversifying to fruit cultivation on their marginal slope farmlands, the small and marginal subsistence farmers of Himachal Pradesh successfully worked to enhance their food security and means of subsistence.

Performance:

- The income from horticultural fruit crops are much higher than the grain crops on such type of lands.
- It encourages the effective use and management of marginal land resources. Farmers are finding it difficult to make the most use of their privately owned marginal lands, which are underutilized for growing other crops, due to small landholdings. It helps to convert non-viable subsistence farming into viable farming by harnessing of appropriate niche potential of marginal mountain lands.
- Fruit farming improves the employment opportunities for landless and women.

Table 3: Climate-resilient rootstock and cultivar of horticultural crops (Malhotra, 2017)

Crop	Rootstock	Characteristics
Mango	131, Kurakkan, Nileshwar dwarf, Bappakai	Salinity tolerant
Citrus	RangpurLime	Drought, Phytophthora tolerant
Sapota	Khirni	Drought tolerant
Anona	ArkaSahan	Drought tolerant
Fig	*Ficus glomerata*	Nematode and salinity tolerant
Pomegranate	*Punica granatum* (variety: Ruby)	Drought tolerant
Ber	*Ziziphus nummularia* var. Tikdi	Drought tolerant, dwarf stature and vigorous growth

B. **Vermicomposting and climate adaptation:**

Intervention:

Vermicomposting is an eco-biological approach to waste management that uses earthworms (e.g., *Eudriluseugeniae*) to turn garbage into compost. It takes at least two to three weeks for earthworms to accept agricultural leftovers from horticulture as a substrate and food source. Earthworms eat biomass and expel it as worm castings, which are digested remains. Worm casts are often referred to as "Black gold." The castings have qualities that restrict harmful bacteria and are rich in nutrients that promote growth and increase the abundance of good soil microflora.

Performance:

Many of its crucial characteristics include improvements in the physical characteristics of the soil and the augmentation of plant micronutrients via chelation and other processes. Growing in popularity as a key element of an organic farming system for growing crops and seedlings is vermicompost. In other terms, "Turning Dirt into Wealth" refers to the process of turning useless garbage into products with value-added features that can start businesses that generate cash.

C. Fruits and vegetable waste utilization for bioenergy:

Intervention:

With its abundant agricultural resources, India generates 50 million MT of vegetable waste, or around 30% of its overall output (Verma *et al.* 2011). Therefore, it would be highly advantageous economically to use these wastes that are produced at many levels of delivery, starting at the agricultural field and continuing through postharvest handling, storage, and processing, and ending with distribution and consumption. Such wastes can be utilized for the development of microorganisms either directly or after proper treatment with enzymes to produce bioenergy. These wastes can be processed to produce biofuel by controlled fermentation. Biomethane, an inexpensive and sustainable source of energy, is produced by the microbial population during anaerobic digestion. Due to their high polysaccharide content (cellulose, hemicellulose, and lignin), waste from the processing of fruits and vegetables can be subjected to solid-state fermentation to produce ethanol and butanol, which can be used in a variety of industries as well as a liquid fuel additive (Laufenberg *et al.*, 2003).

Scope:

One significant biomass source that has the potential to be transformed into ethanol is fruit and vegetable waste. For the manufacture of biofuel, wastes like potato peel, apple pomace, orange peel, and carrot leftovers are a few examples. These wastes can be converted into biofuel, which not only creates products with added value but also lowers the cost of their disposal.

Table 4: Climate resilient integrated farming systems (modified from CRIDA http://icar-crida.res.in/CRIDA%20new/Technology2.html)

System	Technology	Performance
Integrated farming system	Integrated farming systems based on pulses and cotton that use water management techniques that are energy efficient (Sprinkler and Rain gun method)	Higher return, 77 % water productivity over rainfed crop,
	A number of modules for an integrated farming system that combine a variety of small businesses, including farms for crops, animals, poultry, pigs, fish, and ducks.	Diversified enterprises help farmers in mono-cropped paddy growing areas to get the much-needed year-round income, better their lives, and increase their resilience to extreme weather events by reducing risk from a single enterprise in the face of natural calamities.

	Integrated Farming Systems to reduce the impact of drought with in- situ moisture conservation practices by providing irrigation only to critical crop growth stages, using improved varieties of paddy (WGL – 44 Siddi), Green gram (MGG- 295) and pigeon pea (WRG – 65) along with keeping milch cattle for milk production	Higher net return, yield of green gram and pigeon pea were higher up to 25 % in comparison to traditional varieties

5. Challenges for developing climate smart cropping systems

1. Inadequate understanding of CSA concept and framework

The FAO (2010) definition and explanation of Climate Smart Agriculture continue to be well-liked by agricultural stakeholders and development specialists everywhere. However, there are still questions over what technologies and behaviours should be included in the CSA category and which of the three columns—productivity, adaptation, and mitigation—should take precedence in a particular situation.

2. Limited investments to support CSA

Up until now, conservation agriculture and agroforestry have been the methods considered to be in line with CSA's goals that have received the most documentation(Kassam *et al.*, 2009; Garrity *et al.*, 2010). The economic effects of these actions have not yet received much research. The financial case for investment is also muddled because agroforestry and conservation agriculture confront numerous adoption hurdles (Giller *et al.*, 2009).

3. Marginality of agro-ecological regions

In addition to water shortages, significant portions of India have poor soil fertility. The IPCC (2014) predicts that intra-seasonal rainfall variability will intensify and that the frequency of droughts will increase, hence remarkable innovations are needed to maintain sustained agricultural productivity.

4. Including CSA into the current policy frameworks

With CSA becoming one mainstream opportunity to adapt and implement, including climate cropping systems into national and international policy-making is the need of the hour.

5. Way forward and conclusion:

The world faces an increased risk of hunger and poverty in the face of climate change for forthcoming generations. Especially when done sustainably, climate-smart cropping systems methods can sustain agricultural production on a local, national, and international scale. Prioritization must be given to reducing greenhouse gas emissions from all agricultural and non-

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agricultural sources. Building stakeholder confidence and raising their awareness of the effects of climate change require structured training. The urgent requirement is to applyclimate smart cropping systems nationwide while also narrowing the gap between current management practices and crucial agro-advisories.

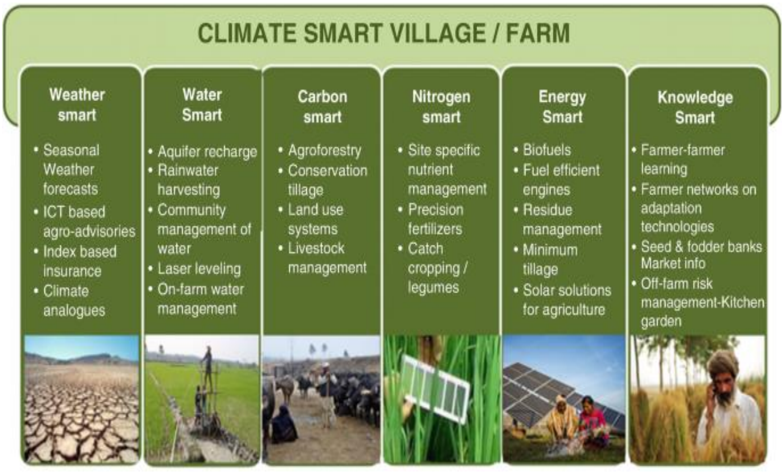

Fig. 3: Components of climate-smart village
(Source: Agriculture and rural development, Cambodia)

Success stories of climate smart cropping systems (Source: FAO)

1. Livestock waste management in East Asia

The demand for animal products is growing rapidly due to East Asia's population expansion, rising income, and urbanization. The rise of large-scale intensive pig and poultry production is primarily responsible for the livestock industry's successful response to this demand spike, but supply growth has also been linked to major environmental problems, especially those connected to manure management. The GEF/United Nations Environment Programme (UNEP)-funded Livestock Waste Management in East Asia Project, which is led by the FAO, was created to finance the costs associated with switching from the status quo strategy of ineffectively addressing environmental issues to a strategic framework for livestock production development that is both economically and environmentally sustainable. Its primary goal was to lessen the severe adverse effects on the environment and human health caused by the quickly expanding concentrated livestock production on water bodies and, therefore, on the populace in three East Asian nations: China, Thailand, and Vietnam.

2. Preserving the Agroforestry system in Mount Kilimanjaro

The southern slopes of Mount Kilimanjaro are 120,000 hectares covered in the "Kihamba" agroforestry system. Among agroforestry systems, the 800-year-old system stands out as one of the most sustainable types of upland farming. It has supported one of the largest rural population densities in Africa without jeopardizing sustainability, supplying livelihoods for an estimated one million people. Certified organic coffee cultivation, the introduction of vanilla as a high-value cash crop, and the installation of trout aquaculture along irrigation system canals are all examples of certified organic agriculture. The irrigation system needs to be upgraded to cut down on water loss, and storage pond capacity needs to be increased to handle extended dry seasons brought on by climate change. In three years, it is anticipated that management changes in the coffee industry alone will raise farm cash income by 25%.

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CHAPTER 13
ROLE OF INTEGRATED FARMING SYSTEM IN SUSTAINED FARMER'S INCOME

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Introduction to IFS system

By combining crop, livestock, fishery, and dairy farming, the IFS system is an effective and sustainable way to farm that aims to maximize land productivity. When using IFS, farmers are guided by the values of sustainability, diversity, recycling, and integration 1370 million people will be in our country by 2030, and 1600 million by 2050. We'll need to produce 289 and 349 MT of food grains each of those times in order to meet future demand. By 2030, the country's current situation predicts a further reduction of cultivable land, with more than 20% of it being used for non-agricultural purposes Gill *et al.*, 2005. According to IFS, the by-products of one type of agriculture can be repurposed as a resource for a different type. Because it makes use of waste as resources, it not only reduces waste but also boosts the productivity of the entire farm (Ministry of Economic Development, Belize).

A group of resource-saving methods known as integrated farming systems (IFS) aim to maximize profitability and productivity while simultaneously minimizing any unfavorable effects of intensive farming and protecting the environment (Lal and Gupta *et al* 199, 2012)

What is the Integrated Farming System?

The Integrated Farming System is a sustainable agricultural approach that combines multiple farming techniques to increase productivity while reducing the negative impact on the environment. The system typically involves the integration of crops, animals, and aquatic resources within a single farm and aims to create a self-sustaining ecosystem by utilizing natural resources and minimizing waste. It's a holistic approach that prioritizes environmental conservation and economic growth.

Efficient use of land and resources

Diversification:

IFS involve the integration of crops, livestock, and fish farming to utilize the land more efficiently. Diversified farming helps in maximizing land use and increasing output.

Reduced waste:

The use of organic waste as compost helps in land reclamation and reduces the use of chemical fertilizers and pesticides. It helps in managing waste and conserving natural resources.

Livestock management

Improved nutrition: IFS ensure the balanced diet of the livestock by providing them with natural feed, which enhances the quality of milk, eggs, and meat.	**Income generation:** The integration of poultry, dairy, and fish farming in IFS provides additional income and employment opportunities for farmers, especially small and marginal ones.
Improved manure management: The use of livestock manure in composts contributes to organic farming practices, reduces water pollution and improves soil health.	**Reduced risk:** The IFS system reduces the risk of livestock loss due to disease outbreaks and weather changes.

Water management

Efficient use:

Water is a scarce resource, and IFS helps in the efficient use of water. Rainwater harvesting and wastewater recycling have proven successful in conserving and utilizing water resources.

Controlled irrigation:

Modern irrigation techniques like drip and sprinkler help in reducing water usage and increasing soil moisture, thereby benefiting crop growth.

Flood control:

The planting of grasses and trees in IFS helps in reducing soil erosion and controls floods and soil degradation.

Financial management

Integrating diversified farming techniques helps in generating additional income, reducing risk, and increasing overall financial stability and security. Farmers can manage their finances more efficiently by adopting the IFS model, leading to improved livelihoods and better quality of life.

Market linkages

IFS emphasize the production of diversified crops. With market linkages, farmers can earn more by getting better prices for their produce.

The integration of dairy farming with milk processing units and supply chains can generate more income and employment opportunities.

The establishment of a local market system helps in cutting out middlemen, leading to higher prices for farmers and fresher produce for consumers.

Climate change resilience

Reduced emissions: The adoption of ifs practices helps in reducing greenhouse gas emissions caused by the overuse of chemicals, pesticides, and fertilizers.	**Increased biodiversity:** Ifs provides habitats for different species of plants, animals, and fish, leading to an increase in biodiversity.
Soil health: Ifs helps to maintain soil fertility, which is beneficial in climate change mitigation and adaptation. A diverse range of crops and livestock in ifs practices enhances the soil health and prevents soil erosion.	**Water conservation:** The integration of livestock and crops in the ifs model helps in utilizing the available water resources more efficiently.

How IFS system aims to double farmers' income

Reduced cost of production

The IFS system reduces the cost of production by minimizing the need for external inputs like fertilizers, pesticides, and feed. This is achieved through the use of integrated crop, livestock, and fish farming, which ensures efficient use of resources.

Diversification

An IF allows farmers to diversify their income sources by combining different farming activities. This ensures that income is not solely dependent on one crop or activity.

Increased product value

IFS results in the production of high-quality organic produce, which can fetch a higher price in the market. The integration of livestock, fishery, and dairy farming increases the income streams as well.

Features of IFS system

Sustainability	The system promotes sustainable agriculture by minimizing the negative impact on the environment and ensuring the efficient use of resources.
Diversity	The strategy encourages the cultivation of multiple crops and integration of different farming methods, which ensures biodiversity and reduces the risk of crop losses.
Integration	The integration of different farming methods facilitates the recycling of resources and ensures maximum utilization of available resources.

Problems of present agriculture

Agriculture's growth rate is stagnant or declining. Growing malnutrition in young children and pregnant women; decreasing net cultivable area due to rapid urbanization; worsening environmental pollution and greenhouse gas emissions; and insufficient food production to feed the future generation. Depletion of the ground water table from indiscriminate use and shrinkage of land holdings as a result of population growth Due to conventional farming practices, low-income farms have experienced an increase in production costs, feed and fodder shortages, low employment rates from monoculture, and issues with farm workers brought on by large-scale migration.

IFS for employment generation

The techniques used by various farming systems led to an increase in the amount of man days in a year as well as gross revenue, net revenue, and income for farmers. According to their research, Murshed and Pems (2011) predicted that an integrated farming system would create more jobs than a conventional farming system. Initial studies using the IFS approach recommended productivity gains of 30–50% and more than twice as many jobs as in arable farming, depending on the quantity, nature, and upkeep of enterprises.

Benefits of the Integrated Farming System

Increased crop productivity

The Integrated Farming System promotes crop diversification and crop rotation, which helps increase the productivity of crops.

Better livelihoods for farmers

Integrated Farming System increases the income output of farmers and provides better livelihoods by adding value to the resources produced.

Less environmental impact

The system reduces the effects of monoculture, minimizes chemical use, and encourages crop rotations. This reduces soil erosion and water run-off for a healthier environment.

Increased income for farmers

The Integrated Farming System can result in more income for farmers through increased productivity, crop diversification, efficient resource use, less use of controls, and increased efficiency of farm inputs.

Challenges faced by farmers in implementing the integrated farming system

1. Lack of knowledge on the Integrated Farming System and its techniques
2. Enforcement of regulations may be lacking on the use of harmful chemicals

Capacity building and training

Farmers:

IFS provide farmers with knowledge and skills to improve the productivity and profitability of their farms. Various programs offer training on crop-livestock integration, soil and water conservation, and nutrient management.

Institutions:

IFS works in partnership with various institutions to provide technical and financial support for implementing sustainable practices on farms

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Policy makers:

IFS can contribute to the government's goal of doubling farmers' income by promoting sustainable agriculture practices, creating market linkages, and providing employment opportunities in the agriculture sector.

Components in IFS

The important components of integrated farming system include all agriculture related enterprises such as agriculture, mushroom cultivation, fish farming, horticulture, sericulture, duck rearing, seed production, feed mill, vegetable production, fodder production, poultry, rabbitry, azolla farming, value addition, seed production, nursery, goat/sheep,pigery rearing, diary, apiary and pigeon rearing. The images of IFS are shown below:

Fig. 1: Overview IFS farm

Cattle Shed

Cultivation of exotic fruits (Dragon fruits)

Apiculture

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Duckery

Ridge and furrow bed

Goat farming

Cattle raring

Challenges faced by farmers while implementing IFS system

Technical know-how

Farmers require technical knowledge to effectively implement IFS, which may be lacking in some rural areas.

Market access

Access to markets is essential to sell the produce and obtain a fair price. Rural farmers may have limited market access.

Limited resources

IFS requires the integration of different farming methods, which requires financial and human resources. This may be a challenge for small farmers.

Advantages of IFS system compared to traditional methods

Higher productivity

IFS results in higher productivity due to the efficient use of resources and integration of different farming methods.

Reduced cost of production

IFS eliminate the need for external inputs, which reduces the cost of production. The integration of different farming methods saves time and energy as well.

Improved soil health

IFS has a positive impact on soil health due to the reduction in the application of harmful chemicals like fertilizers and pesticides

Successful Implementation Stories of IFS system

In Maharashtra, India, IFS has helped farmers to increase their income by 30-40%. In addition, the system has helped to improve soil fertility and reduce the environmental impact of farming.

Conclusion and future prospects of IFS system

Implementation of IFS system

IFS are being implemented in many countries to improve the livelihoods of farmers. With further development of the system, the future looks bright for small farmers. The success of integrated approaches by the farmers across the globe gives a visionary hope for small and marginal farmers of developing nations to boost their economies and enable them to compete in the local and international markets. Increased work opportunities and efficient use of farm resources lead to increased productivity for farm families as a result of integrated farming system. To ensure long-term viability and profitability of the agricultural production system, Integrated Farming System is essential. About 90% to 95% of a plant's nutritional needs are met by recycling resources, which reduces cultivation costs and increases profitability.

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CHAPTER 14

INTEGRATING NANOTECHNOLOGY INTO AGRICULTURAL SYSTEMS FOR SUSTAINABILITY

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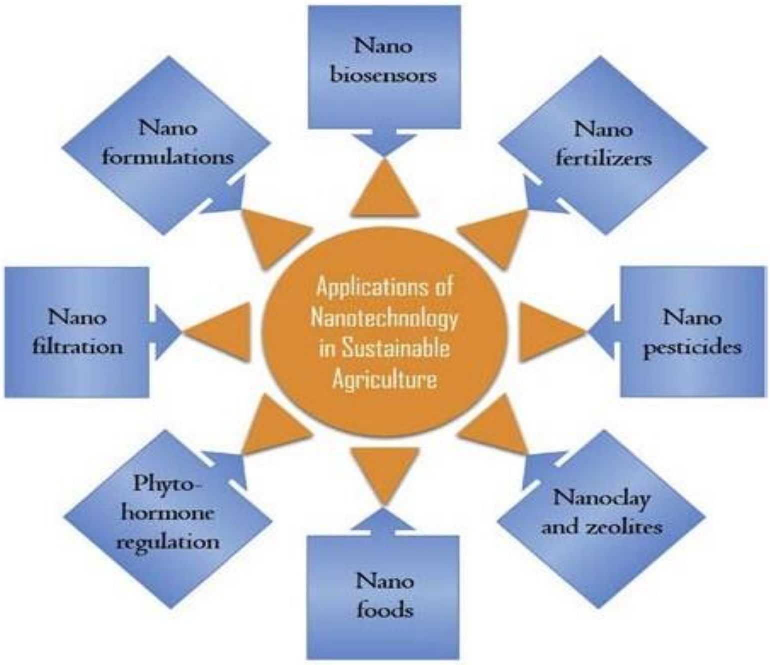
Introduction:

A majority of the population depends on agriculture for a living, making it the backbone of developing nations. The primary goal of agricultural scientists today is to increase crop output and productivity due to the growing global population. The issue has gotten worse due to the rapid shrinkage of agrarian land and the limited energy supplies needed for agricultural operations. In order to increase crop productivity, new information-based procedures and technologies must be developed. In this regard, nanotechnology has found various applications in the agricultural domain as it aids in developing sustainable practices. First of all, nanotechnology refers to the science pertaining to the study of altering matter on an atomic and molecular level, often at the nanoscale level. One billionth of a metre is a nanometer, and at this size, materials and devices show special characteristics that are different from those of their bulk counterparts. Understanding, creating, and leveraging materials and structures at the nanoscale to produce new uses and products with improved qualities is known as nanotechnology. Nanomaterials can be classified intoinorganicnonmetallic NMs, carbon-based NMs, metallic nanoparticles (NPs), and organic polymeric materials. Different commonly used nanomaterial forms include carbon nanotubes, quantum dots, nanorods, nanocapsules, and nanoemulsions. There is also a branch of nanotechnology that focuses on sustainable practices while developing nanomaterials, known as green nanotechnology. Green nanotechnology is the application of nanotechnology to processes that are detrimental to the sustainability of the environment. It entails developing clean technologies to lessen potential risks to public health and the environment from the production and use of nanoproducts, as well as replacing current products with new environmentally friendly nanoproducts.

Why nanotech in agriculture?

With its unique methods to the molecular management of illnesses, quick disease identification, and boosting plant nutrient uptake, among other applications, nanotechnology has the potential to totally transform the agriculture and food industries. Examples of the significant interactions between nanotechnology and agriculture include disease management, better materials for pathogen detection, regulating disease delivery systems, safer agricultural and food systems, and environmental protection. (Welch and Graham, 1999; Suman *et al.*, 2010).The enormous surface area, variable pore size, strong reactivity, and particle shape of nanoparticles are only a few of their remarkable physical and chemical characteristics.Nanotechnology is used in agriculture to make nano pesticides, nano fertilisers, nano biosensors, etc. Compared to traditional chemicals, nanomaterials facilitate the controlled release of molecules by using nanoencapsulation techniques. Nanoscale sensors can be used to track soil and water quality, enhancing crop productivity and preventing the spread of plant diseases brought on by environmental stress. In addition to directly catalysing the breakdown of waste and harmful chemicals, nanomaterials also contribute to bioremediation by increasing the effectiveness of microorganisms in the process. Agricultural soil and water can be bioremediated to break down or eliminate toxins and dangerous substances.



Application of nanotechnology in sustainable agricultural practices

Nanobiosensors

A sensor is a highly developed gadget that reacts to physical, chemical, and biological elements and transforms those responses into a signal or output that humans can use. Nanobiosensors are nanosensors that have been joined to a range of bioreceptors specially designed to bind to the chemicals of interest. Nanobiosensors, which are made on a nanoscale for results detection and analysis at the level of the atom, have been used for the analysis of enzymes and metabolic products, the identification of numerous pathogens, and the detection of chemicals such as glucose, urea, herbicides, pesticides, or other compounds. By providing information on crop plants' nutrient or water status at precise geographical and temporal scales, nanosensors have the potential to help farmers use inputs more effectively. This enables the farmers to use crop protection (insecticide, fungicide, or herbicide) or nutrients, water, or both, only where essential. The employment of autonomous sensors connected to a global positioning system

(GPS) system for real-time monitoring is also increased by nanotechnology-enabled gadgets. Thus, these nanosensors might be dispersed around the field to track crop development and soil quality. For example, by using a flow injection system, a fiber-optic biosensor created by fiber-optic probes coated by antibodies was used to detect food poisons, plant pathogens, and *Escherichia coli*. Hashimoto *et al.* (2008) also created a unique biosensor that combined two biosensors by immobilising two distinct microbes in the same proportion on an electrode, allowing for the quick and accurate detection of soilborne illnesses.

Nanopesticides

There are four basic types of pesticides, although they all serve the same purpose i.e., to either eliminate the undesirable elements or develop resistant plants. These categories includedisinfectants that control bacteria by preventing their spread, fungicides for molds and algae, insecticides that act on insects and herbicides that kill undesired weeds and grasses. Insecticides, pesticides, and insect repellents can all be made using nanoparticles, which have been demonstrated to be efficient against infestations by such organisms. Additionally, DNA and other desirable compounds can be delivered into plant tissues using nanoparticles to protect host plants from insect pests. The main risks of using conventional pesticides at this time, according to Ghormade *et al.* (2011), are the decline in nitrogen fixation, the emergence of pathogen and pest resistance, the contribution to pesticide bioaccumulation, a decrease in soil biodiversity, the fall in number of pollinators, and the depletion of bird habitats.As a result, the use of nano pesticides partially allays these worries, and their combination with herbicides lowers the quantity needed to eradicate weeds. Therefore, preparing the pesticide inside of a shell or in a closed envelope will increase solubility while allowing for a slow and effective release. For instance, water-soluble pesticides can be effectively delivered by using porous hollow silica nanoparticles (PHSNs) loaded with validamycin for controlled release. PHSNs exhibit a controlled release behaviour that makes them a viable carrier in agriculture, particularly for the regulated delivery of pesticides that require both rapid and delayed release for plants (Liu *et al.*, 2006b). Nair *et al.* (2010) reported that the pesticidal activities of silver nanoparticles on the pathogenic fungus prevent the conidial germination of theRaffaelea species, which kills oak trees. Avermectin, a pesticide that prevents neurotransmission in insects, has an extremely brief half-life of about 6 hours since it cannot be exposed to UV rays. It has been suggested that utilising porous Ag NPs with a pore width of 4-5 nm and a shell thickness of 15 nm can increase the longevity of these particles. Silver nanoparticles have an extended life cycle of about 30 days because they encapsulate avermectin and stop it from degrading and becoming harmful when exposed to UV light. Another use of nanoparticles was to coat a pesticide with an emulsion by appropriately mixing water and oil to produce the water-insoluble substance cypermethrin and testing the coating's balance and spraying effectiveness against an uncoated product (Wang *et al.*, 2007). Spodoptera littoralis, a serious insect that primarily affects the plant kingdom and has shown resistant to practically all pesticides, was successfully controlled using a hydrophobic tomato covered in nano silica. This insect responded well to pesticides that kill them at 300–350 ppm. In contrast to conventional pesticides that draws off in the rain, nanoencapsulatedinsecticides adsorbed on the plant floor aid in continuous release for a longer period of time. The environment suffers as a result of these out-of-date approaches to disease and pest control. Because of this, the use of NPs is becoming increasingly popular in sustainable agriculture as it is environmentally friendly.

Nanofertilizers and nanoscale carriers as smart delivery systems

A fertiliser is a substance or mixture of substances applied to soil or plants to provide essential nutrients for optimal plant growth and development. The main goal of fertiliser addition is to speed up the uptake of nutrients from the soil, which improves crop output. Though chemical fertilisers have several drawbacks, the most significant is their low use effectiveness, which is expensive and pollutes the environment (Wilson *et al.*, 2008). Nitrogen is required in large quantities by the majority of plants, and its uptake causes numerous issues for plants. The outcome is that the uptake of nutrients by plants drastically increases and the depleted energy is replaced when fertilisers are delivered gradually and effectively in an encapsulated form. Nanomaterials known as nanofertilizers can either provide plants with nutrients or improve the efficiency of conventional fertilisers. Naderi & Danesh-Shahraki (2013) claim that switching from conventional fertilisers to nanofertilizers is advantageous since they continually release nutrients into the soil under controlled circumstances, preventing water pollution. Nanofertilizers have also been found to be more successful than other fertilisers because they decrease nitrogen loss from leaching, emissions, and enable long-term uptake by soil microorganisms (Liu *et al.*, 2006 a, b, c). For effective delivery of insecticides, fertilisers, plant growth regulators, herbicides, etc., nanoscale carriers would be used (Prasad *et al.*, 2012). These carriers employ entrapment and encapsulation, polymers and dendrimers, floor ionic and susceptible bond attachments, among other techniques, for better storage, efficient supply, and controlled release (Sawant *et al.*, 2006). These methods help to increase their resistance to environmental degradation and, eventually, require less application, which reduces chemical compound run-off and solves environmental issues. Nanoparticle application increased growth rate and seed germination by 33% and 20%, respectively, in compared to conventional phosphate fertiliser. Nanoparticles can serve as fertilisers by giving plants nutrients. The nanoorganic iron-chelated fertilisers showed high absorption, enhanced photosynthesis, and increased leaf surface area (INIC, 2009). Since they can reduce soil toxicity and reduce the frequency of fertiliser application, nanofertilizers also have a substantial impact on soil (Naderi and Danesh-Shahraki, 2013). Therefore, nanofertilisers act as smart delivery systems by imparting enhanced nutrient solubility, controlled release, targeted delivery, nutrient protection, reduced environmental impact.

Nanoherbicide - Improving weed control efficiency

Herbicides are chemical substances or formulations designed to control, kill, or inhibit the growth of unwanted plants, commonly known as weeds. Weeds are undesirable plants that compete with cultivated crops, garden plants, or native vegetation for resources like sunlight, water, and nutrients. Herbicides are an essential tool in modern agriculture, horticulture, and landscaping to manage weed infestations and promote the growth of desired plants. Herbicides can be categorised based on their mode of action, application method, and selectivity. It's important to use herbicides responsibly; as overuse or improper application of herbicides can have negative consequences, such as environmental pollution, harm to non-target plants, and eventually make weeds herbicide resistant. Biological herbicides, natural herbicides, and integrated weed management techniques are some of the eco-friendly and less hazardous alternatives to traditional chemical herbicides that have gained popularity in recent years. These methods seek to successfully manage weeds while causing the least amount of environmental damage and protecting useful plant species. Ananoherbicide is a type of herbicide that utilizes nanotechnology to improve the efficacy, selectivity, and delivery of herbicidal agents. Nanoherbicides are designed at the nanoscale; typically using nanoparticles, to enhance the performance of conventional herbicides and provide more targeted and controlled weed management solutions. Triazine, ametryn, and atrazin herbicides have typically been nanoencapsulated to result in an 84% effective release to plants, according to Grillo *et al.* (2012).

Nanofiltration in agriculture

Water scarcity has a negative impact on the agriculture industries in arid areas. Additionally, the struggle for scarce resources is exacerbated by the rising demand for water for home and industrial uses. Additionally, agriculture is receiving less water than other high priority sectors due to this trend. Controlling water waste and implementing effective irrigation techniques are, in this situation, the most sustainable and economical ways to deal with water scarcity; however, these improvements are slow to take effect and may not be suitable for areas that experience persistent water shortages. An alternate approach to dealing with this problem is to use unconventional water sources, such as recycling, desalination, collecting rainwater, and reusing brackish water (Ghermandi and Messalem, 2009). A highly advanced membrane filtration method called nanofiltration (NF) is mostly used to remove particles from fresh groundwater and surface water, including bacteria, viruses, fungi, nematodes, and other parasites. Nanofiltration can commonly be used for elimination of organic matter, fine particles, turbidity, harmful microorganisms, and selective ions without the use of disinfectants (Mrayed *et al.,* 2011; Riera *et al.,* 2013) The properties of nanofiltersfina a major application in wastewater treatment and water softening processes, by the process of reverse osmosis and ultrafiltration. Pore sizes in nanofilters range from 0.5 to 1 nm. Under operating pressures of 1 and 4MPa, these filters make it easier to fractionate and purify mono or multivalent salts mixtures and organic solute particles with a molecular weight of 100–1000Da (Savage and Diallo, 2005).

Nanofoods- Improving food quality and packaging

Food is deemed to be nanofood when it is produced, processed, or packaged using nanoparticles or other nanotechnology tools or techniques. Food manufactured by nanomachines or food that has undergone atomic modification are not included, nevertheless. Martirosyan and Schneider (2014) claim that nanotechnology has the ability to increase our understanding of food materials at the nanoscale and deliver bioactive components in food to hosts. It also helps with nanoscale systems of filtration for better-adjusting food texture. Nano biosensors engage with food, have an appealing surface, and maintain the food's original colours. With magnetic nanocomposite, they can also be employed as tag sensors. Recently, the food processing industry has made substantial use of nanotechnology in products including organic nano-sized food additives, dietary supplements, and animal feed. Nanotechnology has also been extensively applied to increase agricultural quality and yield. Crop plants such as corn, wheat, ryegrass, tomato, lettuce, spinach, pumpkin, corn and cucumber have all shown numerous positive morphological effects of nanoparticles (mainly metal and carbon based). These outcomes include increased biomass, root and shoot length, and germination rate. In one study, it was also discovered that iron oxide nanoparticles improved agronomical traits like soybean grain production. A study by Kole *et al.* (2013) evaluated the effect of the carbon-based nanoparticle fullerol on the growth of the medicinally valuable vegetable crop known as bitter melon. According to the results of this study, fullerol treatment increased fruit yield by up to 128% and increased fruit weight, quantity, and biomass output by 54%, 59%, and 70%, respectively. The reduction of post-harvest losses caused on by inadequate perishables processing, preservation, and packaging facilities has also showed potential for nanotechnology. Nanoparticles are beneficial in food packing because they function as effective diffusion barriers for gases like oxygen and carbon dioxide due to their nanostructure. Additionally, oxidation, degradation, and other biochemical processes will be slowed down by the use of nanoparticles in packaging, extending the shelf life of food products. For instance, the Tamil Nadu Agricultural University is now working on nanomatrices that can be mixed with packaging material to increase the shelf life of mango commodities. The most widely used materials in the food packaging industry are plastic polymers, which can contain or be coated with nanoparticles for improved mechanical or functional properties. In order to create food storage bins, silver nanoparticles have been effectively incorporated into the plastic. This disinfects the bins and reduces the growth of hazardous bacteria. As a result, nanotechnology is a technique that looks to the future and serves as a form of agricultural biosecurity. Thus, in order to increase the shelf-life of highly perishable fruits and vegetables, it is envisaged that these kinds of nanotechnology-based procedures will be used.

Nanoparticles in plant growth enhancement

The potential use of nanoparticles in agriculture for enhancing plant development has been investigated and metals, metal oxides, carbon-based materials, and polymers are just a few of the materials that can be used to engineer them. Carbon nanoparticles have occupied a significant position among nanoparticles, especially because of their unique mechanical, thermal, chemical, and electrical properties. These nanoparticles can have a number of advantageous impact on plant growth and development. The consequences can be both physiological and physical depending on the quality of the nanoparticles. The efficient use of nanoparticles depends on concentration and varies between plants. The effect of nanoparticles for plant growth enhancement can be divided into two categories:

- **Growth promoter**

According to a study, tomato seedlings' germination rate and vegetative biomass significantly increased after being exposed to multi-walled carbon nanotubes (CNTs)

(Khodakovskaya *et al.*, 2009). According to this study, nanoparticles' ability to penetrate cell walls boosted the amount of water that seeds absorbed, which in turn increased the rate of germination. According to a 2010 study by Srinivasan and Saraswathi, single-walled carbon nanotubes function as nanotransporters for efficient DNA and dye molecule delivery into plant cells. Several studies came to the conclusion that metal nanoparticles (NPs) support plant growth and development. Al-Whaibi (2014) and Xie *et al.* (2011) observed that nano-SiO2 increased physiological factors such as photosynthetic rate, transpiration rate, and electron transport rate, which enhanced plant growth and development. It appears that NPs have a substantial effect on plants' ability to grow.

- **Disease Suppression**

The principal factors influencing the spread of disease in plants include bacteria, viruses, fungus, and nematodes. They deprive plants of sustenance and cause a drop in productivity. According to Jo *et al.* (2009), 200 mg/L of silver NPs significantly reduced the number of pathogenic fungi that could colonise ryegrass. Similar findings were made by Lamsal *et al.* (2011 a, b), who discovered that using silver nanoparticle therapy increased disease inhibition. Candida albicans, Phoma glomerata, and Trichoderma spp. were effectively inhibited when Ag nanoparticles and the fungicide fluconazole were used in conjunction. When compared to Magnaporthe grisea with 50% at the optimal concentration, Jo *et al.* (2009) demonstrated that Bipolarissorokiniana had a more effective quantity for suppressing colony formation using silver.

Potential benefits of nanotechnology applications

Applications of nanotechnology have a wide range of potential uses because of their special nanoscale characteristics and interactions. Nanotechnology has found a large number of applications, from medicine and healthcare, environmental remediation, energy efficiency, agriculture and food production, electronics & optics, water purification, manufacturing & materials, personal care products, textiles, and even space exploration. Nanosensors, which may be able to detect chemical contaminants, viruses, and bacteria; nano-delivery systems, which may precisely deliver medications or micronutrients at the right time and to the right part of the body; as well as nanocoatings and films, nanoparticles, and quantum dots; are just a few of the applications that are anticipated for use in food and agriculture, according to Bouwmeester *et al.* (2009). Applications of nanotechnology deal with difficulties like elevated soil temperatures, drought stress, and inefficient input usage. Nanoscale agrichemical compositions offer the ability to reduce environmental damage while increasing use efficiency. Using nanoporous materials that can retain the water and gradually releases it when there is scarcity could also enhances yields and save water. Nanomaterials can also be applied to photocatalysis in agriculture, where they can be very helpful. For instance, various nanostructures of titanium dioxide (TiO_2) and zinc oxide (ZnO) were studied for use as photocatalysts (Ullah and Datta, 2008). Additionally, the compounds in pesticides are changed into relatively secure molecules like CO_2, N_2, and H_2O.

Ecotoxicological implications of the nanoparticles

A significant amount of produced nanoparticles (NPs) have been let out into the environment as a consequence of the development of nanotechnologies. Research has increasingly focused on assessing the toxicity of the nanoparticles often used in industry in order to safeguard human health and plants from the potential harmful effects of a variety of nanomaterials (Tripathi *et al.,* 2017 a,b,c; Du *et al.,* 2017; Rana and Kalaichelvan, 2013; Yang and Watts, 2005; Rana and Kalaichelvan, 2013). A metal's solubility and preferred binding sites within cells are two of the many variables that could impact its toxicity. Due to the charge at the membrane surface, metal nanoparticles (NPs) can be cytotoxic and have antibacterial, anticandidal, and antifungal properties (Aziz *et al.,* 2016; Patra and Baek, 2017). Since the targeted cell wall's structure affects how effectively nanoparticless cause nanotoxic effects, the sequence of sensitivity of nanomaterials to various microorganisms can be organised as follows: Mould is more sensitive than yeast, followed by gram-negatives, and gram-positives.

Nanotoxicity may also be due to electrostatic interaction between nanoparticles withmembrane and their accumulation in cytoplasm (Rana andKalaichelvan, 2011; Aziz *et al.*, 2015, 2016).

The study of how dangerous compounds affect ecosystems and the environment is known as ecotoxicology. When nanoparticles are discharged into the environment, they may interact negatively with bacteria, plants, animals, and other living things. The main ecotoxicological effects of nanoparticles include bioaccumulation and biomagnification, toxicity to non-target organisms, contamination of the soil and water, effects on the health of plants and crops, transportation and fate of nanoparticles, persistence and degradation, and the emergence of nanoparticle resistance. Therefore, it is essential to carry out comprehensive risk analyses and environmental impact studies before using nanoparticles and other nanoparticle-based products extensively. Additionally, adopting acceptable management practises and legal criteria can assure the safe and long-term usage of nanotechnology in agriculture and other industries. Although nanoparticles have intriguing possibilities for accelerating plant growth, their use in agriculture needs to be carefully considered. Safety and environmental issues must be resolved so as to guarantee that the application of nanoparticles in agriculture is sustainable and does not harm the ecosystems or human health. There may be differences in regional and national rules regarding the usage of nanoparticles in agriculture because this topic is currently being researched.

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CHAPTER 15

NATURAL FARMING: WAY FOR SUSTAINABLE AGRICULTURE

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Introduction:

Increasing population on one hand and shrinking land resources on the other hand has necessitated the generation of vast food demand. Increased efforts to produce more food with indiscriminate input and resource use have resulted in a slew of difficulties and challenges, viz. a loss in soil health and a drop in the water table, inefficient use of resources, inorganic nutrient imbalances; excessive nutrient mining; and developing multiple-nutrient deficits, growing insect-pest and disease issues; Weed flora changes and growing pesticide resistance, contamination and pollution in water bodies and soils endangering human health; Biodiversity loss, emissions of greenhouse gases; erosion and deterioration of the natural resource base, etc., all of which contribute to agricultural unsustainability. So, there is a need of conservation and rehabilitation strategy for food and farming systems that aims to improve rather than eliminate negative effects. It should emphasize top soil regeneration, biodiversity enhancement, water cycle improvement, ecosystem services enhancement, support for bio-sequestration, climate resilience, and bolstering the health and vitality of farm soil. So here comes the need of Natural farming and regenerative farming which can be regarded as some of the most effective ways of sustainable agriculture in long run. Regenerative agriculture is a comprehensive farming method which prioritizes soil health, food quality, increased biodiversity, clean water, and clean air, by increasing soil organic matter, biota, and biodiversity, it enhances soil health. Moreover, here Food and agricultural goods are grown in a manner that emulates/mimics nature. It is an umbrella term and natural farming is component under regenerative farming which emphasizes on:

- Continuous soil restoration rather than degradation
- Improving ecosystem sustainability and resilience
- Bringing environmental and economic advantages to farmers, communities, and nations
- Increase local biodiversity, soil fertility, empower local communities, and strive to farm in the natural manner.

Organic, regenerative, sustainable agriculture and natural farming:

These terms are often confusing and are used interchangeably but they have thin line difference between them.

Organic agriculture

The labeling phrase "organic" refers to goods produced in accordance with strict guidelines established by the Organic Foods Production Act. emphasizes the production inputs (such as non-GMO, no synthetic fertilizer, pesticides, or herbicides). It is more of a replacement agriculture, taking the place of traditional agriculture's synthetic chemicals. Attempts to reduce complexity by managing living things. Organic farming helps in reduction of the harm to the environment rather it has the ability to heal everything, organic agriculture is focused on problems and because of complexity are always needed for a new solution.

Sustainable agriculture

Focuses on the physical manipulation of the land (e.g. no till, cover crops, crop residues, etc).

Regenerative agriculture

A philosophy founded on universal principles rather than a specific set of behaviors. Restoring relationships between people and land, improving soil health, reducing or eliminating the use of harmful chemicals, growing diverse crops, holistic and humane livestock management, innovative and efficient resource use, and equitable labor practices are among the regenerative principles."

Natural Farming:

Natural farming is a chemical-free agricultural approach founded in Indian culture and reinforced with current knowledge of ecology, resource recycling, and on-farm resource efficiency. It is a diversified farming system based on agroecology that mixes crops, trees, and animals with functional biodiversity. It is primarily focused on on-farm biomass recycling, with a focus on biomass mulching, the use of on-farm cow dung-urine formulations, soil aeration, and the avoidance of any synthetic chemical inputs. Natural farming should lessen reliance on commercial inputs. It is seen as a cost-effective farming practice with the potential to increase employment and rural development.

Organic farming is tied by set of rules, while Sustainable and RA are not bound by rules

Natural farming provides a one stop solution to a multifarious issue, including food insecurity, farmer anguish, and health issues caused by pesticide and fertilizer residuum in food and water, as well as global warming, climate change, and super natural event. It also has the potential to create jobs, hence reducing rural youth migration. As the name implies, natural farming is the art, practice, and, increasingly, science of working with nature to achieve much more with less.is defined as "chemical-free farming and livestock-based farming". It is an agro-ecologically sound agricultural system that blends crops, trees, and cattle, allowing for the best use of functional biodiversity. It promises to increase farmers' income while also providing numerous other benefits such as soil productiveness restoration, environmental healthiness, and mitigating and/or lowering greenhouse gas emissions (National Mission on Natural Farming Management and Knowledge Portal, GOI).

Masanobu Fukuoka, a Japanese farmer and philosopher, popularized this farming method in his 1975 book 'The One-Straw Revolution.'Natural farming is recognized internationally as a type of regenerative agriculture—a key system to save the world. Natural farming is encouraged in India through the Bhartiya Prakritik Krishi Paddhati Programme (BPKP) of the Paramparagat Krishi Vikas Yojana (PKVY). BPKP aims to promote traditional native practices. It is identifiedsynonymously by various names like; Zero Budget Natural Farming, Prakrithik Krishi, Cow Based Natural Farming, Shashwat Kheti, Chemical Free Agriculture, etc. GoI is promoting Natural Farming through a scheme named Bhartiya Prakrit Krishi Padhti (BPKP). It is being promoted in India by Padma Shri Subhash Palekar, Maharastra, 1990s.

Although, both organic and natural farming systems are non-chemical methods of farming principally relying on miscellany, on-farm biomass management, rejuvenation of natural nutrient recycling, crop rotation, multiple cropping and efficient resource salvaging but with following variances:

- **Organic systems** in addition to above are open to use of off-farm purchased organic and biological inputs and need based soil correction through natural mined minerals,
- **Natural farming systems** are concentrated on biomass mulching, covering the soil with green cover, novel cow-based dung and urine formulations in omission of all purchased inputs organic, biological or whatever otherwise.

Budget announcement:

"Natural farming will be promoted throughout the country, with a focus on farmers' lands in 5-km wide corridors along the Ganga in the first stage." "States will be encouraged to revise agricultural university curricula to meet the needs of natural, zero-budget, and organic farming, modern-day agriculture, value addition, and management." Both of these non-chemical agricultural approaches are being promoted by the Indian government. Natural farming, through the National Mission on Natural Farming (NMNF), and organic farming, through the Paramparagat Krishi Vikas Yojna (PKVY) and the Mission Organic Value Chain Development for the North Eastern Region (MOVCDNER).

Similarities between Organic and Natural Farming

- Both systems restrict the use of chemical fertilizers and pesticides on plants. To a large extent both are chemical-free and poison-free.
- Farmers are encouraged for consumption of local seed varieties and inherent cultivars of vegetables, cereals, legumes, as well as other crops in both the system of farming
- Nonchemical and DIY pest control solutions are promoted by both

Differences between natural farming and organic farming:

Organic Farming	Natural Farming
In organic farming, organic fertilizers and manures like compost, vermicompost, cow dung manure, etc. are used and added to farmlands from external sources.	Natural farming does not amend the soil with either chemical or organic fertilizers. In reality, neither the soil nor the plants receive any exogenous fertilizers.

Basic agricultural tasks like weeding, tilting, mixing manures, and plowing still need to be done in organic farming.	There is no plowing, no soil tilting, no fertilizers, and no weeding in natural farming; everything is done as it would be in natural ecosystems. In organic farming, earthworms and bacteria are encouraged to break down organic materials right on the soil surface, gradually supplying nutrients to the soil.
Due to the need for large quantities of manures, organic farming is still expensive and has a conservation impact on the environment.	Natural agriculture is a Zero-Budget No-Fee (ZBNF) farming technique that perfectly integrates with regional biodiversity.

Key principles of ZBNF:

- Zero use of external inputs
- Crops to cover the soil for 365 days (Living Root)
- Minimum soil disturbance
- Bio-stimulants as essential expediters for different natural cycles
- Utilize native seed for mixed farming
- Mixed cropping
- The incorporation of trees onto the farm
- Prominence on moisture and waterpreservation
- Introducing animals into farming
- More biological debris in the soil
- Using plant extracts to control pests
- Non-natural pesticides, herbicides, or fertilizers is strictly evaded

4 primary components of ZNBF

- Bijamrita/Beejamrutha
- Jeevamruth/Jiwamrita
- Achhadan (Mulching)
- Waaphasa/Moisture (Soil Aeration)

There are no external inputs used as a principle in Natural farming. Microbial seed treatment, local seeds (use of native varieties), Microbial inoculants for soil health Cover crops for biomass mulching and bio-mass incorporation in order to provide an ideal microclimate for beneficial microbial activities, Tree integration within the farm, mixed farming Integration of livestock, particularly native breeds for cow dung and urine as key inputs for a variety of water and moisture conservation methods. Natural farming aims to improve soil health, preserve biodiversity, safeguard animal welfare, make better use of natural/local resources, and promote ecological fairness and balance. NF is an ecological farming strategy in which the farming system works with the soil's intrinsic biodiversity, encouraging biological activity and monitoring the intricacy of living species, both plant and animal for realizing greater degree of productivity and viability.

Major objectives of natural farming:

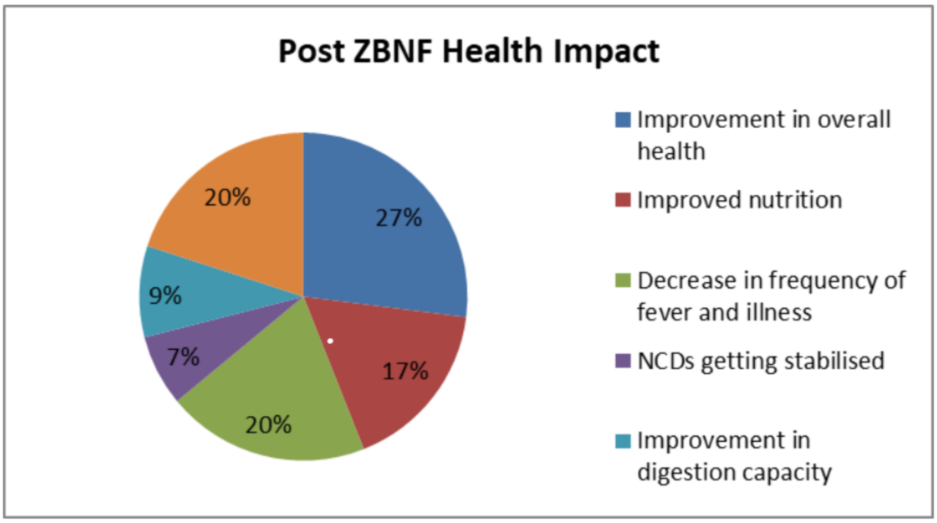
- Preserve natural flora and fauna
- Restore Soil fertility and production and biological life
- Maintain diversity of crop production
- Efficient utilization of land and natural resources (light, air, water)
- Promote inbuilt natural inspects, animals and microbes in soil
- Promotion of local breeds of Livestock integration
- Use of Natural / local based inputs
- Reduce input cost of agricultural production
- Improve economy of farmers

What is the significance of natural farming?

Reduced production costs: Use of low- cost inputs have made it as a cost-effective farming approach with the latent to increase employment generation and rural development at a substantial level.

Better health: Using pesticides and fertilizers have negative effects on both farmers and consumers. Farmers those use chemical inputs are vulnerable to contamination. NF can reduce the risk of incidence of non-communicable diseases linked to the use and appliance of inorganic chemicals in agriculture, such as acute and chronic neurotoxicity, respiratory disorders, and even cancer, by substituting such external inputs with locally produced natural concoctions, inoculums, and decoctions. As Natural Farming does not utilize synthetic chemicals the danger of health risk is mostly reduced. The food produced through this process has a nourishingeffect on the consumers and so provides greater healthbenifits.

Perception of HHs on Health post NF consumption



Source: Assessment of Post NF effects on the Health & Nutrition profile of households (December 2019)

Employment creation: It creates jobs through natural farming input initiatives, cost addition, local marketing, and so forth. The profits from natural farming are reinvested in the village. It can aid in lowering rural youth migration because it has the ability to provide jobs.

Environment protection: It promotes better soil ecology, increased agrobiodiversity, and more judicious water use with substantially lower carbon and nitrogen footprints.

Livestock sustainability: The incorporation of livestock into the farming system is critical in natural farming and aids in the restoration of the ecosystem. Jivamrit and Beejamrit are eco-friendly bio-inputs made from cow dung and urine, as well as other natural resources.

Resilience: Changes in soil structure caused by organic carbon, no/low tillage, and plant diversity promote plant development even under harsh conditions such as severe droughts and withstanding catastrophic flood and wind damage during cyclones. Many farmers benefit from NF because it makes crops more resistant to weather extremes.

Reduced water consumption:

Natural farming maximizes the quantity of 'crop per drop' by incorporating different crops which are synergistic and complementary with each other and cover the soil to reduce needless water loss through evaporation. "Out of 50% of the world's accessible freshwater, 70% consumption is reported for agrarian purpose according to a 2016 WWF assessment. Sixty percent of India's irrigated land is groundwater, which is being overused and causing aquifer water levels to drop. One of the best practices that has been shown to increase water retention capacity is natural farming. It is effective at using the least amount of water and is known to lessen reliance on resources like power and water. In the end, this will protect the groundwater reserve, raise the water table, and lessen the strain on farmers' finances and labor. It is beneficial to increase soil fertility and water retention capacity through practices such as Whapasa. Similarly, soil moisture can be retained in the soil for a longer time thanks to contours and bunds. Since there is ten times as much water in the air as there is in rivers, natural farming essentially aids in increasing the moisture content and porosity of the soil. Natural farming has the potential to revolutionize agriculture in the nation's drought-prone areas. According to a study on the life cycle assessment of NF and Non-NF done in Andhra Pradesh by the Centre for Study of Science, Technology, and Policy, paddy uses less water when practicing Zero Budget Natural Farming (NF). It was shown that NF needed 3,500 thousand litres (average per acre) less water for paddy than non-NF, based on survey data and 1,400 thousand litres in theory.

Eliminates the use of synthetic chemical inputs:

A loss of soil organic carbon and fertility results from the overuse of synthetic fertilizers, especially urea, insecticides, herbicides, and weedicides, which alter soil biology and structure.

Soil health is rejuvenated:

The most direct influence of Natural Farming is on soil biology—on bacteria and other living organisms like earthworms. The soi health and quality is largely dependent on the live organisms that inhabit within it.

Women's agency and community ownership for scaling up of natural farming:

The democratic process of natural farming transformation is facilitated by grassroots initiatives led by women's and men's collectives. SHGs and their federations, in particular, are women's collectives that are active in the organizing, carrying out, and overseeing of programs. As women and their collectives gain a deeper understanding of natural farming and inspire their members to adopt it, they find themselves at the centre of this transformational movement. They have a greater understanding of the harmful effect of fertilizers and pesticide on their farm soil and family health.

Environment conservation:

Greenhouse gas (GHG) emissions from 'Agriculture, Forestry, and Other Land Use' (AFOLU) have roughly doubled in the last 50 years, with forecasts indicating a further increase by 2050 (Tubiello *et al.*, 2014). According to FAO statistics, agriculture accounts for the majority of worldwide methane and nitrous oxide emissions. Excessive fertilizer use in conventional farming has contributed greatly to global greenhouse gas (GHG) emissions and climate change. In 2016, the amount of greenhouse gas (GHG) emitted per nutrient ton of fertilizer produced was 1.1 metric tons of CO2/nutrient ton. Climate change will impair global food security and may alter the nutritional qualities of particular crops. When carbon dioxide levels are increased, the concentrations of Mineral levels in various crops (for example, wheat, rice, and soybeans) might be up to 8% lower than usual. Protein levels may be decreased as well, while carbs are higher (FAO, 2015). A meta-analysis of 1090 studies on yields (mainly wheat, maize, rice, and soybeans) under various climate change situations suggests that climate change may cut yields significantly in the long run. (From Porter *et al.*, 2014), By encouraging the use of an agroecology framework, Natural Farming seeks to mitigate risks re lated to climate change uncertainty.

It promotes the use of inexpensive domestically grown inputs by farmers and the avoidance of industrial herbicides and chemical fertilizers. By enhancing the fertility and firmness of the soil, natural farming has demonstrated that farmlands are more resilient and can shield crops from harsh weather. Orchards, crops, and farming fields in their natural state have particularly remarkable resilience to climate fluctuations. The crops grown in Andhra Pradesh using Natural Farming proved more resilient to strong winds during the 2018 Pethai and Titli storms than conventional crops. According to a CEEW study titled "Zero Budget Natural Farming for the Sustainable Development Goals Andhra Pradesh, India," paddy crops in Vishakhapatnam, 2017 fared significantly better against wind and water-logging during a bout of cyclonic winds than nearby non-NF (Zero-Budget Natural Farming) paddy fields. This feature would lessen the amount of money that farmers lose as a result of unfavourable weather. Furthermore, farmer and community driven extension architecture continuously provides the hand holding support and knowledge dissemination.

Livestock sustainability: In order to practice natural farming and help the environment recover, animals must be incorporated into the farming system. Eco-friendly bio-inputs like Jeevamrit and Beejamrit are produced using natural resources like cow dung and urine.

Components of natural farming:

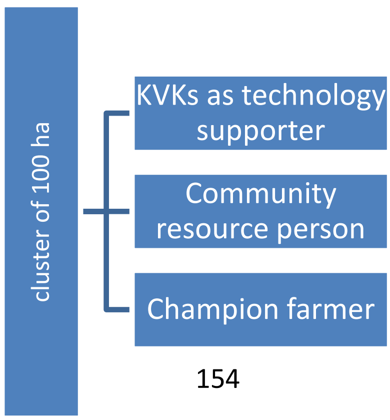
- According to natural agricultural practices, plants get 98% of their nutrients from the air, water, and sunlight. High-quality soil that is teeming with helpful microorganisms can fill the remaining 2% of the gap. (As in forests and natural systems)

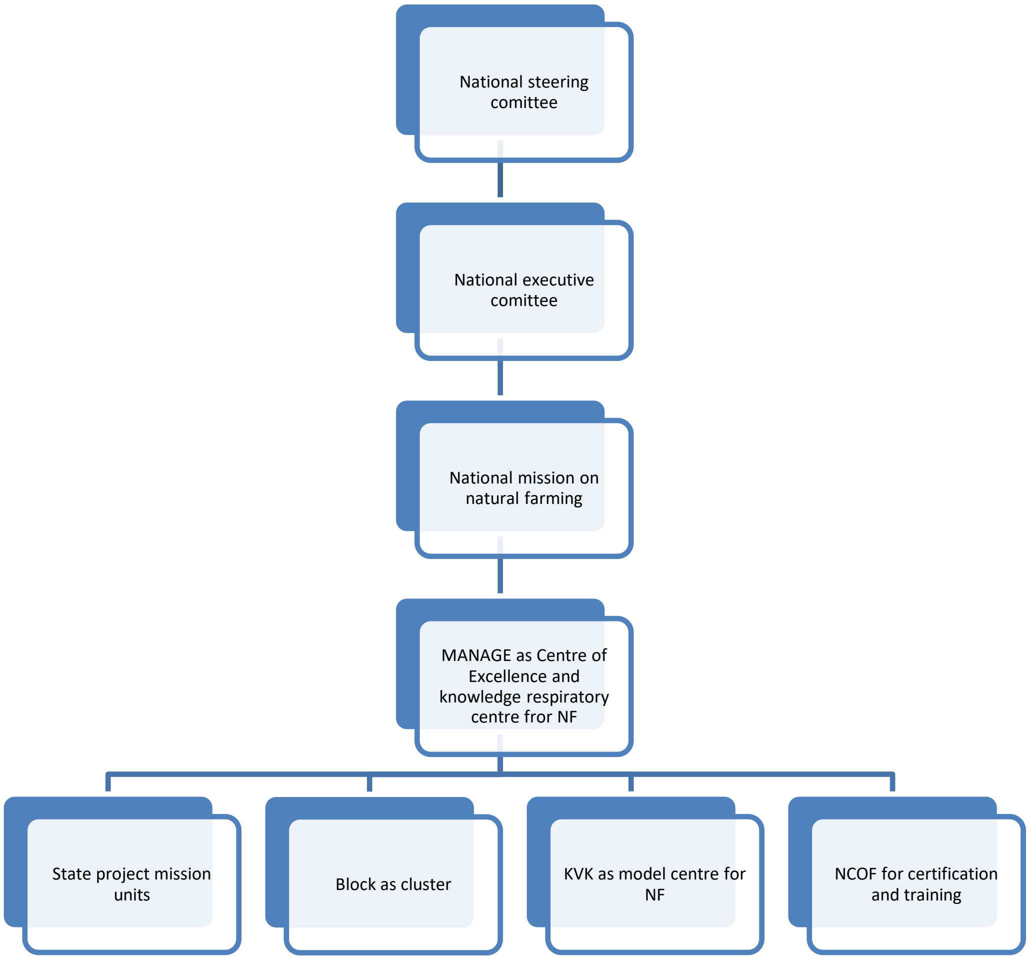
- An organic mulch should constantly be applied to the soil to prevent weed growth and to encourage the development of beneficial bacteria.
- To boost soil microflora, farm-made bio-cultures like "Jeevamrit, Beejamrit, and others" are added to the soil instead of fertilizers. It claims to enhance farmers' income while also offering a variety of extra benefits like soil fertility restoration, environmental health, as well as cutting and/or decreasing GHG emissions. Jeevamrit and Beejamrit are created using very little desi cow dung and pee.
- For Gomutra, the system needs cow manure and cow pee specially from Desi Cow which is the purest form of all breeds.
- In natural farming, neither chemical nor organic fertilizers are added to the soil. In fact, no external fertilizers are added to soil or given to plants whatsoever.
- In natural farming, decomposition of organic matter by microbes and earthworms is encouraged right on the soil surface itself, which gradually adds nutrition in the soil, over the period of time.
- In natural farming there is no plowing, no tilting of soil and no fertilizers, and no weeding is done just the way it would be in natural ecosystems.
- Natural, farm-made pesticides like Dashparni ark and Neem Astra are used to control pests and diseases.
- Weeds are considered essential and used as living or dead mulch layer.
- Multi-cropping is encouraged over single crop method.
- earthworms is encouraged right on the soil surface itself, which gradually adds nutrition in the soil, over the period.
- In natural farming there is completeavoidance of tilling the soil and use of fertilizers, and no weeding is done just the way it would be in natural ecosystems.
- Multi-cropping is encouraged over single crop method.

Potential areas for natural farming:

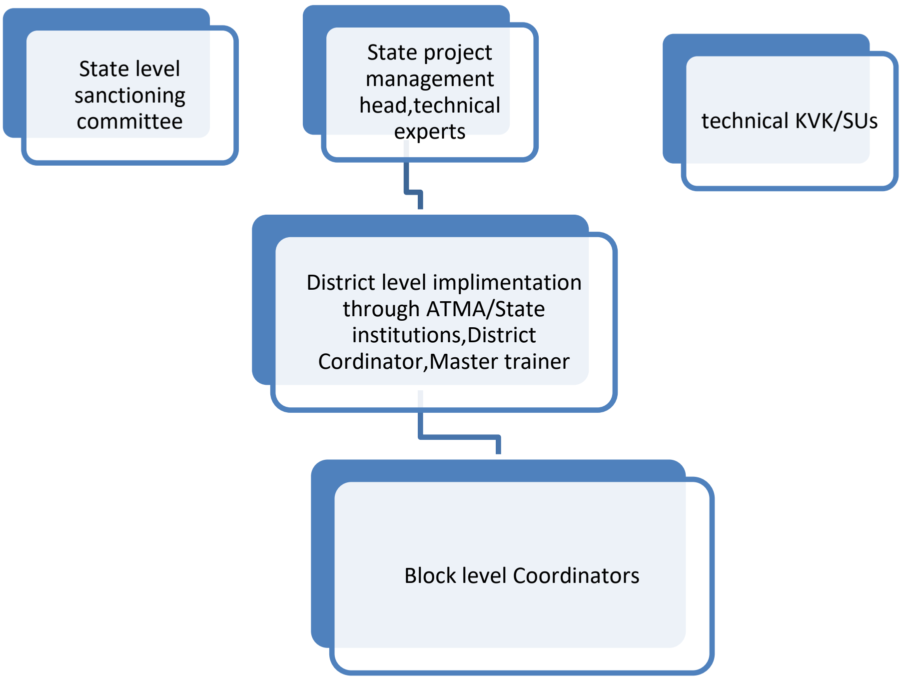
- Areas with very low consumption of fertilizers and other agrochemicals
- Areas under rain fed farming, Hilly areas, Tribal dominated
- Performs better during drought year
- Area suitable for cluster approach
- High value and low nutrient requiring crops growing areas

Proposed mode of Implementation:(At Central level)





Proposed implementation under mission mode:(State level)



Issues related to natural farming:

Decline in yields: Following the switch to organic farming, yields in Sikkim (India's first organic state) have decreased. Aftermath to their ZBNF (Zero-Budget Natural Farming) profits diminish after a few years, many farmers have reverted to traditional farming.

Unable to boost productivity and income: While ZBNF has undoubtedly helped maintainsoil fertility, its role in enhancing productivity and profitability is not unquestionable yet**.**

Low availability of natural inputs: The absence of readily available natural inputs is occasionally cited by farmers as a barrier to switching to chemical-free agriculture. Every farmer lacks the time, persistence, or labour necessary to produce their own inputs.

Deficiencies in nutrients: In low-input farms (farms that use less fertilizer and pesticides), nutrient deficiencies are comparable to those of chemical inputs, while they are lower in high-input farms. When such nutrient deficiencies are severe, the yield may decline over time, thereby posing problems with food security.

Components of natural farming in detail:

Jeevamrit:

Preparation method of jeevamrit

- Jeevamrit is a fermented liquid organic manure rich in beneficial micro flora (nitrogen fixers, phosphorus solubilizers, actinomycetes and fungi) which support, stimulate the plant growth.

Water (200 lit) + Fresh cow dung (10 kg) + Cow urine (10 lit) + Jaggery (gur) (2 kg) + Pulse flour (Besan) (2 kg) + Soil from same farm (1.0-1.5 kg)

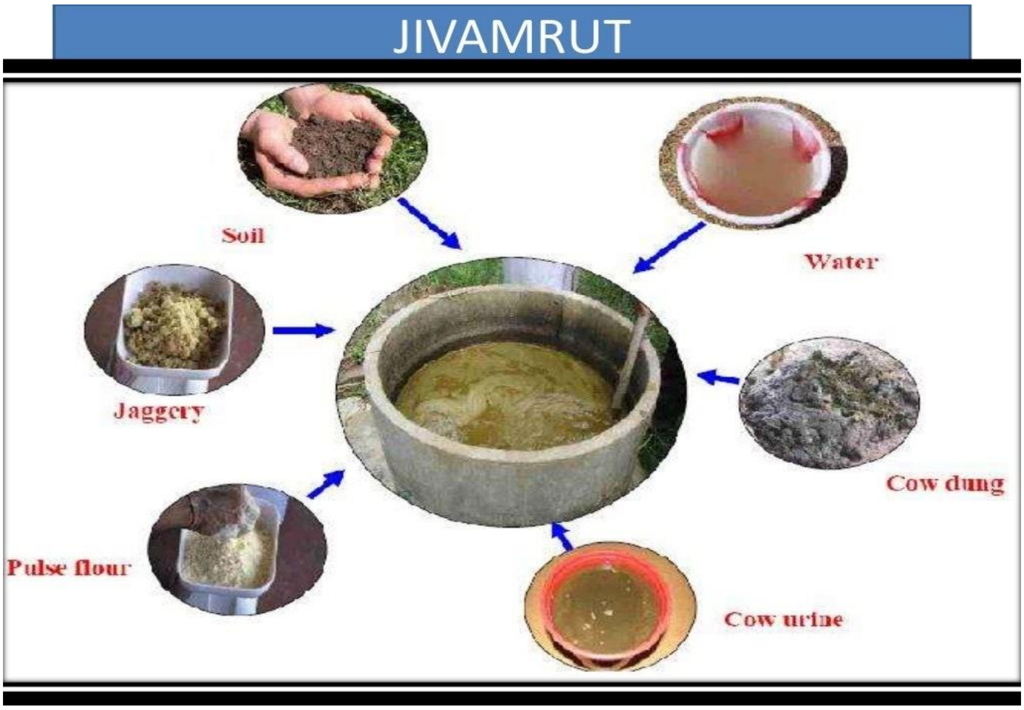
Add all the material in a plastic drum (220 lit. capacity) and mix thoroughly

Keep the drum in shade covered with gunny bag, cotton cloth or plastic mosquito net

Stir the mixture for 5-10 minutes for twice a day (morning and evening) with wooden stick

Jeevamrit ready for application at 9th day and it can be applied up to 12th day

- Apply @ 5% conc. at 21 DAS/DAP & @ 10% 20-25 days interval for 3,4,5 & 6 times for short (60-90 days), medium (90-120 d), medium-long (120-135 d) & long (135-150d) crops.
- For fruit crop @2-5 lit. in the basin once in a month.



Bijamrit:

Beejamrit is an age old practice of agriculture and is sustainable also. It is used for seeds, seedlings or any planting material in protecting young roots from fungus. Beejamrit is a fermented microbial solution, with loads of plant-beneficial microbes, which is used for seed treatment. It is expected that the beneficial microbes would colonize the roots and leaves of the germinating seeds and help in the healthy growth of the plants.

Inputs needed: 5 kg cow dung, 5 litre cow urine, 50 gram lime, 1kg bund soil, 20 litre water (for 100 kg seed)

Preparation of Beejamrit:

Step 1: Take 5 kg cow dung in a cloth and bind it using tape. Hang the cloth in 20 litre water for up to 12 hours.

Step 2: Simultaneously, take one litreof water and add 50gram lime in it, kept stable for overnight.

Step 3: Next morning, continuously squeeze the bundle in the water thrice, so that all the nutrients of cow dung is mixed in the water.

Step 4: Add handful of soil, approximately 1 kg in the water solution and stir well.

Step 5: Add 5 litres desi cow urine in the solution and limewater, and stir it well.

Application as a seed treatment: Add Beejamrit to the seeds of any crop; coat them, mixing by hand; dry them well and use them for sowing. For leguminous seeds, which may have thin seed coats, just dip them quickly and let them dry.

Panchgavya:

Panchagavya is also an ancient product for enhancing growth, yield and quality of the agri and horticultural crop.

- Consists of ten products viz., cow dung, cow urine, milk, curd, ghee, jaggery, banana, tender coconut, and water.
- The product of local breeds of cow has higher potency than exotic breeds.
- Mix 7 kg cow dung and 1 kg cow ghee (keep for 3 days)
- Mix 10 lit. of cow urine and 10 lit. of water (keep for 15 days)
- Mix cow milk (2 lit.), cow curd (2 lit.), tender coconut water (3 lit.), jaggery (3 kg), yeast (100 g) and well ripened banana (12 nos).
- Panchgavya will be ready after 21 days.

Method of application:

1. Sprayed on crops @ 3% conc. at pre-flowering phase (once in 15d, 2 sprays), flowering and pod setting stage (once in 10 d, 2 sprays) and once at fruit/ pod maturation stage
2. Fertigation @ 50 litres/ha either through drip or flow irrigation.
3. Seed soaking or seedlings dip for 20 minutes.
4. Rhizomes or sett soaking for 30 minutes.

Handi khata

Ingredients:

- One Earthen Pot
  [Approx. 25 litre capacity]
- Fresh cow dung -5 Kg [Country cow]
- Cow urine [Approx. 5 litre]
- Gur/Jaggery [Molasses] -250 g

- Neem leaves-1 kg [*Azadirachta indica*]
- Karanja leaves -1 kg [*Pongamia pinnata*]
- Arakha leaves -1 kg [*Calotropis*]

Procedure:

- Chop (Neem, Arakha& Karanja) leaves in to small pieces.
- Then add 5 kg cow dung, 5 kg cow urine, 250g jaggery and all the chopped leaves to the pot.
- Thoroughly mix it and cover the mouth of the pot with a cloth. Keep the pot in shade for a week (7 days).
- Stir the content twice every day.
- After a week take out only the liquid portion from the pot keeping the solid part inside. The solution is called (Handikhata). This can be kept for 6 months for use.
- Then add about 5 litres of cow urine only to the pot and repeat the process and reuse for 4 months with adding of cow urine time to time.
- After 4month it is required to prepare fresh solution with all the ingredients once again.
- 60-70 lit sufficient for 1ha of crop for 1 season.
  Uses and dose:
- The standard recommended dose is 20 ml per 1 litre of water.
- For nurseries and younger plants- 10-12 ml/litre water.
- Spray it 4 times in 15 days interval.
- Waste decomposer:A microbial consortia (bio-fertilizer, bio-pesticide, bio-control and soil health reviver) developed by NCOF, Ghaziabad, used as
  - Quick composting of bio waste,
  - Foliar spray as bio-pesticide for control of diseases by producing antimicrobial metabolites-4 times at 10 d interval,
  - Fertigation- 180 litre product for 1 acre
  - *In-situ* composting of crop residues- 180 l/acre product for 1 acre
  - Seed treatment- 1 bottle (30 g) mixed with 30 g jaggery for treating 20 kg seed

Method of preparation:

- 200 litre water + 2 kg jaggery + 1 bottle waste decomposer (30 g)
- Stir the solution twice a day for 5-7 days.

- After 7 days the colour will change and foam will be formed.
- 180 litre can be used leaving 20 litre and the same procedure is continued.

Composting:

- Spread 1 ton of compost as layer on a plastic sheet placed under shade
- Sprinkle 20 liter of the above prepared solution over the compost layer
- Spread one more layer of compost above the existing layer
- Sprinkle 20 liter of the solution over the compost layer
- Use the solution for 10 compost layers
- Maintain 60% moisture during entire period of composting
- Turn over the compost at 7days interval
- The compost is ready to use after 30 days

Mulching: Mulching can be defined as covering of soil surface using any biological or non biological material i.e. live crops and straw (dead plant biomass) dust, plastic sheet to conserve moisture which in turn lower soil temperature around plant roots, prevent soil erosion, reduce runoff and reduce weed growth.

There are two types of mulches:

Crop residue mulch: This comprises any dried vegetation, farm stubble, such as dried biomass waste etc. It is used to cover the soil against severe sunlight, cold, rain etc. Residue mulching also saves seeds from birds, insects, and animals.

Live mulch: Live mulching is the process of developing multi-cropping/inter cropping patterns of short duration crops in the rows of a main crop. It is suggested that the pattern should be of monocotyledons and dicotyledons in the same field, in order to provide all the essential nutrients. Monocots, like wheat and rice, supply nutrients such as potash, phosphate and sulphur, while dicots such as pulses are nitrogen-fixing plants. Such practices reduce the demand of a particular type of plant nutrient.

Whapasa: Whapasa means the mixture of 50% air and 50% water vapour in the inter space between two adjacent soil particles. It is the soil's microclimate on which soil organisms and roots thrive upon for most of their moisture and some of their nutrient requirement. It enhances water availability, water-use efficiency and builds resilience against drought.

Plant protection measure in Natural farming: All the plant protection measures through use of different botanicals discussed below are mainly prophylactic measures to control disease and pest incidence.

Neemastra: Neemastra is used to prevent or to cure diseases, and kill insects or larvae that otherwise eat plant foliage and suck plant sap and also helps in controlling the reproduction of harmful insects. Moreover, Neemastra is very easy to prepare and is an effective pest repellent and bioinsecticide for Natural Farming.

Inputs needed: 200 litre water, 2 kg cow dung, 10 litre cow urine, 10 kg fine paste of neem leaves.

Preparation of Neemastra:

Step 1: Take 200 litre of water into a drum and add 10 litre of cow urine. Then add 2 kg of local cow dung. Next, add 10 kg of fine paste of neem leaves or 10 kg neem seed pulp.

Step 2: Then stir it clockwise with a long stick and cover it with a gunny bag. Keep it in shade as it should not be exposed to either sunlight or rainfall. Stir the solution every morning and evening in clockwise direction.

Step 3: After 48 hours, it is ready for use. It may be stored for use up to 6 months. It should not be diluted with water.

Step 4: Filter the prepared solution with a muslin cloth and apply directly on the crop through foliar spray.

Controls: All the sucking pests, jassids, aphids, white fly and small caterpillars are controlled by Neemastra.

This is a natural insecticide prepared from leaves which have specific alkaloids to repel pests. It controls all sucking pests and hidden caterpillars that are present in pods and fruits.

Inputs needed: 20 litre cow urine, 2 kg neem leaves, 2 kg karanj leaves, 2 kg custard apple leaves and 2 kg datura leaves.

Preparation of Brahmastra:

Step 1: Take 20 litre of cow urine in a vessel and add 2 kg of fine paste of neem leaves, 2 kg of paste prepared from leaves of karanj, 2 kg paste of custard apple leaves, 2 kgs paste of castor leaves, and 2 kg paste of datura leaves into it.

Step 2: Boil it on a small flame, till one or two foams (overflow level). Stir in clockwise direction, then cover the vessel with a lid and keep on boiling it.

Step 3: After formation of second foam, stop boiling and allow it to cool for 48 hours so that the alkaloids present in the leaves are released into the urine. After 48 hours, filter solution using a muslin cloth and store it. It is better to store in pots (earthen pots) or plastic drums under shade. The solution may be stored for use up to 6 months.

Application: 6-8 litre of Brahmastra diluted in 200 litre of water can be used as the foliar spray on the standing crop. This ratio may be changed depending upon the severity of pest attack as follows:

100 litres of water +3 litres of Brahmastra

15 litres of water +500 ml of Brahmastra

10 litres of water + 300 ml of Brahmastra

Agniastra

It is used to control all sucking pests and caterpillars.

Inputs needed: 20 litrecow urine, 2 kg pulp of neem leaves, 500 gm tobacco powder, 500 gm green chilli, 250 gm garlic paste and 200 gm turmeric powder

Preparation of Agniastra:

Step 1: Add 200 litre cow urine to a container. Then add 2 kg neem leaves paste, 500 gram tobacco powder, 500 gram green chilli paste, 250 gram garlic paste and 200 grams turmeric powder.

Step 2: Stir the solution in clockwise direction and cover it with a lid and allow it for boiling till we get foam.

Step 3: Remove from fire and keep the vessel under shade, away from direct sunlight for cooling up to 48 hours. During this fermentation period, stir the components twice a day.

Step 4: After 48 hours, lilter with a thin muslin cloth and store it. It can be stored for 3 months.

Application: 6-8 litres of agniastra should be taken and diluted in 200 litres of water for spraying. The following ratio are to be followed based on the severity of pest attack.

100 litres of water+ 3 litres of agniastra

15 litres of water+ 500 litres of agniastra

10 litres of water+ 300 litres of agniastra

Dashaparni: Dashaparni ark acts as one of the most powerfulsubstitutes for Neemastra, Bramhastra, and Agniastra. It is used to control all types of pests and is being used depending on the level of infestation.

Inputs needed: 200 litre water, 20 litre cow urine, 2 kg cow dung, 500 grams turmeric powder, 10 grams Asafoetida, 1 kg tobacco powder, 1 kg chilly pulp, 500gram garlic paste, 200 gram of ginger paste, Any 10 leaves*.

Preparation of Dashparni:

Step 1: Take 200 litres of water in a drum, add 20 litres of cow urine and 2 kg of cow dung. Mix it well and cover with the gunny bag and keep aside for 2 hours.

Step 2: Add 500 gram of turmeric powder, 200 gram of ginger paste, 10 grams of Asafoetida into the mixture. Stir it well in the clockwise direction; cover with gunny bag and keep overnight.

Step 3: Next morning, add 1 kg of tobacco powder, 2 kg of hot green chilli paste and 500 gram of garlic paste and stir it well with wooden stick in the clockwise direction, cover with gunny bag and leave for 24 hours under shade.

Step 4: Next morning, add paste of any 10 types of leaves* (from the list given at the bottom) to the mixture.

Step 5: Stir thoroughly and cover with the gunny bag. Keep it for 30-40 days for fermentation so that the alkaloids present in the leaves will get dissolve in the mixture. Stir twice a day

Step 6: Filter this after 40 days with a muslin cloth and use it.

Application: The prepared kashayam of 6-8 litres should be diluted in 200 litres of water for spraying.

*Neem leaves – 3 kg, Leaves of Pongamia pinnata – 2 kg, Leaves of Annona sqamosa- 2 kg, Castor leaves (Ricinus communis) – 2 kg, Datura leaves (Datura metel)- 2 kg, Leaves of Calatropisprocera – 2 kg, Leaves of Vitex negundo – 2 kg, Leaves of Datura stramonium – 2 kg, Leaves of Nerium indica – 2 kg, Leaves of Hibiscus rosa – 2 kg, Mango leaves (Mangifera indica) – 2 kg, Leaves of Lantana camara – 2 kg, Leaves of Casia tora – 2 kg, Leaves of Guava (Psidium guava) – 2 kg, Leaves of Pomegranate (Punica granatum) – 2 kg, Leaves of Drumstick (Moringa oleifera) – 2 kg, Leaves of Coffee (Coffea arabica) – 2 kg, Leaves of Mahua (Maduca indica) – 2 kg, Coco leaves (Theobroma cacao) – 2 kg, Leaves of Acacia nilotica – 2 kg, Leaves of Psoralea corylifolia – 2 kg, Leaves of Bitter Gourd (Momordica charantia) – 2 kg.

Current scenario of natural farming in India

Many leading states like Andhra Pradesh, Gujarat, Himachal Pradesh, Odisha, Madhya Pradesh, Rajasthan, Uttar Pradesh and Tamil Nadu are the front runners in takeing up initiatives for natural farming promotion are among the leading states. Till date more than 10 lakh ha. area has been covered under natural farming in India. Andhra Pradesh is the most leading state in adoption in Natural farming,

Main challenges in natural farming adoption:

- Knowing &understaning the nature - based on keen observations
- Willingness to take risks and leave the comfort zone - new paradigm
- Risks associated with transition - support the transition
- Environmentally compartible technology -confidence on ITKs
- Need for investment in new tools etc. - finding alternative financing mechanisms
- Need for good business management with key performance indicators - data management- forward & backward linkage
- Learning, training, coaching are a big need, lifelong learning, but limited and not accessible - train the trainer, farmer-to-farmer coaching

Way forward:

- In rainfed regions outside of the Gangetic basin, natural farming needs to be promoted with a focus.
- Comparing rainfed regions to places with widespread irrigation, only one-third as much fertilizer is used per hectare in the former.
- In order to address the issue of readily available natural inputs, the government will support microenterprises that produce inputs for chemical-free agriculture. The establishment of village-level input preparation and sales shops must be combined with the promotion of natural farming.
- The government ought to create a supportive environment where farmers can share knowledge and assistance with one another while they undergo this change.
- It is necessary to upskill agriculture extension workers on sustainable agriculture techniques in addition to changing the curricula in agricultural universities.

Conclusion:

The nation's quest towards Atma Nirbharta (Self-reliance), with farmers at its centre, is centred on agriculture. Our focus has constantly concentrated on efforts for improving, empowering, and stabilizing farmers in the technical, economic, and social spheres. In pursuit of environmentally sound and commercially successful solutions, we are always investigating new approaches. One strategy that has the ability to accomplish all of these objectives is natural farming. It is supported by our extensive traditional knowledge and relies on locally accessible resources, making it an agriculture approach that is sustainable and profitable. However, the yield generated from natural farming is low in initial years of farming due to lack of supply of nutrients (particularly nitrogen is the limiting factor).So, there is no fix set of management practices.So over initial years the farmers should undergo integrated management practices with best agricultural practices like conservation agriculture, silvipasture, multi-strata agroforestry, farm nutrient management and farmland irrigation for all the area in Natural farming and slowly we can move forward to natural farming. It evolves over the years, over crops, over places and over farmers. To summarize in a single line Science led promotion of different forms of BPKP (Natural farming) including organic farming is imperative for sustainable and economical future of Agriculture.

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