Chapter 1

Soil Science and Ecosystem

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Abstract

The role of soil in the human life is indispensable. Soil remains at a central hub when nutritional requirement of the living community is concerned. In terms of ecosystem services, the soil tends to provide various services to the environment as whole. These services can be categorized under provisioning services like providing anchorage to the plants, supporting services cover taking care of nutritional requirement of plants and microorganisms, regulating services includes waste and nutrient recycling, cultural services involve protection of artifacts and heritage sites under soil. For the conception of global food security, the main thrust should be on the soil and its functional ability to support the crop requirements. Sequestering the carbon into the soil system not only reduces the concentration of greenhouse gas carbon dioxide in the atmosphere, but also imparts good physio-chemical properties of the soil

system. The most important challenge of the human population is to protect and manage this natural capital sustainably without hampering its production function.

Keywords: Ecosystem services, food security, climate change, carbon sequestration

I. INTRODUCTION

The term ecosystem applies to a network which is created as a dynamic interaction of the living community with other species and the corresponding abiotic environment in which it harbors (Benbow *et al*., 2019). For a given existing community, the abiotic environment which comprise of land, air, water, temperature and sources of nutrition are the key characteristics which determine the function and abundance of the concerned community. The suitability and access of these resources play a major role in selection of species or a group of species which will thrive in the given situation and will continue to do so in case of ever-changing interaction of these abiotic environmental conditions. An organism studied in isolation always impart partial information, if the dynamics of the ecosystem it resides in, is ignored (Hanson *et al*., 2012).

Land characteristics which are eventually translated into the nature of soil it beholds, needs to be studied more carefully. Although, land is classified under non-living resource but there is consensus among the scientists to consider soil as the natural living body (Souza, 2022). Soil itself is formed from the complex interaction of rocks and minerals with surrounding climate features, macro- and micro-organisms residing, topographical features of the landform and ultimately, the variable duration of interaction of these factors. However, studies on soil often receive inadequate attention from the scientific community compared to the functional importance it provides.

Soils provide a plethora of functions which can be conspicuously seen along with functions which are only noticed when dwelled with deeper insights. Noticeable attributes of soil include anchorage of plant to the ground, base material for construction of buildings, storage of rainwater, recharge of ground water table, habitat for various macro-organisms and protection of archaeological heritage below the ground. While, a variety of function which remains overlooked by a layman includes supplier of essential nutrient elements, buffering of the chemical environment, filtration of water, decomposition of plant and animal residue, site for efficient bio-geo-chemical cycles, preserver of natural biodiversity of microorganisms, a potential tool for mitigating greenhouse gas emission by sequestering carbon from the atmosphere to name a few (Huang *et al*., 2012).

II. SOIL AND ECOSYSTEM SERVICES

Ecosystem services (ES) can be regarded as set of benefits one can obtain on account of utilizing that ecosystem as whole. Millennium Ecosystem Assessment (2005) describes ES under four basic heads which are- provisioning, regulating, supporting and cultural services. The ecosystem services provided by soil as a system under these heads are discussed as (Dominati *et al.*, 2011)-

1. Provisioning Services

Under the provisioning services category, soils are accounted for the direct tangible good it provides. The most obvious function the soil has been performing is in terms of providing physical anchorage and support to the plant community. Good soil structure ensures better root penetration and prevention of lodging of cropped plants. Another important provisioning service the soils are known to provide is the raw materials one need for the construction of any building or related structure. Soil is an integral component of materials like brick, cement, sand, mortar, etc.

2. Supporting Services

The soils impart their importance in supporting services as well. Owing to their nature and composition, soils retain a large amount of nutrients in their colloidal clay fractions. These elemental nutrients are released into the solution depending upon the chemical equilibrium surrounding the root system of the plants. Not only of the plant community, but nutritional requirement of microbial community is also taken care by soil. Various micro-flora inhabiting the soil has adaptive mechanism to extract the essential elements required for their growth and metabolism. Thereby supporting biological diversity within and above it.

3. Regulating Services

The soils are the key components to regulate and maintain various nutrient cycles. By retaining various nutrients and harboring microorganisms which can metabolize these nutrients, soils aids in recycling these essential elements. Soil also helps in buffering against abrupt chemical changes which may arise during environmental variability. Soil serves as a filtering agent when rainwater has to percolate deep down the ground in order to recharge the groundwater aquifers. Completion of water cycle also cannot be imagined without giving due emphasis to the soil. Evaporation and infiltration of rainwater contributes significantly to the hydrological balance of the Earth.

Apart from it, soil plays a vital regulatory function in terms of decay and decomposition of dead organic tissues. Transformation of organic waste into organic matter and humus along with recycling of the nutrients contained within is the service for which humans will remain indebted forever.

4. Cultural Service

Humans are deeply connected to the soils culturally. Various sites of cultural heritage are well preserved within the soil. Historical marvels and archaeological artifacts are cautiously protected within the domain of soil before being explored. Soils of various regions bear special religious and spiritual values for humans. Ultimately, after completing their journey of life, humans are buried in the soil itself to mark the importance of soil to the mankind.

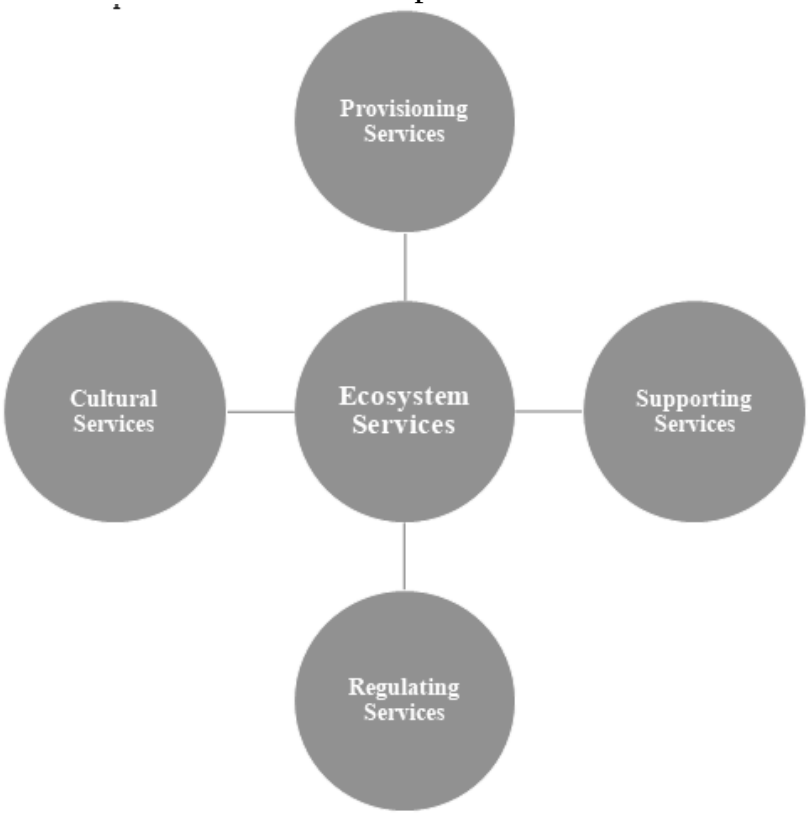

Figure 1: Diagrammatic representation of various ecosystem services

III. IMPORTANCE OF SOIL ECOSYSTEM FOR ENSURING FOOD SECURITY

The pressing need of the society to obtain sufficient food of good nutritious quality cannot be imagined without giving due emphasis to soil. The concept of food security will be realized only if we maintain a healthy and productive soil ecosystem (Lal, 2013). The research trends in the past few years have been focused more on the food production and processing rather than on

the importance of soil to achieve the notion of food security (Bouma and Mc Bratney, 2013). Now, the focus needs to be shifted from intra-disciplinary research to broad inter-discipline which relies on soil health and its management as the key idea. It should also take into account the role of soil ecosystem as a whole not only for the sake of food security, but should also encompass the concept of global climate change, biodiversity conservation, water management environmental pollution (Hopmans *et al*., 2011).

The food production comes under umbrella of the ecosystem services of the soil. As a matter of fact, an ecosystem is a broad concept; it has to multi-disciplinary in order to include the key contribution each discipline offers towards the services they provide. The idea is to formulate an integrated approach of the services by connecting the linked disciplines (Millennium Ecosystem Assessment, 2005).

Soil contributes nearly 98% of the global food supply of humans (78% directly through soil grown crops and 20% indirectly through animal food source which ultimately feeds on soil grown crop) (FAO, 2015). The soil is involved in the life cycle of plant from its beginning of the life cycle to its senescence. Growth of plant includes sowing of seed into the soil. The soil is responsible for the storage and supply of water required for the transpiration and thereby, regulating suitable temperature and oxygen supply to the roots. Soil also supports plant growth by supplying essential nutrient elements required for plant to complete its life cycle and maintain a suitable chemical environment around the roots. By harboring various plant growth promoting macro- and micro-organisms, soils maintains a rich biological diversity. Animals and livestock feeds on the plants produced in the soils, their health and nutrition also depends on the food material they acquire from the soils. The animal excreta in turn, again act as manure for the plants after recycling by the soil system. So, ultimately soil serves a central role in food production (Raj *et al*., 2019).

Soil also transforms the raw organic residues into the resistant humus fractions which serve as sink for sequestered carbon, regulating the climate change. Various agrochemicals when added to improve the production status of plants also reside into the soil for longer periods. These chemicals when leached or transported by runoff to the water bodies pollute the aquatic bodies and disrupt their natural environment. Thus, these processes describe the role of soil in food production, biodiversity maintenance, water management, relation with climate and pollution regulation (Barton *et al*., 2016).

To provide a holistic view of the importance of soil in terms of ecosystem services, one can point out following functions like high-quality food production, checking sediment and nutrient losses, efficient water and nutrient

cycling, storing rainwater and recharging ground water, maintaining soil microorganism health, making agriculture climate resilient through carbon (C) sequestration. However, soil health status and food security can be impacted by soil structure degradation, loss of vital nutrients, decreased organic carbon status, and by the evil phenomena of soil erosion and runoff (Pimentel and Burgess, 2013).

Based on the results from various studies, it has now become evident that the life of every living being is supported by soil, which is the principal and self-sustaining vital resource. Soil, plant, animal, and human systems all have complex interactions with one another. Because each of these elements depends on the others for survival, a better habitat and an ecologically sound system have to be created. The components like plant, animal and human all have a higher chance of surviving in ecosystem that is healthy and stable. Soil health is the key idea regarding the foundation for crop health, the amount and quality of food and thus, the overall health of both animals and humans.

IV. IMPORTANCE OF SOIL UNDER CLIMATE CHANGE CRISIS

Global climate change has now attracted attention of many scientists and policy formers in this 21st century. The aberrant increase in average global temperature, high carbon dioxide levels, increase in pollutant levels and other green house gases in the atmosphere, irregularity in the amount and distribution of precipitation leading to more frequent events of drought as well as flood (Zurek *et al*., 2022). All these events hasten the rate of environmental degradation and make the agricultural food system more vulnerable to uncertainties. Under these circumstances of climate change, soil assumes greater role in cushioning and protecting the food production system.

One of the major component of soil, which is highly co-related with the impacts of climate change is the organic matter content of soil or soil organic carbon (SOC) status. It has been established that the soil ecosystem is the third largest sink for carbon sequestration after forest and marine ecosystem (Walker *et al*., 2022). Plant and animal biomass which remain in soil after their death helps in long-term carbon storage in the soil ecosystem. Depending on the growing conditions and rate of decomposition like ambient temperature, availability of water and nutrients along with the management interventions, these plant and animal tissues remain in various pool of soil organic matter. Higher addition of photosynthetic carbon input compared to loss of the existing carbon in the form of respiration by microorganism lead to net carbon surplus or carbon sequestration (Batjes, 2012). Researchers have estimated that approximately 1500 PgC is being present in top 1m of soil (FAO and ITPS, 2015). This entrapment of carbon into the soil system serves twin benefit. It not

only reduces the global impact of greenhouse gas carbon dioxide on the atmosphere, but also improves the food production capacity of soil. SOC plays a pivotal role in maintaining the fertility status of soil. It serves as a storehouse of major nutrient element like N, P, S, etc. and increases the availability of many nutrient elements by regulating soil reaction i.e. soil pH.

Due to innate character of the constituents from which it has been formed, it also has a profound impact on the physical properties of soil. Improvement in aggregation status, increase in the water holding capacity, decrease in the bulk density and concomitant reduction in penetration resistance of soil are favorable benefits obtained by increasing SOC. Undecomposed organic matter also serves as a food source for various beneficial microorganisms and in turn, govern their community composition and abundance. Thus, the functions which are dictated by SOC are elusive in terms of soil fertility and productivity. It is the key component which determines soil quality which effects plant growth and ultimately reflects in food quality (Zdruli *et al*., 2017). These properties of soil are more relevant in maintaining food production capacity of soil under climate change crisis. However, environmentally detrimental anthropogenic activity like deforestation may account for loss of carbon as high as 25% of the total SOC stocks from the soil owing to exposure of the protected stock resulting in rapid decomposition of the organic matter (FAO and ITPS, 2015).

V. IMPORTANCE OF SUSTAINABLE SOIL MANAGEMENT

The mere account of performance indicators of soil health and quality is not sufficient for holistic understanding of the functions a soil system provides. We must dwell deeper by developing a framework that acknowledges the extensive value that soil gives to human health by taking into account the ecosystem services and natural capital of soils (Grima *et al*., 2023). By harnessing connections and collaborations between soil science and other fields including ecology and economics, a constructive strategy needs to be devised to emphasize the significance of soils alongside other natural resources in preserving the Earth's functionality (Bunders *et al*., 2010).

In terms of functions, soil provides growth medium to provide food, fuel and fibre; protect our heritage; regulate the atmospheric fluxes of gasses; clean the water; recycle waste; act as a vital gene pool (D'Costa *et al*., 2006). Regardless of serving as the biogeochemical heart of the Earth's life support system, soils frequently lack the consideration of authorities and the general public (Bouma, 2010), particularly in terms of soil sustainability and conservation. While the direct utilization of water and air has an immediate impact on our health, the relationship between human health and soils is

frequently obscure and remains yet to be fully explored. But, as we tackle the issues of global warming and rising populations, soils are becoming more and more integral to the notion of human wellbeing.

The soil as a natural resource is made up of materials such as mineral matter, organic matter, water, air and possess important characteristics that can be determined through processes involved in development of soil such as horizonation, aggregation, and humification (Churchman, 2010). These soil reserves are regarded as the natural capital which influences various processes (Robinson *et al.*, 2012). These bring about transformations and alterations via interactions within the soil materials, leading to changes in the soil characteristics under variable environment. While, principally ecosystem services arise only through material and energy flows. For instance, in soil ecosystem, output product of carbon dioxide (CO_2) is in the form of food material produced through plants, while input of CO_2 through organic matter, helps to regulate the climate. The role of soils in regulating and storing water in the water cycle, waste disposal and recycling helps to maintain the material flow in the environment. An indispensable goal is to increase or preserve the natural capital of the soil since, it promotes soil resilience and keeps ecosystem services in harmony. Our emphasis on ecosystem services shouldn't overshadow the crucial function of natural capital or lead to the supply of services at the price of potentially irreversible modifications to the stock value of natural capital. The example being, the current practice of intensive agriculture without paying due consideration to the revival of soil as a resource. Another serious threat to soil ecosystem as a whole is the rising risk of soil erosion and land use changes under increasing human population (Borrelli *et al.*, 2020).

It can be said that to meet the daily demand of various necessities, humans are very much dependent on soil. Humans shall remain indebted forever in terms of economic services a soil as a system provides, yet they often neglect the importance of a healthy soil. To support the current and future needs of the human population, the management of the soil should be devised in a sustainable manner. Conservation tillage, green manuring, addition of organic manures, crop rotation, intercropping, agro-forestry systems, etc. should be included in management strategy (FAO, 2022). Moreover, use of suitable mechanical and agronomic measures according to the slope and erosion hazard of the area like contouring, bench terracing, strip cropping, etc. can also be included. Hence, sustainable soil management should be looked upon as high priority goal with steps to elevate or maintain the health status of the soil.

VI. CONCLUSION

The information in this chapter has highlighted the importance of soil as a natural resource in the life of humans. The soil system should not be studied in isolation. Rather, an inter-disciplinary approach involving ecology, atmosphere and economic principles should be integrated into the overall domain of soil science. The nutrients that plants need for growth are provided by the soil; animals then eat plants to fulfill their nutrient requirements, and humans, who in turn eat plants and animals, receive their nourishment indirectly from the soil. Dead plant and animal tissues are decomposed to release the nutrient elements again into the soil. This inter-linkage highlights the importance of healthy soil in the ecosystem. The soil also serves as an important medium to mitigate the impact of climate change in the environment. Soil has huge potential to sequester carbon from the atmospheric carbon dioxide and in-turn improves the fertility status of soil. By using suitable management options, we can improve the productivity and sustainability of the soil ecosystem services

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