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Review Article

The Effect of Climate Change on Soil Health: A Review

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Abstract

The phrase "soil health" mentions to the entire functionality of the soil as determined by the biological, chemical, and physical characteristics of the soil that are necessary for long-term, sustainable agricultural production by little impact on the environment. The ability of soil to carry out environmental and agronomic tasks, such as biomass productivity, sensitivity to management inputs, and resilience to biotic and abiotic stressors, is referred to as soil health. Since it is impossible to assess directly, soil fertility status and other specific soil parameters, including organic matter content, might be utilized in order to infer the state of the soil. Climate change may have an effect on soil health through temperature changes, salinity, hydrology, and the availability of organic matter. Main characteristics of the soil that are crucial for preserving its health are its desirable texture, structure, and tilt. The impact of several anticipated global change drivers, such as increasing atmospheric carbon dioxide levels, rising temperatures, changed precipitation patterns, as well as nitrogen in the atmosphere accumulation, on the environmental, substance, and organic functions of soil, should be taken into account when describing the condition of soils in connection with changes in the climate.

Keywords

Climate Change, Soil Health, Soil Texture and Structure

1. Introduction

The biological, chemical, and physical characteristics of soil that are necessary for long-term, sustainable agricultural productivity with little impact on the environment are referred to as soil health, and they give an overall picture of the functionality of the soil. It is impossible to quantify soil health directly; instead, it must be inferred by monitoring and measuring certain aspects of the soil, such as its fertility and organic matter content. Studying soil microorganisms in their unique settings has also gained more attention because microbial diversity is closely linked to the structure and function of soil [19].

The soil's capacity to carry out ecological and agronomic tasks, such as biomass productivity, sensitivity to management contributions, plus resilience both biological as well as natural pressures is referred toward as soil health. The soil's capacity to sustain and maintain the expansion of crops and creatures while simultaneously preserving and enhancing the surroundings is known as soil wellness in relation to agricultural land use. Good soil structure, tilt, and texture are major factors that are necessary to keep the soil healthy. The soil exhibits reactivity, possesses ideal water and nutrient retention capabilities, and has good internal drainage.

Strong nutrient cycling, little erosion susceptibility, and adequate aeration are examples of pertinent soil processes. The ideal amount of organic matter (SOM) in the soil, which stands necessary for many important characteristics of the soil

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along with processes, remains a powerful display of soil health. For soil to be considered healthy, it needs to have the right elemental concentrations and balance, sufficient nutrient stores, and be largely free of pests and diseases, such as weeds and nematodes. In addition, due to its intrinsic resilience, healthy soil must be very resistant to processes that cause it to degrade and capable of recovering after being perturbed [3].

The terms "reductionist" and "integrated" refer to the two approaches taken in the consideration of the idea of soil quality, or the closely associated idea of soil health. The former is predicated on estimating soil conditions through the use of a collection of independent markers for distinct qualities of the soil that are physical, chemical, and biological. As such, reductionist methodology shares many characteristics with traditional quality evaluations in different disciplines, like science of materials. As the alternate a combined approach creates the postulation which soil wellness is much complex greater than the total of its constituent parts. It acknowledges the potential that several processes and attributes may interact to produce emergent qualities [16].

Achieving the maximum or potential production depends in large part on the climate, which also affects the soil, an essential component of the agricultural environment. Elevated air temperatures lead to elevated soil temperatures, who's consequently amplifies that chemical reactivity speed as well as diffusion-controlled responses of solutions. In regions that get rain, variations in rainfall brought on maybe caused by changing environment an influence with regard to availability on surface moisture, which is crucial for crop stand development and germination [17].

The speed at which biological stuff breaks down, nitrogen intake, additionally plant metabolic procedures were all impacted because of temperature on the ground. Elevated soil and liquid temperatures have a significant impact on chemical reactions that influence minerals and natural substances in the soil. Thus, their quantities with the soil microorganisms' movement affect soil productivity and nutrient cycling. The two main roles that soil microorganisms play are that they retain carbon and nutrient-rich minerals (mostly N, P, and S) within them live plant matter, which serves as a reliable storage tank to nutrients that are accessible to plants quickly. They also operate as agents of nutritional element change and transportation. Trace gas generation is influenced by microbial processes in the soil and is affected by variations in the plant leftovers' C: N proportions that are back on the ground. The rate at which soil erosion occurs may accelerate due to climate change, further impeding food production. Rainfall increases will hasten the rates of soil erosion, thus diminishing agricultural output. Increased sedimentation in streams and reservoirs will be an additional adverse effect of rapid soil erosion. Decreases in rainfall have the potential to cause a dry spell and a rise in the risk of wind erosion, which is another way that erosion could quicken [22]. Thus, this article's goal is to review how soil health is affected by climate change.

2. Climate Change and Soil Health

Changes in climate may have an effect on soil health through temperature regimes, salinity, hydrology, and the availability of living things [8]. The mechanisms of biology and C and N cycling of soil will be impacted by elevated CO concentrations, rising temperatures, atmospheric N deposition, variations in rainfall totals, seasonal variations, and extreme occurrences like floods and droughts. These factors drive also have an influence on plant diseases, nutritional availability, soil erosion events, and soil structure, which will ultimately affect ecosystem functionality and agricultural productivity. Soil qualities, including biological, chemical, and physical aspects, are essential markers the condition of soil and climatic change [31].

2.1. Soil Physical Properties

The actual characteristics of soil reveal details about the flow of water and air across the soil, in addition to factors influencing development of roots, germination, as well as erosion procedures. Thus, a variety of physical characteristics of soil serve as the basis for additional chemical and biological activities, which may also be influenced by land use, location in the landscape, and climate. Through changes in water circulation via the soil, root diffusion in the soil, and water obstruction, the physical characteristics and procedures of soil impact soil wellness. Significant soil physical attributes that are influenced by climate change and affect soil health are as follows: [21].

2.1.1. Soil Structure (Porosity, Aggregate Stability)

Soil structure refers to how the primary and secondary particles are arranged and organized inside a soil mass, regulating the amount of moisture and air in the soil. In addition to a variety of both biological and chemical characteristics plus managing techniques, aggregate stability—the ability of particles of soil to withstand external drive like intense precipitation and agriculture is dictated through soil structure [5]. Since it contributes to the preservation of key ecosystem functions in the soil, like the accumulation of organic carbon (C), water transport and storage, the ability for infiltration, and the activity of the microbial and root communities, it is thought to be a useful indication of soil health. Additionally, it can be utilized to gauge the soil's resistance to erosion and modifications in management. The quantity as well as condition of the existing biological stuff, the inorganic components within the soil matrix, the agriculture techniques used, as well as organic physical processes like shrink-swell and thaw-freeze behavior all have a significant impact on the characteristics and nature of the building. A reduction in the soil's organic matter content causes a decline in the stability of the soil aggregate, an increase in the vulnerability to runoff, compaction, and erosion [17].

2.1.2. Porosity

The capacity of soil to hold the air and water in the root zone required for the growth of plants is determined by its porosity, which is a measurement of the empty spaces in the substance expressed as a percentage (void volume to total volume) and the distribution of pore size [28]. The physical quality in the soil, pore volume functions, bulk density, and micro porosity are all closely related to pore properties. While a number various indexes for soil, such as capability for soil aeration, plant accessible relative field capacity and water capacity, are directly influenced by the properties of water release and soil porosity. Because the distribution of pore sizes and soil porosity are directly linked to root growth and the activity of soil enzymes. Furthermore, scenarios of future climate change that involve higher temperature and CO as well as unpredictable and intense rainfall episodes could impact how roots form and the soil's biological activity. The distribution of pore sizes and soil porosity will therefore likely have an unexpected impact on soil functions [23].

2.1.3. Water Available in the Soil, Infiltration and Distribution

As field-based data continue to improve, soil water modeling is becoming more and more interested in soil water infiltration—the rate at which water enters the soil surface and flows into soil depth [5]. A number of soil characteristics, including as porosity, field capacity, the lowest amount of water that plants can access (apart from osmotic potential), macropore flow, and texture, influence the availability of water for plant growth and significant soil processes [15, 28] In order to evaluate the effects of management, plant available water capacity has been included in integrative soil health testing [13].

Furthermore, the movement and accessibility of water in the soil may change quickly in response to climate change, particularly in the case of variable and intense rainfall or drought events. As a result, management techniques that maintain or even improve water infiltration and available water in the soil, like the planting of cover crops, conservation tillage, and the incorporation of organic matter, may help lessen the effects of severe erosion events or rainfall and drought events [18, 29].

2.1.4. Bulk Density

Bulk density is regularly monitored to define the status of soil density in reply to land use and management, particularly with regard to land management activities and climate change pressures, such as varied and heavy rainfall and drought occurrences [20]. The relationship between bulk density and soil organic matter (SOM) or SOC concentration is inverse. Elevated temperatures can cause a loss of organic C through accelerated decomposition, which can raise bulk density and make the soil more prone to compaction [25].

2.1.5. Rooting Depth

Variations in rooting depth may impact the amount of water available to plants, the salinity of the subsoil, the SOC content, or other characteristics that may point to physicochemical limitations in the soil profile. Subsoil limitations such salinity and excessive chloride concentrations are anticipated to have a higher effect on plant availability of water and, consequently, plant productivity during extended droughts [23].

2.1.6. Soil Surface Cover

A sheet of crop deposits or a biological soil crust, for example, acts as a soil surface cover and performs a number of crucial ecological tasks, such as stabilizing the soil, reducing the amount of erodible surface area, retaining water and nutrients, fixing carbon (C) and in certain cases, nitrogen, and promoting the germination of native seeds. Aside from soil crust, other indicators of soil structural characteristics that can be used to describe changing climate in the context of soil health of include soil seal formation and sodality [3]. The development of soil crust affects a variety of soil procedures, including infiltration of water, diffusion of oxygen, overflow, evaporation of surface water, and wind [8].

2.1.7. Temperature of the Soil

Gains and damages of surface solar radiation, evaporation, conduction of heat through the soil profile, and transfer of convective through the gas movement and water all influence the temperature of soil regime [17]. Similar to soil moisture, the majority of procedures are primarily influenced by the temperature of soil. Increased microbiological activity, faster nutrient release, faster nitrification, faster organic matter breakdown, and an overall enhancement of chemical weathering of minerals are all caused by warmer soil temperatures. But the kind of vegetation developing on the surface of the soil will also have an impact on its temperature; this vegetation may alter due to climate change or management of adaptation [23].

2.2. Soil Chemical Property

2.2.1. Soil PH

One of the primary chemical markers of soil health, pH of soil is a role of parent material, weathering period, vegetation, and climate. Trends in changing of soil pH can be used to evaluate the effects of changing land use and agricultural methods. claimed that the majority of soils will not experience abrupt pH shifts brought on by climate change factors such high temperatures, CO fertilization, erratic precipitation, and atmospheric N deposition. But these climate change drivers will probably affect the pH of the soil by affecting the amount of organic matter present, the cycling of carbon and other nutrients, the availability of water for plants, and eventually the productivity of plants [26].

2.2.2. Electrical Conductivity

Soil electrical conductivity (EC), a quantity of salt concentration, is reflected to be a conveniently measurable, consistent display of soil quality/health, in addition to serving as a surrogate measure of soil structural degradation, particularly in acid soil. It can disclose patterns in biological activity, agricultural performance, salinity, and the cycling of nutrients, especially nitrate [25]. The biological condition of soil has been assessed using electrical conductivity as an indicator in chemical relation to crop management [10].

Under changing climate scenarios, there will be a rise in temperatures and a decrease in precipitation [30]. The soluble salts concentration and rainfall in soils from four climatic regions—the Mediterranean, semi-arid, slightly arid, and desert—have a nonlinear connection that starts there. Specifically, the sites with less than 20 mm of rainfall had significantly higher soluble salt matters, and vice versa. An extensive evaluation of how changing climate drivers affect soil EC, a crucial indication of soil health in various ecosystems, is required [28].

2.2.3. Sorption Capacity and Cation Exchange Capacity

Sorption capacity and cation exchange capacity (CEC) are considered important determinants of soil chemical quality, particularly the retention of major nutrient cations Ca, Mg and K, and immobilization of potentially toxic cations AI and Mn; these properties can thus be useful indicators of soil health, informing of a soil’s capacity to absorb nutrients, as well pesticides and chemicals. Since CEC of soils coarse-textured and low-activity of clay soil is recognized to that of soil organic matter [32] the growing decomposition and damage of SOM due to increasing temperature [6] may main to the loss of CEC of these soils. Low CEC of soil may consequence in amplified leaching of base cations in reaction to high and strong precipitation events, thus transferring alkalinity from soil to waterways [23].

2.2.4. Plant Available Nutrients

Extractable nutrients N, phosphorus, and potassium are included in Doran *et al*., (1999)'s list of necessary soil properties to meet the requirements of signs for screening soil quality/health because "they provide information on plant-available nutrients and potential loss from the soil which Indicating productivity and environment quality." The amount of nutrients that can be extracted from a soil can be used to measure its ability to support plant development, or it can be used to determine threshold or critical values for the assessment of environmental hazards [5].

Cycling of nutrient, particularly N, is closely linked with cycling of soil organic C [32], and hence drivers of changing climate such as raised at temperatures, variable rainfall, and N in the atmosphere deposition are likely to impact N cycling and possibly the cycling of other plants-available nutrients such as phosphorus and sulfur, although the direction and exact magnitude of change in plant available nutrients need to be investigated in detail.

2.3. Soil Biological Properties

"The soil biota is adaptable to changes in environmental situations, while the chemistry (and physics) of the soil system provides the context" [16]. Because biological indicators integrate important soil functions in ways that other indicators do not, they entail complex adaptive systems—the biota—and are therefore essential to the assessment of soil condition in the context of changes in the climate [27].

2.3.1. Soil Organic Matter (SOM)

Soil organic Matter is made up of an extensive variety of both existing and non-living elements. It is generally agreed upon that SOM is one of the most complicated and varied elements of soils, with a wide range of characteristics, purposes, and turnover rates. It supplies and/or supports, contributing to soil charge characteristics, acting as a source and sink of carbon and nitrogen, controlling the cycling of phosphorus and sulfur to varying degrees, having the capacity to form complexes with organic compounds and multivalent ions, offering substrates and habitat for microorganisms and fauna, and influencing aggregate stability, trafficability, water retention, and hydraulic properties.

Reduces in soil organic matter can result in a decline in fertility and biodiversity, as well as a loss of soil structure that lowers water holding capacity, increases erosion risk, and increases bulk density, which in turn causes soil compaction. SOM is a primary driver of soil functions. Global warming will be lessened by land use and management strategies that promote the accumulation of SOM and help absorb CO from the atmosphere. By storing more water during droughts, soil organic matter (SOM) can enhance soil resilience by reducing the effects of flooding that accompany intense rainfall events [23].

2.3.2. Soil Carbon

Soil C is directly connected to ecosystem performance and it has “memory”, that is, changes across time; however, but it may not encompass all ecosystem traits [14]. The soil contains carbon in various forms and for different durations, but much of the research has centered on soil organic carbon (SOC) due to its significant alteration by human activities. It is expected to decrease as global temperatures rise, potentially impacting crucial soil functions, processes, and overall soil quality and health [15].

2.3.3. Light Fraction and Macro-Organic Matter (Labile Organic Matter)

The primary component of SOM's light (or low-density) fraction and macro-organic components is mineral-free particle leftovers from plants and animals. These materials act as a labile nutrient reservoir and a quickly recyclable substrate for soil microorganisms [9]. Light fraction and macro-organic matter may serve as early indicators to gauge how well management practices are changing in the adaptation process to climate change because they are responsive to changes in management techniques. For instance, when the temperature rises, the labile soil organic C is rapidly depleted. Furthermore, future increases in CO may lessen the sequestration of soil C produced from roots, which is a significant source of labile light fraction C [12].

2.3.4. Potentially Mineralizable C and N

Since it serves as a bridge between autotrophic and heterotrophic organisms during the nutrient cycling process, the amount of mineralizable organic matter in the soil is a good predictor of the quality of the organic matter. Since it influences the dynamics of nutrients during individual growing seasons and may be used to evaluate management strategies and C sequestration over long time periods, it is a valuable indicator for evaluating soil health under climate change [9].

2.3.5. Soil Respiration

Since soil respiration can be measured as either CO_2 production or O consumption and is positively correlated with SOM content, it is frequently used as a biological indicator of soil health. Global and regional climate models predict changes in soil respiration, particularly in terms of its temperature response and relative responsiveness to variations in the seasonal timing of rainfall [4].

2.3.6. Soil Microbial Biomass

The living part of SOM, microbial biomass is thought to be the most variable carbon pool in soils and a sensitive indicator of changes in soil processes. It also has connections to the dynamics of soil nutrients and energy, facilitating the transfer of carbon between SOC. Like labile C, soil microbial biomass is sensitive to short-term environmental changes. Lately, long-term simulated climatic warming tests have shown a notable drop in soil microbial biomass [11]. The shift in microbial biomass C, rather than the total microbial biomass C, may offer a more sensitive assessment of changes in soil C processes in response to climate and land-use changes when paired with the C isotope labeling technique [24].

2.3.7. Enzyme Activity

Given their close relationship to the cycling of nutrients and soil biology, their ease of measurement, their ability to provide comprehensive information on both the microbial status and the physicochemical soil conditions, and their quick response to changes in soil management, soil enzyme activities may be used as indicators of change within the plant-soil system [2, 27].

Additionally, changes in the amount and quality of carbon that plants absorb below ground may stimulate microbial enzyme activities; the amount and quality of these enzymes and C turnover may have an impact on how well the microbial community functions in the soil; and the size of soil aggregates may have an impact on how much microbial enzyme activity stimulation occurs. The overall view of their use as indicators of changes in soil health is supported by the fact that soil microbial enzyme activities involved in organic C turnover, nutrient cycling, and greenhouse gas emissions will respond to the combined effects of numerous global change drivers (such as climate change, land-use change) [23].

2.4. Mitigation of the Adverse Effect of Changing Climate on Soil Health

It is possible to influence certain soil qualities and lessen the negative effects of climate change on soil health by implementing conservation tillage and residue management techniques. By adjusting for radiant radiation and insulating effect, the surface residues have a substantial impact on soil temperature. Crusting can be reduced and soil water flow can be increased by any management strategy that shields the soil from the impact of raindrops. Surface residue accumulation can be facilitated by the use of mulches, cover crops, and no-till methods. Heavily mechanized soil can become compacted due to increased bulk density and decreased porosity, which is an unwanted consequence of mechanization. By using i) regular incorporation of organic wastes and leftovers, the application of green manures, rotation of legumes, decreased tillage, use of fertilizers, and supplemental irrigation, conservation agriculture practices contribute to an increase in soil organic matter. ii) Adding fertilizer with a drill after chemical weed control and planting seeds without disturbing the soil; iii) preserving surface residue; reducing tillage; recycling residues; and using legumes in crop rotation. A portion of the residue must be set aside for soil treatment with the goal to increase soil tilth, fertility, and production [31].

3. Conclusion

By utilizing indicators (quantifiable characteristics or values) that connect the physical, chemical, and biological attributes of soil to ecological functions and can be monitored regarding both climate change and sustainable land management, we can understand the impacts of climate change on soil health. Key soil health indicators that are affected by climate change include aggregate stability, soil organic matter (SOM), carbon and nitrogen cycling, microbial biomass and activity, as well as microbial fauna and flora diversity. The selection of indicators for inclusion in a basic data set is based on their capacity to integrate with other soil-related processes, their adaptability to management and climate-related changes, and their simplicity of use, reliability, and measurement rate [1].

Statistical evaluation of the expected effect of changes in the climate on soil health is a challenging endeavor that is directly tied to land degradation issues because of weather forecast uncertainties. Land degradation has been reduced thanks to conservation farming [32]. To combat the effects of warming temperatures on the biological, chemical, and physical properties of soil, however, site-specific management strategies for crop development, soil and water conservation, and integrated nutrient management must be determined [7].

Abbreviations

C	Carbon
CO	Carbon Monoxide
CEC	Cation Exchange Capacity
EC	Electrical Conductivity
N	Nitrogen
P	Phosphorus
S	Sulphur
SOC	Soil Organic Carbon
SOM	Soil Organic Matter

Author Contributions

Zinash Nigussie is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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