

## The Role of Soil Quality Parameters in Enhancing Agricultural Productivity

Ravikant Nanwatkar<sup>1</sup>, Anushka Ghule<sup>2</sup>, Aryan Tufchi<sup>3</sup>

### Abstract

*Thus one can define soil quality as a set of physical, chemical and biological properties of the surface layer of the Earth's crust that affects agriculture production. In this study, some of the factors which are related to soil quality include pH, texture, organic matter content, nutrient availability and microbial activity that affect crop germination as well as yield. It looks at the way in which the soil factors influence plant growth and development, distribution of resources in agriculture and the sustainability of agriculture. This knowledge is important to enable proper management of the soils, improvements of the soil and in turn improvement of agricultural productivity. The knowledge of these parameters is thus important as it provides direction when it comes to management of our soils. The paper also explores physical, chemical as well as structural attributes of the soil and its connection to crop productivity with an aim of deepening understanding of soil treatments, soil protecting practices and better sustainable farming practices for soil. This article shows how in order to obtain long-term sustainability and food security in the years to come the use of integrated soil management should be initiated.*

**Keywords:** Soil quality, agricultural productivity, soil pH, organic matter, nutrient availability, soil texture, microbial activity, soil management, crop growth, sustainable agriculture

### INTRODUCTION

Soil quality is coined as the ability of the soil to perform or support life within a defined ecosystem to support plant and animal production and vitality, water, and air quality, and for human populations. When it comes to agriculture, the condition of the soil is very important due to the fact that the quality of the crop yield, the nutritive value of the crops, as well as the sustainability of the farm depends on the soil. Good soil can also supply the necessary nutrients required for plant growth, has good ability to anchor the root system, and ensures good water uptake and drainage. In addition, there are various microorganisms that harmoniously inhabit healthy soils to facilitate releases of nutrients and decomposition of organic matter for accelerated growth of plants. There are several factors which affect the quality of the soil and under the following groups: physical, chemical and biological [1-3]. There

are numerous physical properties that pertain to soil that are useful in the management of water, root penetration, as well as aeration. Chemical factors include soil acidity/alkalinity, and the accessibility of nutrients (hence nitrogen, phosphorus, and potassium contents), CEC and generally the presence of other interfering chemicals like heavy metals. Biological aspect relates to microbial population inclusive of bacteria, fungi, earthworms and other microorganisms that have a role of decomposing organic materials and cycling of nutrients [4-5]. The other factors are external factors which include soil use practices, methods of watering, application of pesticides/ fertilizers, and

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climate among others. Extension of a single type of crop, frequent use of chemicals and wrong tillage operations reduce or stale the soil and thus increase the rate of erosion and diminish the bio-diversity of those backward lands. Consequently, sustaining and enhancing the quality of soil is crucial for many years food production, environmental conservation and productive agriculture. Figure 1

To ensure that the society feeds the nation, there is the need to ensure that there is healthy soil to support the growth of crops since it will act as a backbone for agriculture [6-9]. It helps the plant to offer mechanical support and ensure that roots penetrate through the soil, have a firm stand, and get access to water and nutrients. Having high organic content and earthworms, the nutrient cycling is enhanced in that the nutrient nitrogen, phosphorus and potassium among others are released in balanced proportions to plant requirements. The other one is the natural method that helps recycling material within the natural system and assisting the addition of nutrients to the soil, helping to make agriculture more organic and less dependent on chemicals. However, healthy soil has better structural character and porosity to enhance water infiltration and water retention as well as reducing water stress and soil erosion on crops. It assists in this aspect by its ability to bring forth a big variety of microbes in the soil and improve root of plants and also control plant diseases. More to the point, for sustainable productivity and sustainability of the farming system, it is crucial to keep the soil healthy [10-11]. Importance of Soil in Agricultural Productivity: Highlight the role of healthy soil in supporting plant growth, nutrient cycling, and overall productivity. As such, the purpose of this study is to determine the role played by the quality of the soil affects crop yields and the sustainability of the farmland in the long run. The study seeks to establish how various physical and chemical properties of soil like pH, organic matter, nutrients, particle size distribution, and microbial properties affect the growth, development and crop yields on a number of crops. By doing so, the study aims at putting forward several indices that define the presumably healthy soil under conditions of intensified production and increased, and stable crop yields. Further, the study looks at how conservation and improvement of soils would enable sustainable farming since it decreases the use of fertilizers and other chemical inputs, farm predictability and resource sustainability. Finally, this study aims at contributing useful knowledge and advice to enhance soil management and encourage the farmer, agronomist and policymaker towards better stewardship of the soil toward sustainable food security [12-13].



Figure 1. Testing of soil parameters.

### SOIL QUALITY PARAMETERS

Hence, soil pH is an important aspect in that it affects nutrient status, presence and activity of plants and microbes within the soil system. It is a measure of the soil's level of acidity/alkalinity that is on a scale of 0 to 14 with the neutral point at 7. The slight to moderate acidity of the soil, with most crops indicating optimal pH levels ranging from 6.0 to 7.5, provides the best environmental condition in which most of the nutrients such as nitrogen, phosphorus, potassium, calcium, and magnesium are readily absorbable by plants. If the pH of the soil is either too high or too low from this range, nutrients become either limited or lethal. For instance, in concentrated conditions such as in areas with low pH, it is possible to note the toxicity of aluminum and manganese while phosphorus is rendered unavailable to roots thus affecting plant growth.

On the other hand, farming in alkaline soils (high pH) has a negative impact on the micronutrient availability such as iron, zinc, and copper that plays a very important role in various physiological processes in plants. Also, there is a strong relationship between population and activity of microorganisms and revealed aspects of the soil matrix such as PH influences microbial organisms and their activity including matters on decomposition of organic matter and nitrogen fixation [14-16]. High acidity or alkalinity is disadvantageous to the beneficial microbes which are responsible for cycling nutrients and hence fertility of the soil. Thus, it is highly advised to keep the pH level of the soil to be optimum so availability for plant uptake and for the growth of the microbes supporting the crops' yield for sustainable agriculture Figure 2.



Figure 2. Modes of soil testing.

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Soil texture and structure are two significant characteristics that define a soil's capacity to hold water, drain water, get adequate aeration, and support root penetration and growth, and all these characteristics are crucial when selecting a site for planting [17-19]. Soil texture refers to the relative proportions of sand, silt, and clay particles in the soil. The sand has a large size of particles, yet it provides excellent aeration and drainage but compares poorly on water and nutrient holding capacities, thus requiring more frequent watering and use of fertilizers. This is while clay soils are made up of fine grainy particles in which most water and nutrients are held, but this sort of soil has poor internal drainage and low air penetration thus tends to water logging and restricted root development. The slit with a particle size between sand and clay also provides a good water holding capacity and water permeability with low fertility levels. One of the important factors here is soil structure that is the manner in which solids compose soils into aggregates or what are termed as 'peds'. In well-structured soils, there are well-formed and adequate inter-connected voids that allow water infiltration, root penetration, and gas exchange. Physical factors that affect soils include soil structure and compaction and soil crustation; these are uncomfortable to plant roots and lead to poor aerated and infrequent supplies of water to the plant. Soil texture and structure determination is thus very crucial in as much as determining and managing the physical attributes to enhance root growth, water use, and overall sustainable crop production [20-23].

The other element is organic matter which contributes to the fertility, water reserve capacity and activity of microorganisms in the soil. Organic matter consists of partially decomposed plant and animal residues and provides for itself, plant nutrients such as nitrogen, phosphorus and sulfur in a more measured and sustained manner by way of its slow decomposition through the action of microorganisms. It is also efficient in a way as it slowly feeds the plant thus not requiring any application of chemical fertilizers and the plant continues to grow in a steady manner. Also, the content of organic matter enhances the physical characteristic of the soil whereby it increases in structure as well as porosity. It helps in aggregation of soil particles and increases capabilities like water holding capacity and water shedding, water resistance against erosion besides helping in improving water infiltration and air-filled porosity. This is particularly useful during dry seasons so as to ensure availability of moisture to the plants' roots is still sustained. In addition, organic matter provides homes to diverse and actively growing microbial populations of bacteria, fungi and earthworms that assist in nutrient cycling, disease control and decomposition of organic matter. These beneficial microorganisms nonetheless not only improve the soil fertility but also the latter's ability to withstand the attacks of pests and diseases as well as other adverse effects of the environment. In other words, it is crucial to cultivate and maintain good soils and structures in order to organize organic matter for creation and support of fertile, well productive soils that can feed a nation in an ecological way [24-26].

Macronutrients and micronutrients that are available to the plants and the crops are vital in plant health and crop production. Macroelements including nitrogen (N), phosphorus (P) and potassium (K) are normally needed in large quantities as they are essential to plant growth and development. When in a more active state it plays a necessary role for creation of amino acids, protein, and chlorophyll essential for vegetative development and leaf formation. It plays a role in energy transfer within plants, development of roots as well as flowers and seeds production. This element influences action of enzymes, water management in a plant and stress tolerance which contributes to the desirable changes and quality of fruits and grains. Other macronutrients a crop requires are calcium, magnesium, and sulfur. Calcium plays the role in rigidifying the cell walls and enhancing the roots and leaves formation while magnesium plays a role in the synthesis of chlorophyll. Sulfur is involved in the synthesis of proteins and in the working of enzymes [27-28]. Nevertheless, in small concentrations, few elements including iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), borons (B), molybdenum (Mo) are also significant in the soil solution for crop plants. These minor elements are used in a variety of processes such as enzyme catalytic processes, regulatory processes involving hormone action, and the transporting of nutrients in the plant. When any of these nutrients is deficient or inward, there is a poor growth and yield of crops and they become susceptible to diseases. Hence, it is mandatory and crucial for a plant to

satisfy both the macro and micronutrients so that adequate metabolic activities and enhanced agricultural productivity could take place. Macronutrients and micronutrients that are available to the plants and the crops are vital in plant health and crop production. Macroelements including nitrogen (N), phosphorus (P) and potassium (K) are normally needed in large quantities as they are essential to plant growth and development. When in a more active state it plays a necessary role for creation of amino acids, protein, and chlorophyll essential for vegetative development and leaf formation. It plays a role in energy transfer within plants, development of roots as well as flowers and seeds production. This element influences action of enzymes, water management in a plant and stress tolerance which contributes to the desirable changes and quality of fruits and grains. Other macronutrients a crop requires are calcium, magnesium, and sulfur. Calcium plays the role in rigidifying the cell walls and enhancing the roots and leaves formation while magnesium plays a role in the synthesis of chlorophyll. Sulfur is involved in the synthesis of proteins and in the working of enzymes. Nevertheless, in small concentrations, few elements including iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), borons (B), molybdenum (Mo) are also significant in the soil solution for crop plants. These minor elements are used in a variety of processes such as enzyme catalytic processes, regulatory processes involving hormone action, and the transporting of nutrients in the plant. When any of these nutrients is deficient or inward, there is a poor growth and yield of crops and they become susceptible to diseases. Hence, it is mandatory and crucial for a plant to satisfy both the macro and micronutrients so that adequate metabolic activities and enhanced agricultural productivity could take place.

Since microorganisms are involved in nutrient cycling and the general well-being of the soil and influence plant vigor, the activity of these microorganisms is crucial. Bacteria, fungi, actinomycetes and protozoa correspond to a complicated and stable microcosm of soil which plays vital bio macromolecules processes. This is why one of the important tasks of organisms belonging to this group is the fragmentation of organic matter which in turn releases such nutrients as nitrogen, phosphorus and sulfur insoluble forms usable by plants. For instance, the nitrogen-fixing bacteria reduce atmospheric nitrogen to ammonia thus charging the soil with ammonia which is an essential nutrient in plant growth. Mycorrhizal fungi are also endomycorrhizal fungi that engage in mutual relationships with plant roots and assist in expanding its area of water and nutrient acquisition, especially phosphorus apart from increasing stress and disease resistance among plants. These tiny organisms also play a role in the creation and consolidation of soil structure through the release of substances that help in the creation of stable micro-aggregates in the soil, of course improvement of aeration of water intake by encouraging root penetration. Besides, a diverse population of microbes can outcompete the plant pathogens to obtain resources in the soil and also produce natural antibiotics that control pests, hence, the reduction in the need for chemical fertilizers. Indeed, it can easily be argued that the existence of a healthy microbial living culture in the soil horizon is one of the best indicators of soil fertility since it enhances nutrient cycling, plant health, as well as the longevity of the agro-production process.

Tillage and compaction are some of the factors that determine root development, water intake, and growth of plants on the soil. This process allows the air to penetrate into the soil thus allowing roots to get enough oxygen required in their processes such as respiration. Thus, when the oxygen concentration increases they are capable of extending their length and breadth in search of water and nutrients effectively in a plant. Despite this, soil compaction or a condition that affects soil whereby it is compressed due to the influences of gravity or other forces such as use of heavy equipment, overgrazing, or walking regularly on planes degrades the pore space of the soil through which air and water can access through. This results in poor surplus water removal, poor root permeability, and increased storages of pollutants such as carbon dioxide around the rooting zone. Thus, compacted soil hinders the growth of plants through restricted growth, yellowing of leaves as well as low output because of stress and nutrient shortages. Compaction can also amplify the velocity of arriving water and subsequently worsen its effects on the soil through erosion. On the other hand, a good structure that has a variety of pores in the soil enables water to infiltrate, roots to penetrate and improves microbial activities within the root region for healthy plant growth. This means that the practical steps like, not tilling the land

frequently or using Implements that help in the formation of soil crumbs and having controlled traffic on the field must be used to avoid soil compaction for proper aeration of the soil hence enhancing its productivity for the longest time [29-30].

#### **IMPACT OF SOIL QUALITY ON CROP GROWTH AND YIELD**

The nature and supply of nutrients in the soil are critical for the crops health, rate of growth and eventual yield as plants use the nutrients to perform several vital activities. Essential nutrients like nitrogen, phosphorus, potassium, calcium, magnesium and sulfur are needed by the plants in the right proportions to enable them to perform activities such as producing energy, growth of tissues, photosynthesis, respiration, and protein synthesis. For instance, nitrogen encourages the formation of the vegetation and chlorophyll while phosphorus helps with roots and flowering and lastly potassium aids in water balance and disease immunity. Lack of these elements results in development of some evident problems such as the appearance of yellow leaf, slow growth, poor fruit formation, and low immune response to pests and diseases. On the other hand, more of some nutrients interferes with the absorption of other nutrients and creates either toxicity lockout. They are also important since they are in smaller amounts, and are needed for enzyme activities, hormone regulation, and transport of nutrients in the plant. Yielding quality and quantity can therefore be said to be dependent with the nutrient levels of the soil in relation to the health of crops. Balancing nutrients combined with efficient use of soil testing nutrients, efficient use of fertilizers and implements reduce chances of a plant not getting the right nutrients it needs hence increasing the yields, produce quality and make farming sustainable Figure 3.

Soil erosion and deterioration of soil fertility are adverse effects of improper soil management and are very disastrous to the sustainability of agriculture production. Sedimentation includes a loss of topsoil layer that is the prime layer in terms of fertility and productivity of soil. This layer is richer in organic matter and nutrients which the beneficial microorganisms needed for plant growth are mainly found on this layer. Thus, when it is lost, the land becomes almost incapable of supporting good production of crops. Some of the forms of erosion include the following; deforestation, overgrazing, frequent tilling of the soil without application of protective crops or crop residues. The process of erosion makes the soil layer to reduce in thickness, infertile, compacted, which affects water percolation and aeration. This limits the chance for root growth and penetration hence competition for the nutrients and water that would enhance plant growth and productivity.

**Figure 3.** Impact of Soil Quality on Crop Growth and Yield.

In this case, eroded soil is washed to the water channels hence causing sedimentation and pollution of the water hence worsening the status of the environment. Soil erosion also leads to decline of soil fertility and hence the use of synthetic fertilizers for farming, but the use of fertilizers does not have adequate benefits of upgraded topsoil. Hence, practices like cover production, practicing cultivation along the slopes, minimum tillage, and maintaining vegetation cover are excellent tools that should be adopted in the management of soils in order to control for erosions, maintain soil fertility, and keep the farming land as a viable resource for as long as possible.

Used water low retention and irrigation refers to the factors through which water is taken up by the least and through which it is made available to the plants; some of the qualities include texture, organic matter and structure of the soil. Thus, the aspect of soil that can be described as the ratio between sand, silt, and clay has a significant influence on water properties. This is due to the nature of the large particle sizes and the many spaces within the sand that make it difficult for water to be held in the soil and this has an added disadvantage of requiring water often. However, the two are characterized by differences in the following aspects: clay soils contain small particulate matter as well as small pore spaces that retain water tightly and which may hinder easy supply to the plant roots as well as can lead to waterlogging. Silt is intermediate to sand in its capacity of holding water and in the rate of infiltration. This type of matter helps in increasing the capacity of the soil to absorb and retain moisture in the water. It holds water to be gradually provided to the plants' root systems especially in the dry spells thus reducing the amount of watering needed. Besides, a suitable structure, which includes stable aggregation and suitable ratios of both macropores and micropores in the soil, enhances proper distribution and infiltration of water as well as root penetration and drainage. Soils have a capability in relation to runoff and losses due to evaporation which are essential for the irrigation system as much as it provides water to the root zone. Hence, soil modification, regular application of organic materials, and methods of maintaining the physical structure of soils are recommendable steps that will improve interactions with water and increase the efficiency of water conservation in use of irrigation systems in Agricultural activities.

It is aware that the role and effects of soil quality in the ability and productivity of different crops are also not the same because they require different nutrient, moisture and root conditions such as the cereals, legumes and vegetables among others. Wheat, rice, and millet for instance, should be planted in land with good drainage, moderate fertility, and available macronutrient elements especially nitrogen for staking vigorous vegetative growth. This crop can grow on different earthy sticky but is best suited for the loamy soil with better structural stability and medium water holding capacity. Beans, peas, and lentils are amongst the most useful crops that are capable of nitrogen fixation from the atmosphere via assisting bacteria – rhizobia, unlike most other crops that require nitrogen-enriched soils. Despite this, they are very much affected by soil acidity and prefer well drained, slightly acidic soils with moderate supply of phosphorus and calcium to facilitate nodulation and flowering. Fruits, such as tomatoes, followed by carrots, and green leafy vegetables require a good quality soil to grow due to the nature of the organs they possess such as shallow root systems and high nutrient as well as moisture demand. Most preferred habitats are in areas with dark colored Clay loams with organic matter, good water holding capacity and low tendencies of compaction for the root system and nutrient absorption. To know how poor soil conditions affect all crops to some degree but to different extents, it is crucial to understand the categories of poor soils: fertility, compaction, poor drainage, and inadequate pH. While under ordinary conditions cereals can somewhat withstand the deficiency, vegetables may not develop properly at all while legumes show low nodulation and protein yield. Hence there is a callous need for the farmers and the agricultural experts to know the type of soil requirements that each crop type needs in the field so that productive and sustainable farming systems may be enhanced.

#### **SOIL MANAGEMENT PRACTICES TO ENHANCE SOIL QUALITY**

Organic supplements are crucial for improving the quality of the soils and the nutrient level and are mainly of two groups, soilless amendments and Inorganic fertilizers. Compost, animal dung, green

manure, crop residues, etc., enhance the condition of the soil in relation to physical, chemical, and biological characteristics. These materials also gradually disintegrate over the years, and make available to plants, nitrogen, phosphorus and potassium besides aiding in the addition of organic manure. Organic matter increases the stability of soil structures, improves water status, reduces the soil compaction, and increases the microbial populations and nutrient cycling and disease suppression. Compost and well-decomposed manure are particularly useful in raising soil CEC and make it possible for it to retain necessary nutrients and deliver them to the plant. However, the inorganic fertilizers are manufactured through chemical synthesis and contain nutrient sources that are in a readily assimilable organic form and they provide the nutrients to the crop that are required instantaneously from time to time. It is normally applied when there is a need to supplement nutrients and also to increase yields in crop farming. Nonetheless, the use of excessive or even unproportioned inorganic sources of fertilizers may result in leaching, soil acidification not to mention reduced microbial population. Hence, there is the need to incorporate both organic and inorganic sources through adequate and proper management practices in order to enhance the fertility of the soil, enhance the opportunities of the long-term soil health and prospects of sustainable agriculture Figure 4.

Diversification implicates redistributing of some crops and farming in different areas to other regions and on different fields while crop rotation concerns changing the type of crop planted on the same field at different times is also important practices which ensure that the soil is healthy, has a good structure and there is sustainable use of the fields. This is because rotating crops implies a change of crops in a specific field in a particular year; thereby reducing the likelihood of extracting the same nutrients from the soil continuously. Soon, different crops require different nutrients and root systems; while corn's root is deep to loosen and turn over subsoil pillars, legumes on the other hand with small and shallow roots fix nitrogen from the air naturally. This not only provides the correct nutrients at the right time but also helps in good structure of roots and soil by feeder roots and other organic matters. Also an important aspect of crop and soil management is that crop rotation has a high impact of interrupting pest and disease cycles. Most of the time, growing the same crop for many times is succession leads to **buildup of**

**Figure 4.** Soil Management Practices to Enhance Soil Quality.

Pests and pathogens of that particular crop making itchy and damaging. They break these cyclic patterns and decrease the use of chemical pesticides, making the agro ecosystems healthier. Furthermore, the intercropping of cover crops and legumes also serves to increase the microbial activity in the production system, and control weeds and acts as a barrier to soil erosion through the provision of cover. However, monoculture practices result in such setbacks of nutrition deficiencies, increased pest attacks, and ground fatigue. Thus, crop rotation and diversification in the course of farming are two of the factors that increase the yield per acre of land with the positive effect on the resources' non-renewable, keeping the fertility of the soils for a longer time Figure 5.

Reduced tillage and no-till farming practices are conservation practices for which the goal is to reduce the destruction of the soil structure and the loss of soil and improve the organic matter status. Conservation tillage is different from intensive tillage that involves regular and intensive soil inversion and it does not involve turning off the soil with the crop residues. This approach is ideal because it promotes good structure, porosity, and root development of the soil particles. With conservation tillage, the soil surface is protected by plant residues against the direct force of impact of raindrops and water flow, hence minimizing erosion and loss of nutrient rich layers of the soil. Besides, undisturbed soils contain moisture and support microbial as well as earthworm-induced decomposition of the organic matter and recycling of nutrients. Gradually, the debris accumulation from roots and residues on the soil surface enhances its water storage, fertility and carbon stocks. No-till systems do also have the same benefits of reducing fuel and labor cost since there are fewer passes with the machinery involved.

However, changes in croplands for the purpose of implementing these posts may only need slight alterations in weed and pest management, sometimes with cover cropping and integrated pest management. In conclusion, conservation tillage is one of the core strategies of regenerative agriculture that have the potential of supporting sustained soil fertility; conservation of the environment; and maintaining high productivity of farmland in the current fluctuating climate Figure 6.

Cover cropping is a vital practice in sustainable agriculture that greatly improves soil health, prevents erosion, and enriches the soil with organic matter. By planting cover crops such as legumes (e.g., clover, vetch), grasses (e.g., rye, oats), or brassicas (e.g., radishes, mustard) during fallow periods or between crop cycles, farmers can protect and rejuvenate the soil.

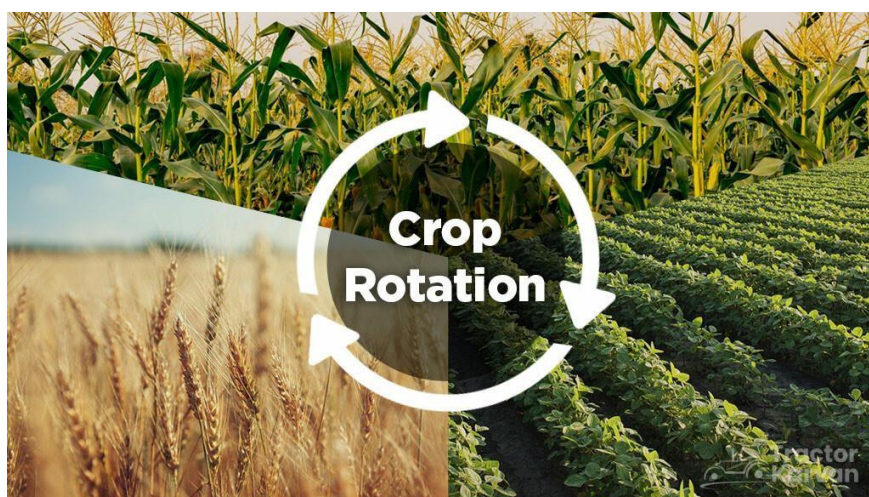


Figure 5. Process of crop rotation.



**Figure 6.** Crop processing.



**Figure 7.** Cover cropping.

One of the primary benefits of cover crops is erosion control—these plants shield the soil surface from wind and water, reducing the loss of nutrient-rich topsoil. Their root systems also help bind soil particles together, improving soil structure and stability. In terms of soil health, cover crops suppress weeds, reduce pest and disease cycles, and enhance biological activity by providing food and habitat for beneficial soil organisms. Leguminous cover crops are especially valuable because they fix atmospheric nitrogen through symbiotic relationships with soil bacteria, naturally boosting nitrogen levels for future crops. When cover crops are terminated and incorporated into the soil, they decompose and contribute significant amounts of organic matter. This increases the soil's water-holding capacity, enhances nutrient availability, and supports a thriving microbial community. Over time, the use of cover crops leads to healthier, more fertile soils that are better equipped to support high-yield, sustainable crop production Figure 7.

Despite the fact that cover cropping is a highly beneficial practice in the agricultural calendar, few farmers will incorporate this practice due to lack of information in implementation and importance of the practice. These plants are usually cropped at certain periods or between the different cycles of the main crop; these may include clovers, rye, vetch, and buckwheat. Their most significant role is an erosion control; being alive they are able to anchor through their root systems and canopies to prevent clints from being eroded by rain or wind in areas of nutrient topsoil. Also, the roots of the cover crops have the benefits of conduits in the soil that enable water to infiltrate through them; result in less compacted soils and make aeration easier. These crops get rooted in the soil and fix some of the nutrients that can otherwise be washed out when the seeds of the crops grow, die, or are incorporated into the decomposing tissue of the soil ecosystem. This enriches microbial activity by enhancing efficiency of nutrient cycling, fertility levels and physical organization of the soil Figure 8.



**Figure 8.** Process of soil testing.

#### **CHALLENGES IN SOIL QUALITY MANAGEMENT**

Soil degradation means the disappearance of the properties and fertility of the ground"; one of the elements of the overall degradation process is degradation of the physical structure of the soil. The soil particles and their spatial relationships thus refer to structures of the physical makeup of soil where they

are formed or are in the process of forming. A good structure of the soil is one that is aggregated in such a way that it promotes free movement of air and water as well as root penetration as well as microbial actions. However, as a result of the unsustainable practices including tiling, deforestation, overgrazing and construction, the structure of the soil can be rendered compacted or fragmented. Through this, the generator is able to come up with a general overview of the effects of soil compaction which are; since the pore space is reduced, roots and water cannot penetrate through and this results in surface runoff and soil erosion. As well, a breakdown of soil structure reduces the cohesion of the soil particles and causes it to be easily blown away by wind or washed away by water with the best soil – the topsoil. Physical deterioration may also comprise crusting, where a durable layer forms on the surface of the soil and thus there is poor uptake of water and nutrients as well as emergence of the seed. Such changes affect soil productivity in the long run by diminishing the ability of the soil to sustain plant life, as well as retard productivity and even cause ecological problems like reduced water aquifer replenishment Figure 9.

Climate change affects soil condition and food production mainly through its influence on temperature, changing rainfall, and other extremities that have recently become more frequent. The increase in temperatures also promotes the rate of decomposition of organic matter in the soil, this causes reduction in nutrient elements like nitrogen and phosphorus in the ground. This reduction in mass lessens the soil aggregation, which increases its vulnerability to erode as well as compaction. Also, higher temperatures enhance rates of evaporation of water from the soil, hence reducing water availability in the soil for the plants. For instance, changes in rainfall regimes such as increased intensity but less frequency of rainfall results in waterlogging and soil erosion during the rainy season while during the dry season, the lack of moisture delays plant growth. These pathogenically chaotic are also being destructive to the soil microorganism which otherwise play crucial roles in the cycling of nutrients and plant-soil relations. Moreover, Climate change induced saline soils have affected arable soils mainly around the coastal regions and arid zones because soluble salts which are dangerous to plant root and soil organisms accumulate within these territories. In this regard, there are blurred proper water management and soil erosion, which makes agricultural productivity low, crop yields small, food quality poor, and agricultural production hail, pests, and diseases prone. This becomes a problem because farming becomes more unpredictable and less viable; this is true because many-dependent communities from climate sensitive areas rely mainly on agriculture Figure 10.



**Figure 9.** Soil degradation.



**Figure 10.** effects of climate change soil condition.

Control of fertilization is equally complex given that both over fertilization and wrong nutrient application have potential deleterious effects to soil health and the environment. While fertilizers are very important for replenishing so that crops can grow well, their excess usage can cause the nutrient leaching, the nitrogen and phosphorus fertilizers will be washed down into the water bodies. This may lead to eutrophication which results in formation of toxic algae, low dissolved oxygen levels and death of aquatic organisms. In the soil itself though, the problem of over-fertilizing can lead to mismatches in the nutrient availability and thus deficiencies or toxicities in the soil organisms growing mass and lower crop resistance. For instance, it can slow down the absorption of other minor elements such as potassium or magnesium and therefore; this will affect the general health of the plants and the quality of their yield. Besides, frequent application of chemical fertilizers without the inclusion of organic inputs destabilized the physical structure of the soil, reducing soil micro fauna and micro flora activity as well as the natural fertility potential of the soil in the long run. In other words, the most suitable strategy in this case is what is referred to as system of soil, nutrient and crop specific and climate tailored nutrient management. The strategies include precision farming, application of fertility with precision, crop rotation especially with legumes in soil is also very effective in solving the problems of nutrient depletion hence no expansive use of synthetic fertilizers which takes a long time to decompose. In conclusion, effective use of fertilizers contributes growth of crops and, in addition to this, conserves the soil and physical surroundings for future use Figure 11.

#### **TECHNOLOGICAL INNOVATIONS FOR IMPROVING SOIL QUALITY**

Automation and Eradication is changing farming by converting the soil properties with the use of GPS, sensors, drones and so on in a real time manner and watering and other farming inputs like fertilizers, pesticides and so on. These tools allow farmers to gathering precise data of the particular territory, or the field, so it facilitates variable rate application instead of applying the same in the entire field. Soil probes installed in the ground constantly to test the soil and make the information such as soil moisture, temperature, its acidity-alkalinity and nutrient deficiency Availabilities easily accessible to the farmers. GPS technology that may be incorporated in the farm machinery allowing for the precision in mapping and direction when applying the fertilizers, as well as the seeds so that there is no over-application. Drones used with high definition cameras and multispectral imaging are used to cover broad areas with imagery that shows problems, for instance nutrient deficiency, pest or water problems which are not visible at close physical examination. Thus, it enables farmers to maximize on the use of

resources by focusing on troubled areas; it also increases crop yields and minimizes negative effects on the environment. In so doing, precision agriculture also keeps the input usage to the minimum and reduces structural and biological disturbances on the field. In the long run, these technologies help in sustainable farming and also make it efficient Figure 12.

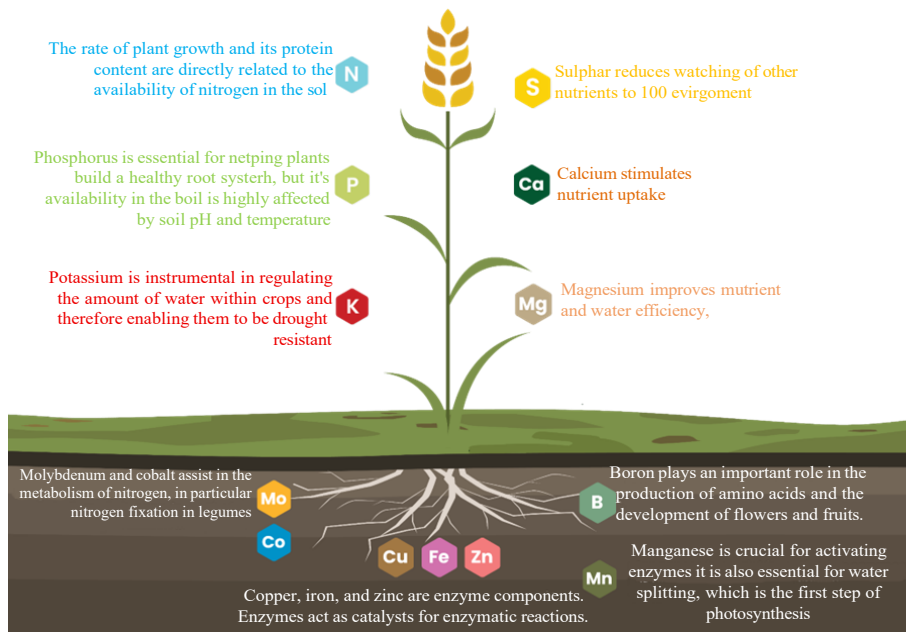


Figure 11. Balancing Fertilization

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Figure 12. Precision Agriculture.

Soil amendments with biogenic products is an effective, sustainable practice in improving flexible soil characteristics to support fertility due to the innovative use of the natural characteristics of the biological sources like microbes, composts and bio char. It is important to fertilize the soil by adding living organisms or organic matter to the soil that enhances nutrient solubility, soil structure, and microbial population. Beneficial organisms such as, the bacterium Rhizobium, Azospirillum fungi like Mycorrhizal Fix nitrogen from the atmosphere decomposes the organic matter and establishes a symbiotic relationship with the root hair of plants. First, it helps in absorption of nutrients, gets the roots to grow, and enables plants to develop immunity to pests and diseases. Bio char, which is the black substance derived from the thermal degradation of organic matter in the absence of oxygen or pyrolysis, is still another soil amendment. It enhances soil structure, water content and nutrient content possession especially in degenerated or sandy soil. It also plays a role in long-term carbon storage, thus reducing Greenhouse gas emissions and climate change. It is always desirable to mix the bio char with compost or microbial inoculants mainly because it provides a suitable environment for the activity of microorganisms and enhancement of overall soil health benefits. Along with that it, successfully substitutes the chemical fertilizer supply while practicing sustainable and regenerative soil health Figure 13.

Soil management technologies have been developed a lot over the years providing specific ways and means of Soil assessment. The traditional approaches to soil test, may serve as an investigational tool albeit with limited, and delayed information. However, using the current reach modern technological advancement, one can obtain accurate and real time data of various parameters of soil being the nutrient content, pH, moisture, organic matter, the salinity as well as microbial activity. Portable soil sensors and lab-on-a-chip devices would not require laboratory analysis, thus, samples can be tested on site and results obtained shortly. These tools aid decisions to be made instantly including use of fertilizers, irrigation and even the crops to be grown. Also, remote sensing technologies and satellite images show broad field patterns of soil conditions and any visible deterioration in vegetation's health, which may point to soil problems. Spectroscopy-based devices such as the near-infrared and the mid-infrared analyzers are now being used to quantify soil organic carbons, minerals, the content of soil and the texture and particle size distribution accurately.

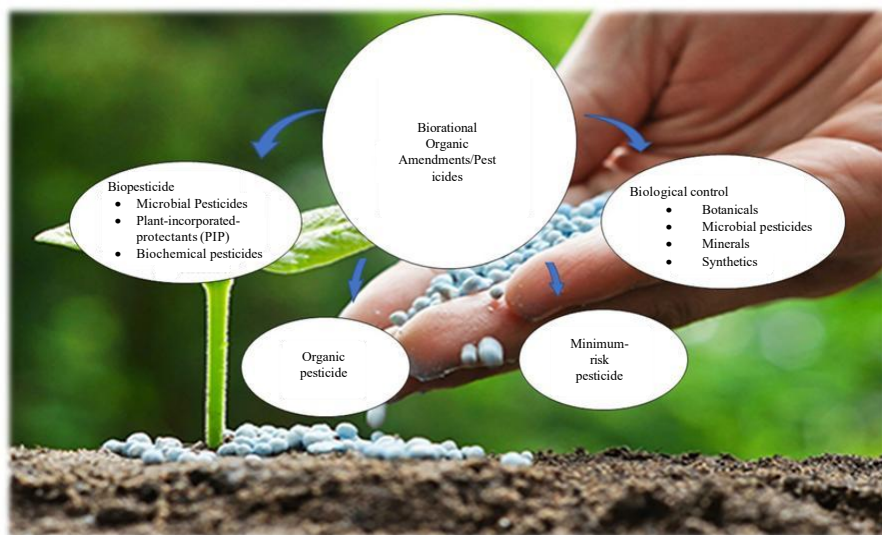


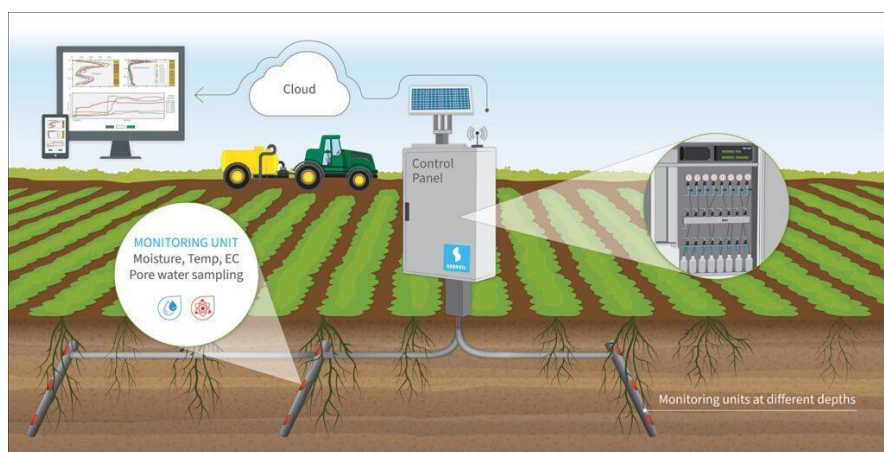
Figure 13. Biological Soil Amendments.

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Additional tests for instance, microbial carbon, microbial biomass and enzymes are gradually being included in the tests to give an overall view on the biological health status of the specific soil. These have been developed into software applications and decision tools used in tweaking such factors related to soil in order to result of embracing the modern technologies to monitor the health of the soil that leads to high crop yields, low or negligible effects on the environment, and sustainable agricultural production since efforts is made to ensure that the soil remains viable and productive Figure 14.

### CASE STUDIES AND EXAMPLES

Successful practices of soil management after observing and working on different continents, it is possible to enhance the quality of the soil to raise the productivity of crops, the sustainability of agriculture and the income of farmers. A well-known example can be the conservation agriculture, which is practiced in a number of the sub-Saharan African countries including Zambia and Kenya. Various measures such as minimum tilling, use of cover crops and crop rotation yield higher yields of Maize, sometimes twice that of traditional farming and at the same time an improvement in the structure of the soil and water holding capacities. The species powerhouse example again is Sikkim state of India from where the state government has implemented 100 percent organic farming. Yet, through composting, green manuring and organic bio-fertilizers, Sikkim not only ensured the longevity of the quality of the soil but also saw a longer term improvement to the quality of the crop and thus its market value that ensured better profitability and sustainability of agriculture. Likewise, the two states of the America such as the Iowa farmers who adopted no-till practices and using cover crops observed that the erosion and nutrient runoff was reduced and with increased provision of organic matter in the soils the soils became more resistant to both drought and flood. Even in the initially considered barren Cerrado region of Brazil, supercharging of the barren nutrient-poor soil with lime, developed with the help of fertilizers and proper management turned the region into one of the most productive agricultural areas of the globe. The outcomes of the case studies in this paper demonstrate that degraded soils can indeed be reclaimed when the correct management practices are both appropriate and specific to the area in question, resulting in enhanced productivity, food security, and climate change vulnerability. Soil management practices differ from one region to another given differences in soil characteristics, climatic conditions, land slope, and the crop to be grown; thus, practicable measures must be adopted in each region to enhance sustainable agriculture. In areas with a low water availability especially in the regions like parts of Rajasthan in India or several regions in Africa, some of the strategies used in the management of water include: mulching, drip irrigation, rainwater handling, and use of crops that do not require much water.



**Figure 14.** Soil Health Monitoring Tools.

On the contrary, in humid areas where there is a lot of rainfall as in Southeast Asia or the Amazon basin, there is leaching and depletion of nutrients. Here, measures like Agroforestry, contour farming and the use of compost and manure will assist in giving the soil the fertility and structure it requires in order to minimize erosion. In developed regions such as the Europe and North America where high levels of farming intensity implies erosion from machinery and chemicals then it has been managed through cover crops, crop rotation, conservation tillage and precision farming to enhance the structural integrity and stock of the soil. Nepal or Andes hilly and mountainous areas can make use of terrace farming and vegetative barriers to avoid landslides and minimize the area of rugged terrain that is available for cultivation. Hence, while farming in coastal or the saline areas such as Gujarat or Bengal delta could shift to the use of salt-tolerant varieties and gypsum application as well as the proper drainage system in order to reclaim and control saline arable lands. Such strategies on regions demonstrate that the best practice for the management of soil is not universally dependent on the other geographical area and type of soil and production system is to be put into account in the further practice for increasing productivity of the soil and the yields.

## CONCLUSION

- Soil health is known to be one of the critical factors influencing crop production because it affects the growth and yield of crops. Some of the important aspects of the physical properties of the soil are the structure, texture, organic matter content, the availability of essential nutrients, and the ability of the soil to retain moisture, the pH level and the biotic activity for plant growth. Organic matter and small life forms in the soil are highly effective in cycling the nutrients and enhancing root growth and improved aeration and aggregation promote air and water movement for respiration and nutrient absorption respectively. Some of the nutrients such as Nitrogen, phosphate and Potassium are very essential in sustaining crop production though they have to be administered in right proportions to avoid compromising the fertility of the soil in future due to imbalances. On the other hand, unfavorable soil characteristics such as soil degradation, soil compaction, soil erosion, soil salinity or soil pollution results in low. Multifaceted field research as well as experience obtained from field trials indicate that desirable soil properties and dynamics can be effectively recovered by enhancing organic matter content and structure, precision agriculture, and minimum/conservation tillage, and using soil management technologies; which often result in higher and more sustainable crop yield levels. That is why preservation and improvement of the quality of this important resource should not be viewed as solely a problem of environmental preservation but a key to sustainable agricultural productivity and, therefore, food security.
- The following are the important areas of research that need to be set for future in the fields of soil health and management: One major area is the progress in quantifying more extensive C sequestration and stocks where beyond simple chemical assessment and analysis through assessment of biological and physical factors such as microbial diversity, soil respiration, enzyme activity and stability of bulk density and particle size fractions has been done. These should be also effective, versatile and ensure on-field quick and accurate insights for precision agriculture. One of the other important research areas is the adaptation of strategies for climate-smart and sustainable ways of managing the earth's soils, which Bio-based inputs are microbial inoculants, biochar, and green manures enhancing fertility of the soil with the least inputs on the environment. More research should also be conducted on practices for storing carbon in the soil including the practice of regenerative agriculture to mitigate climatic change as well as to improve the soil. However, it is imperative that regional research should be carried out to establish developed soil strategies taking into consideration climatic factors, crops to be grown as well as socio-economic factors especially for small holder farmers in developing countries. The exploration of long-term consequences of innovative modern technologies such as artificial intelligence, Internet of things and satellite data to analyze the state of soil as well as integrating them in the practice can offer new approaches to better implementation of the analyzed soil at scale with maintaining the health of the earth's soil. Last but not the least, research that addresses the multidisciplinary area of both the soil science and economics, policies, and social behaviors will have to be carried out so as to ensure that while the

innovations which exist are sound scientifically, they are also feasible for deployment in the farms across the world by the farming community.

- Government Interference is essential in EEPROM of sustainable practices that ensure long-term production in agriculture besides checking on depletion of land productivity. Therefore one of the recommendation focuses on encouraging and promoting sustainable farming through offering subsidies or tax relief or funding to practice sustainable techniques such as removal of toxic chemical use and encouragement of organic farming, conservation agriculture, crop rotation, cover cropping, and reduced tillage. Governments should also spend on education and training that will enable the farmers to acquire the relevant information about the soils, technologies and climate smart agriculture. Soil testing services must be availed at farmer level and these should be subsidized by government through provision of soil health cards or soil testing digital applications. Furthermore, it is important to include promoting the use of bio fertilizers, compost, natural soil conditioners instead of chemicals as a policy measure to check pollution and encourage soil biodiversity. It is thus important to invest in research and development most importantly on soil health in regions, and novel monitoring systems. Policymakers should also encourage on farm-based soil conservation practices especially in vulnerable regions such as eroded or drought material areas to incorporate people in the conservation of the soil. Finally, the incorporation of soil conservation into the country's policies on climate change and agriculture will help to guarantee that the care for the soils will be given priority in food security and climate change mitigation and adaptation. If implemented sequentially, all these can go a long way in helping foster an environment where farmers and ecosystems benefit mutually.

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