

Optimizing Soil Fertility for Enhanced Plant Growth and Ecosystem Health

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Abstract

Optimizing the soil fertility is vital to agricultural crop growth and ecosystem health because it provides the key nutrients needed for plant productivity and biodiversity preservation. The key components affecting soil fertility, plant productivity and also health of ecosystem are examined in this chapter, with a significance on the association between soil microbes and plant yield. These components include soil pH, nutrient dynamics, soil composition, and structure. In order to boost soil fertility, it highlights conventional methods like crop rotation, cover crops, and biochar that enhance soil fertility and quality, foster agricultural crop yields, and conserve ecological balance. The focus is on carbon C and nitrogen N management strategies that optimize crop growth and yield while maintaining sustainability of crop and soil over the period of time. With a focus on sustainable techniques that enhance biocapacity of soil and ecosystem health. The main objective of this chapter is to enhance the crop-soil productivity and ecosystem health by adopting the tactics of conventional and non-conventional practices.

Keywords: Soil Fertility, Biochar, Cover Crop, Ecosystem Health, Micro and Macro Nutrients

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Introduction

Essential elements of plant productivity, biodiversity, and ecological balance, soil fertility is the underpinning of agricultural yield and the health of the ecosystem (Yousefi et al., 2024). It involves the soil's ability to underpin biological activity and resist worsening, as well as its ability to provide key nutrients in adequate amounts and quantities for plant growth and development (Thomas and Singh, 2019). Optimizing soil fertility has become more and more crucial for managing sustainable agricultural practices and ecosystem probity as the world's food demand hikes due to increasing population and shifting nutritional trends. The direct impacts of soil quality and fertility on crop yield, quality, productivity, and resistance to environmental stresses (Biotic and Abiotic) make it crucial. Higher plant growth is stimulate by nutrient-rich soils, which facilitate productive photosynthesis and nutrient uptake-two processes essential for elevated agricultural crop productivity (Havlin, 2020).

On the other side, the degradation of soil, which is distinguished by erosion, salinization, and nutrient depletion, makes environmental issues like deforestation, erosion, and climate change inadequate (Haruna et al., 2020). Fertile soils are essential for ecosystem health, such as carbon and nitrogen sequestration, water filtration, and the provision of a natural environment for multifarious creatures, which extend beyond agriculture. As a result of interrelated functions, regulating soil fertility needs a comprehensive strategy that affects a balance between ecological control and agricultural demands (Adetunji et al., 2020). This chapter investigate techniques for maximizing fertility of soil for boost health of ecosystem and crop growth. Exploring the primary concepts of soil fertility, such as microbial activity (MA), soil organic matter (SOM), and nutrient advancements (NA), comes first. For the purpose of enhance soil fertility and health and minimize their negative impacts on the health of ecosystem, sustainable management techniques (SMT) like crop rotation, organic modifications, and integrated nutrient management (INM) are enclose. The main objective of this chapter is to enhance the crop-soil productivity and ecosystem health by adopting the tactics of conventional and non-conventional practices.

2. Understanding Soil Fertility

A fertile soil could be defined as the capacity of soil to provide the essential material in adequate amount to plants preventing toxic amounts to plants. Soil fertility can be influenced significantly by chemical, physical, and biological factors, consequently possess an effect on plant development. A fertile soil comprises macronutrients i.e., phosphorus, potassium, nitrogen, etc. and as well as holds nutrients required in small quantities (Javed et al., 2022). A soil can be fertile naturally or attain fertility by adding manure and other organic matters. Fertile soil has a pH range from 6 to 8, high CEC, contains organic matter, capacity to attain moisture contents, diversity of microbes, and a huge extent of topsoil (Regassa et al., 2023).

2.1 Role of Nutrients

There are 16 elements required to complete plant life and their normal growth. C, H, and O₂ are present in water and air. The remaining 13 nutrients are taken up by roots in mineral forms or added to the soil by fertilizer application.

Macronutrients: are needed by plants in large quantities. Further sub-divided into non-mineral, primary, and secondary nutrients. Non-mineral elements are C, H, and O₂, while nitrogen, potassium, and phosphorus are primary elements and calcium, magnesium, and sulfur are secondary nutrient elements. Nitrogen plays a vital role in chlorophyll synthesis and is present in organic, inorganic, ionic, solution and gas forms. Generally, plant uptake nitrogen in inorganic form; Nitrate (NO₃⁻) and Ammonium (NH₄⁺) (Fathi, 2022). The presence of these elements enhances soil fertility, the growth of plants through new leaves and root formation, and consequently increases the production of aerial plants (Taha et al., 2024). Phosphorous (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Zinc (Zn), Iron (Fe), and Copper (Cu) exist in the form of cations. In general, more positive charges are attracted to negative sites of soil particles. Additionally, low CEC leads to the leaching of nutrients. Inorganic phosphorus exists in an anionic form with one or more negative charges which depends upon the pH of soil. Phosphorus makes bonds with Fe⁺, Al⁺, and Ca⁺, broken edges, with lime and other oxides. This bonding limits the movement and availability of phosphorus to plants. Moreover, Ca, mg, and S play key roles in cell elongation, enzyme activation, amino acid, and protein production (Hameso, 2023).

Micronutrients: These nutrients are required in small or traces quantities but are as significant as macronutrients. They comprise; Manganese (Mn), Iron (Fe), Boron (B), Copper (Cu), Zinc (Zn), Molybdenum (Mo), Sodium (Na), Chloride (Cl), Nickel (Ni), Cobalt (Co), Silicon (Si), and Selenium (Se) (Taşğın, 2017). Manganese Mn is found in form of oxides, silicate, carbonates and is available at pH below 5.5 and has its antagonistic association with Fe. Plant uptake Zn in cationic form and its availability decreases by increasing the pH. Availability of Zn decreases to plants in mineral soil, organic soils, with huge contents of organic matter. In case of plant nutrition, exchangeable and dissolved Cu are of high significance and its availability reduced at neutral pH. Iron is present as ferrous and ferric oxides, iron sulfides (pyrite), iron silicates, and iron carbonates. Hornblende, biotite, and chlorite are primary mineral forms of Fe. Fe solubility in soils is greatly controlled by the soluble hydrous iron oxides (Figure 1).

It has significant role in the activation of various enzyme in plants consisting: catalase, fumaric hydrogenase, cytochrome and oxidase. About 10 ppm is concentration of Boron in the earth's crust. B concentration in soils is associated to the degree of weathering and its extent in the parent materials. Major source of plant-available Boron is organic matter and is immobile in plants so that deficiency symptoms appear in growing points and upper leaves of plants (Daniels and Haering, 2006). Chlorine appears as chloride ion in salt beds, sea water, and sea wells. Cl is mostly present in plants and soils. It occurs mostly in water soluble chlorides in plants. Contrasting other essential elements existing in native rocks, Cl is extremely mobile in soil and does not appear to be fixed by soil colloidal system. Several minerals are source of molybdenum in soil such as molybdenite, ferrimolybdate, powellite, wulfenite, jordisite and ilsemanite. MoO₄²⁺ is primary form of molybdenum used by plants (Hodges, 2010).

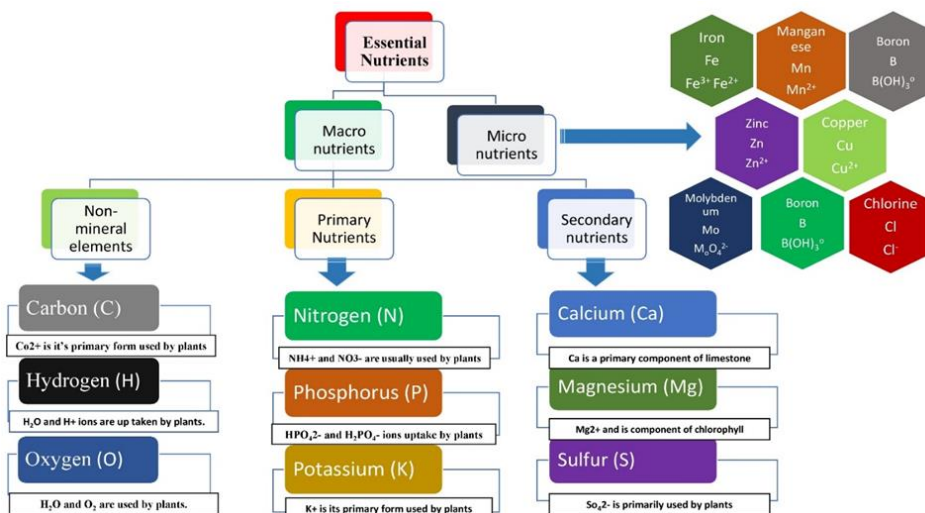


Fig. 1: Distribution and primary role of Micro and Macro Nutrients in plant and soils. (PPT)

2.3 Soil pH and its Influence on Soil Fertility

Soil pH is a very significant factor for fertility of soil to regulate the soil processes and reactions which indicates the alkalinity and acidity of the soil by measuring pH on pH scale ranges from 0-7. The pH is defined as hydroxyl ion (OH⁻) activity. Most of the plants maintain a pH from 5.5 to 6.5 due to their tolerance. The rate of mineral solubility and nutrients is enhanced in acidic soils as compared to in neutral or slightly alkaline (Javed et al., 2022). Soil pH also related to microorganism diversity; soil acidification usually leads to a decrease in microbial population. Precisely, epiphytes, bacteria and actinomycetes diversity decreases as soil pH declines. This effect is mostly noticed in the upper layer surface of soil compared to subsoils (Tibbett et al., 2019). Soil pH is also regulated by the percolation of basic cations K, Mg, Na and Ca after releasing weather minerals, departing Al₃⁺ and H⁺ ions to exchangeable cations; the dissociation of carbon dioxide in soil solution to produce carbonic acid, which dissolved and released hydrogen ions (Neina et al., 2024). Humus is also a source of carbonic acid; humic material releases CO₂ from soil having calcium carbonates, which can be converted to carbonic acid or soak up by plants. This carbonic acid helps in releasing nutrients to plants (Radulov & Berbecea, 2024). Consequently, there's a mutual relationship between biogeochemical processes and soil pH in terrestrial ecosystems, specifically, in soil. On this basis, soil pH affect many biogeochemical processes, in return some biogeochemical processes also influence soil pH to some extent (Philippot et al., 2024).

3. Soil Composition and Structure

Soil is made up of living and non-living things. Soil is formed when large rocks break into smaller pieces, which further break into sand and silt, which are transported by water and wind. The importance of soil lies in its fertility. Farmers and manure fertilizers to soil to make it more fertile. A fertile soil produces more crops.

3.1. Soil Composition

The soil acts as a natural substrate for terrestrial plants to absorb inorganic minerals. The thin uppermost layer that envelops the earth's surface is called soil. A significant factor that influences plant development and spread, aside from temperature, is the quality of the soil. It is affected by topography (regional surface features), the presence of living organisms, and the chemical composition of the soil. Soil composition may be divided into four main components: 25 % of air, 25 % of water, 5 % of biological matter, and 45 % of mineral matter. The overall properties of the soil and its capacity to support life are related to each component (Pouyat et al., 2007).

3.2. Soil Structure

Soil structure influences water infiltration, root penetration, bacteria growth, interment behavior, plant growth potential, air circulation, nutrient availability, root support, genetic pool support, nutrient recycling, and soil health (Chang et al., 2022). Soil structure plays an essential role in influencing both biological and physical processes, such as the erosion of soil susceptibility, permeability, the rate of infiltration and water availability for plants. A desirable soil structure supports various biological activities, including microbial communities, mesofauna, and vegetation organisms. This facilitates water and oxygen fluxes, promoting plant growth and nutrient recycling (Romero-Ruiz et al., 2018).

3.3. Role of Soil Microorganisms in Plant Growth, Soil and Ecosystem Health

Microorganisms found in soil, such as fungus, bacteria, and archaea, are essential to ecosystem functions. The structure and functions of soil ecosystems are impacted by their metabolic diversity, which propels the cycling of key elements. The generation of organic matter and the cycling of nutrients are two ways that microbes help creating soil. Their byproducts enhance soil structure and make it more plant-friendly (Aislabie et al., 2013). The decomposition of organic materials, the mobilization of nutrients, reduction and oxidation, symbiosis N-fixation, and photoautotrophic activity are all attributed to soil. In order to maintain soil health, soil microbes, archaea, and fungus regulate the weathering of minerals and the cycling of nutrients (Nacke et al., 2011). By absorbing, detoxifying, and recycling pollutants, agricultural chemical products, and spills of fuel, soils reduce the risk of injury to both beneficial creatures and people.

Table 1: By using microbes and bio fertilizers enhance crop growth and ecosystem health.

Category	Bio agents	Role/Function	Beneficial for ecosystem health	Positive impacts on growth of plant	References
Nitrogen fixation	Rhizobium	In legumes, symbiotic nitrogen fixation	Increases soil fertility and lessens reliance on chemical fertilizers.	Increase root-shoot growth also overall growth of plants	(Singh et al., 2019)
	Azotobacter	Nitrogen fixer that lives freely	Increases the amount of nitrogen available in non-legume crops	Stimulates vegetative growth and seed germination	(Adesemoye & Kloepper, 2009)
	Azospirillum	Fixer for associative nitrogen	Raises the amount of nitrogen in the soil	Enhance uptake of nutrients and root proliferation	(Khan et al., 2009)
Solubility of phosphate	Bacillus and Pseudomonas	Dissolves phosphates that are bonded	Enhances the soil's phosphorus bioavailability	Boosts plant growth and enhances flowering	(Thomas & Singh, 2019)
	Mycorrhizae	Improves absorption of micronutrients and phosphorus	Soil structure stabilization and increase cycling of nutrients	Boosts health of root and tolerance against drought stress	(Jha et al., 2022)
Mobilization of Potassium	Frateruria aurantia	Causes potassium minerals to dissolve	In soils, enhancement of potassium cycle	Enhances the metabolism and resilience to stress of plants	(Smith & Read, 2010)
Decomposition of organic matters	Trichoderma spp.	Breaks down organic materials and manages soil contaminants	Increases amount of organic carbon and heavy soil structure	Defends plants from diseases, fosters robust development	(Glick, 2012)
Biocontrol Agents	Pseudomonas fluorescens and Bacillus subtilis	Inhibits plant diseases and builds resistance throughout the body	Minimizes the usage of chemical pesticides and increases biodiversity	Encourages robust root systems and lowers losses	(Adnan et al., 2019)
Growth-Promoting Microbes	Plant Growth-Promoting Rhizobacteria (PGPR)	Make growth hormones (such as gibberellins and auxins)	Improves soil quality and maintains microbial balancing	Boosts the vigour of seedlings and the overall production of biomass	(Wu et al., 2005)
Bio fertilizer Consortia	Several microorganisms	Add phosphate solubilizer, nitrogen fixers, and other substances	Enhancement of nutrient cycling through synergy	Maximizes the resistance and absorption of nutrients by plants	(Attia et al., 2020)

The availability of soil nutrients may restrict the number of detoxifying bacteria that may be found, however microbial processes like immobilization and solidification are advantageous (Dominati et al., 2010). Pollutants that leak from soils have the potential to harm aquatic ecosystems and endanger human health. Pollutants are not released into water because soils absorb and hold onto them. Soil wettability and hydrophobicity are influenced by microbial products, clay, and organic matter concentration, which in turn impacts contaminant filtration (Bergmann et al., 2011). As the base for soil food chains and determinants of plant variety, soil microbes, archaea, and fungus are the main sources of biological variety on Earth. By enhancing availability of nutrients and exceeding diseases, these advantageous species promote plant development. Additionally, by mineralizing C and nutrients, microbes greatly contribute to the soil's capacity to store carbon. Nitrous oxide and methane emissions from soils are controlled by denitrifying fungi and microbes, as well as bacteria that produce and consume methane (Table 1) (Angel et al., 2012).

4. Practices for Optimizing Soil Fertility

According to past research scientist work on optimizing soil fertility through different practices like crop rotation, cover cropping and biochar practices. All these practices beneficial for soil health and also for good quality crop under healthy ecosystem. Compost, manure, biochar, and green manures are examples of organic amendments. Crop rotation has advantages for management of insect-pests and nutritional replenishment in soil, also improving soil structure and texture and reducing erosion (Tetteh et al., 2017).

4.1. Biochar Effects on Plant Growth and Soil Fertility

Biochar is a solid, carbon-rich material that is manufacturer by partially burning biomass or organic waste (OW) with little oxygen. Biochar has been proposed to accomplish a number of sustainability objectives, such as improvement in structure and texture of soils, enhancement of microbial activity, carbon sequestration, ultimately result in increased yield and production of crops, and also making it a promising instrument for sustainable agriculture (Chen et al., 2019). They also sustain ecosystem like small stoves used for food processing in developing nations may help lower respiratory illnesses and lessen the strain on forests, while the pyrolysis process used to produce biochar produces a number of useful byproducts, including hydrogen, bio-oil, syngas, process heat, and liquid smoke (Barrow, 2012).

According to a recent meta-analysis of 177 individual research by (Jeffery et al., 2011), the positive impacts of adding biochar to soils outweigh the negative (only one study demonstrated negative effects) and neutral effects. They discovered that the addition of biochar increased crop productivity by about 10% on average. There seems to have been a slight rise, which could be because there are many different kinds of biochar and substrates under widely differing circumstances. This comparatively modest overall biochar effect could also be explained by the fact that pure biochar does not directly add nutrients to the soil (Sohi et al., 2010). In contrast, increasing the C/N ratio raises the risk of nitrogen immobilization, necessitating extra fertilization to create agriculturally desirable conditions. Recent studies have already demonstrated the benefits of using compost and biochar together, especially in light of the rising expenses of artificial fertilization and even the declining prospects for the finite supply of phosphorus and other element supplements (Campion et al., 2023).

4.2. Increasing Soil and Crop Productivity through Cover Cropping

Cover crops improve soil structure and texture through different mechanisms and enhance plant growth and development. Decomposition of leguminous crops in the soils; this method contributes to nutrient and nitrogen levels in the soil (Haruna et al., 2020). Cover crops help improve air and water flow by increasing soil health and minimizing compaction. Their dense growth damages weeds and reduces competition, and their root structure stabilizes the soil, reducing erosion and preserving nutrient-rich topsoil. Also, cover crops aid in the management of pests and diseases by drawing helpful insects or releasing naturally occurring suppressive substances, as well as by helping to conserve moisture levels by shading the soil. When combined, these advantages make the atmosphere more suitable for plant growth and development (Koudahe et al., 2022). Cover crops have the potential to directly or indirectly (Figure 2), favourably or unfavourably, affect the soil's nutritional status, which is defined as the collection of physical, chemical, and biological characteristics that are strongly linked to the availability of nutrients. A numerous cascading effect is determined by the close connections between all of these factors (Adetunji et al., 2020).

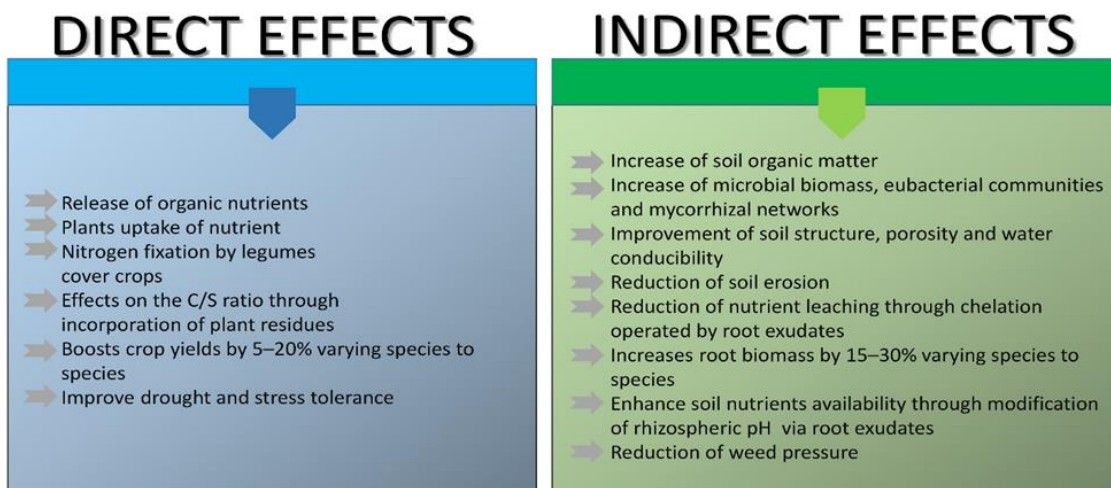


Fig. 2: Direct and Indirect effect of cover crops on plant and soil productivity. (PPT)

4.3. Maintenance Soil and Crop Quality through Crop Rotation

Diversifying cropping systems with crop rotation is advantageous to improve soil water conservation and raise the amount of soil nitrogen, per several documented research. Cover crops such as rye and phacelia (*Phacelia tanacetifolia* L.) were found to be effective in absorbing water and nitrogen, lowering nitrate leaching in irrigated broccoli (*Brassica oleracea* var. *italica*) by 70%, and lowering soil fertilizer use. Numerous significant benefits of the diverse farming system have been reported globally. For instance, by blending broadleaf and cereal crops, mixed cropping patterns increase grain yield and water use efficiency. According to two global studies (Li et al., 2019; Miller et al., 2003) by compared to monoculture, crop rotation diversity or improved crop rotation has been associated with increased levels of soil organic carbon (SOC). Typically, enhanced soil enzyme activity is a result of the crop rotation system's differences in crop residue quantity, homogeneity, and dispersion (McDaniel et al., 2014). Through crop rotation, farmers can increase soil organic carbon (SOC), nitrogen fixation and crop yield in agricultural production processes, decrease soil depletion, and better control weeds, insects, and diseases. For instance, the most varied rotation of corn-soybean-wheat boosted the capacity of soil's organic carbon (SOC) by 7% in comparison to consistent soybean in two recent long-term rotational tests of consistent corn, consistent soybean, corn-soybean, and corn-soybean-wheat rotation (Zuber et al., 2018). Additionally, rotational and cultivating associations with soil organic matter were 7% higher than those of standard farming. An additional advantage may arise from the mutual retention or expansion of these plants' production abilities. A greater range of crops can be used to improve soil composition, texture, and SOC sequestration while increasing output, which will lessen environmental and soil adverse effects (Brady et al., 2015; Zuber et al., 2018).

Table 2: Mechanism of crop-soil productivity and ecosystem health enhancement through cover and cash crop.

Crop type (Cash and Cover crop)	Soil Enhancement	Mechanism of crop growth enhancement	Beneficial for ecosystem health	References
Legumes (alfalfa and clover)	Fixation of nitrogen	Boost soil nitrogen supply to lessen demand for artificial fertilizers	Biodiversity enhancement and improve structure of soil	(Reeves, 2018)
Grasses (barley and ray)	Organic matter addition	Water retention and soil improvement	Stop the erosion of soils and control weeds	(Haruna et al., 2020)
Brassicac (mustard and radish)	Scavenging of nutrient and bio fumigation	Reduce soil-borne illnesses and pests, and absorb any remaining nutrients in the soil	Decrease pests growth and increase soil health	(Scavo et al., 2022)
Broadleaves (buckwheat and sunflower)	Non-legume and Phosphorus Mobilization	Increase the amount of phosphorus available for future harvests	Encourage pollinators and beneficial insects	(Yousefi et al., 2024)
Cash crops in rotation (corn and wheat)	Diversified nutrient use	Reduces the disease and pest cycles and enhance the utilization of nutrients	Preserve soil fertility and minimize the accumulation of pathogens	(Sharma et al., 2018)

5. Managing Soil Fertility to Increase Crop Yield

The potential of plants to absorb nutrients from the soil will be improved by advancements in plant growth and development under the subject of genetics, mainly in relation to root design, the impact of root exudate on rhizosphere biological chemistry, and improved nutrient metabolism within the plant (van de Wiel et al., 2016). For instance, genetic diversity in the organic acids that exudation from plant roots has been shown to improve soil P solubility and mobilization, hence improving P use efficiency (Balaban et al., 2016). Past studies showed in the current special issue of wheat grain micronutrient uptake was enhanced by soil inoculation with *Rhizophagus irregularis* at planting, despite notable genotype-to-genotype variation (Pellegrino et al., 2020). According to Lisuma et al. (2020), soil P, K, Mg, and S declined while N and Ca increased during the cultivation of tobacco. This is probably because there was more nicotine deposited in the rhizosphere. The impact of immersing rice seedlings in a P-enriched solution before to transplanting was evaluated by (Oo et al., 2020). These findings suggested the possibility of higher biomass and P uptake by seedlings.

5.1. Nutrient Management Factors in Soil to Enhance Plant Growth

Crops' nutritional requirements and the soil's ability to supply nutrients are measured via soil testing in order to implement effective nutrient management (Sattari et al., 2012). Over application of nutrients increases residual nutrient reserves, which can lead to offsite transfer and deteriorate environmental quality if they are not used or recovered in succeeding crops (Thomas Sims & Kleinman, 2005). This is particularly crucial for ongoing applications of animal or other waste based on crop N requirements, as the amount of P and nutrients applied in the form of trash frequently surpasses crop demand (Havlin, 2020). Suggestions for nutrients based on soil testing have proven reliable and trustworthy. Models for recommending nutrients should be regularly updated to take into account developments in plant genetics and advances in technology for managing soil and crops, which have an impact on crop nutrient requirements. Xie et al. (2020) illustrated a linear increase in nutrient accumulation with rising yield using the QUEFTS model (Quantitative Evaluation of the Fertility of Tropical Soils). Following yields that reached between 60% and 70% of the potential yield, nutrient buildup somewhat declined. Because over application errors are reduced, fertilizer use efficiency will be greatly increased by trustworthy instruments that can measure nutrient demand. Plant-nutrient examination is a useful technique for determining nutrient requirements for a variety of crops and enhancing the precision and dependability of nutrient recommendations. The development of significantly improved leaf-dry-matter-N content estimates by (Song et al., 2020) using data from the field boosted the precision of rice N nutritional analysis.

6. Ecosystem Health and Soil Fertility

The intrinsic features of the ecosystem health and fertility of soils, such as soil texture, nutrients in the soil, and climate, influence plant growth and productivity. EFA studies employing local yields for fundamental commodities at the sub-national level, demonstrating results varied by a factor of 2–10, validate this heterogeneity in time and geography (Wiedmann & Lenzen, 2007). Sustainable yields can be resolved at subnational scale through resource-effective and sustainable management techniques that strike a balance between cropping above-ground NPP and sequestering carbon, ensuring that soil respiration does not outpace soil formation. The biophysical quotient, which measures the effectiveness of substrate stabilization as a soil formation indication and is the ratio of soil respiration (CO₂ outflow) to residual soil C, could be used to address sustainable yields (Smith et al., 2007). As an alternative, sustainable yields could be measured at the point where the belowground NPP does neither decrease nor grow (Dhital et al., 2010; Walsh et al., 2010).

6.1. Sustainable Biocapacity and Health of Soil Ecosystem

Soil ecosystem health is linked to the supply of soil ecological services, such as fertile soil in terms of biologically productive land, which arises from interactions among the soil biota and their physical and chemical surroundings (Kamal et al., 2010). Biologically productive land is provided by the ecological integrity of the soil, and the state of the soil microenvironment depends at least in part on an understanding of the needs of the soil ecosystem (Sobolev & Begonia, 2008). Aspects of soil quality that determine ecosystem productivity, including below-ground NPP, are completely missing from the EFA technique (Mancini et al., 2016). As a result, we offer a broad framework for discussing the health of soil ecosystems that may be applied to estimating local biocapacity based on ecologically sound sustainable yields (Thomsen et al., 2012).

6.2. Effects of Soil Management Strategy on Soil Health and Services of Ecosystem

Soil health may be diminished and the provision of soil ecosystem services may be restricted as a result of environmental stresses and soil management techniques that affect the interactions between soil biota and their chemical and physical surroundings (Hodson, 2010). In addition to mitigating climate change, alternative sustainable and intelligent resource-efficient management techniques may enhance the physical and chemical quality of soil, supporting soil biota and soil formation (Mench et al., 2009). Higher soil organic matter boosts the soil health and plant yield and productivity. A rise in soil organic matter also enhances aeration, water retention (which prevents soil erosion), and other physical properties of the soil (Tack & Meers, 2010). In order to maintain the health of the soil ecosystem, it is necessary for anthropogenic emissions to have no effect on the biological component of the soil ecosystem, meaning that the amount of NPP harvested should not be greater than the amount of soil organic matter formed (Tack & Meers, 2010). Phytoremediation of the toxic metal content to an environmentally tolerable level could be implemented as a chemical quality measure for contaminated soils to promote soil formation and soil biological mass (Schütz et al., 2018).

Conclusion

Underpin plant yield and the conservation balance of nature, soil fertility is a basic element of sustainable agriculture and the ecosystem's health. This chapter emphasizes the multiplex function of soil fertility and encloses the pivotal effect of nutrients, pH, and soil composition on plant growth and development. It reveals how significantly improving the health of soil and crop yield and productivity can be gained by optimizing fertility of soil using scientifically held-up techniques including crop rotation, cover crops, and the use of biochar. Nutrient management and the advancement of soil biodiversity have become vital strategies to boost the resilience and efficiency of agricultural approaches. Long-term benefits for agricultural and ecosystem resources are possible with these practices, which also contribute to sustainable biocapacity and the universal well-being of soil ecosystems. It is important to implement comprehensive management of soil fertility evaluation in order to promise stable ecosystems and undergo agricultural productivity. In the scene of climate change and rising global needs, addressing the issues of sustainable growth and food security will require combining traditional grasp with modern techniques. Innovative techniques of soil management and the formation of comprehensive structures that promote ecological probity and agricultural yield and productivity should be the focus of future research.

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