Soil Health and Crop Yield: The Critical Overview

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Abstract

Soil health is crucial to natural ecosystems. It maintains biodiversity and manages climate of earth. Healthy soil boosts crop resilience to drought and diseases, as well as fruit and vegetable quality and nutritional content. Earthworms, microorganisms, and insects must be present and active for soil to stay healthy and fertile. Pollination, pest control, water regulation, and carbon sequestration boost crop yields in good soil. Soil microorganisms including bacteria, fungus, and actinomycetes cycle nutrients, break down organic materials, and reduce illness. Soil erosion, nutritional imbalance, salinization, pollution, acidity, compaction and water logging reduce crop production. Soil loss is the most obvious feature of degraded landscapes, which also include erosion, salinization, water contamination, and soil compaction. Conservation tilling, cover crops, crop rotation, and organic fertilizers help improve soil. These strategies enhance soil structure, richness, and microbial activity, making it better for farming and the environment. In addition to these practices, understanding the physical, chemical, and biological properties of soil is essential for maintaining its health. Factors such as soil texture, pH levels, and organic matter content significantly influence fertility and productivity. The presence of diverse microbial communities not only aids in nutrient cycling but also enhances soil structure and plant growth. Addressing soil degradation through integrated management practices, including the use of compost and biofertilizers, can restore soil vitality. These approaches improve nutrient availability, foster beneficial microbial populations, and enhance the soil's capacity to support robust crop yields. Emphasizing sustainable soil management is vital for ensuring long-term agricultural productivity and environmental resilience.

Keywords: Soil health, Soil structure, Crop yield, Microorganisms, Environmental factors

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Introduction

The preservation of water quality, increased plant production, nutrient recycling and decomposition management, and sequestration of greenhouse gases from the atmosphere are just a few of the ecosystem services that occur when soil is healthy. Soil health is fundamentally connected to sustainable agriculture, as the diversity and activity of soil microorganisms are essential components of soil health. Agricultural sustainability denotes the ability of a crop production system to continuously generate food without inflicting environmental damage (Wang, 2022). Arbuscular mycorrhizal fungi (AMF), cyanobacteria, and beneficial nematodes enhance water use efficiency, nutrient availability for plants, phytohormone synthesis, soil nutrient cycling, and plant resilience to environmental stressors. Agricultural practices indicate that organic farming and tillage improve the soil health by increasing the abundance, diversity, and activity of microorganisms. Conservation tillage can increase farmers' profitability by reducing input and labor costs compared to conventional tillage, while organic farming may lead to higher management expenses due to increased labor demands for weeding, pest control, and fertilizer application (particularly nitrogen-based), which typically demonstrate less consistency and stability than synthetic fertilizers. It is essential to formulate plans and implement actions to protect and restore soil health in agriculture (Gupta et al., 2022).

Soil health or quality is defined as the sustained ability of soil to operate as an essential living system within ecosystems and land use, facilitating biological productivity, enhancing air and water quality, and protecting the welfare of plants, animals, and humans. In soil, “health” emphasizes the importance of its various biotic constituents (Janzen et al., 2021). As soil is inanimate, the concept of 'health' is based on analogy rather than homology. The absence of a control soil complicates the assessment of soil health in contemporary agricultural systems. The spatial heterogeneity of soil, defined more by its diverse qualities and processes than by any average measure, along with its temporal dynamism. When assessing how soil management affects the functional sustainability of soil (soil health) in agricultural systems, temporal patterns operate effectively (Gao et al., 2018). It is hard to define soil health as "the capacity of a specific soil to fulfil its functions" since there may be inconsistencies between these functions and the intended use of the soil (Toor et al., 2021).

This study aims to influence future cropping system design and optimization by examining the effects of traditional cropping systems on soil health, microbiological markers, and other pertinent metrics for measuring soil health and degradation induced by agricultural practices.

1. Understanding Soil Health

It will be easier to characterize soil functionality thoroughly if the key elements of the soil system and their interactions are understood. Completing a procedure is difficult due to the complex physical, chemical, and biological properties and processes of soil. Soil health is the capacity of soil to act as a dynamic living system, shaped by ecosystem conditions and land use, to support plant and animal productivity, enhance the quality of the air and water, and promote overall environmental and biological wellbeing. (Doran et al., 2018).

It is crucial to understand the quantitative effects of land uses and soil management techniques on soil functionality in order to develop an exhaustive index. Detailed interrelations must be accurately represented by this index. A recent study determined that "soil quality" and "soil health" are synonymous concept, it is essential to combine biotic and abiotic indicators and utilize their interconnections to present a comprehensive perspective (Pervaiz et al., 2020).

The swift increase in the world population and anticipated growth render food production imperative. The FAO indicates that food security initiates the "poverty trap" cycle by intensifying global demand for land resources, leading to land degradation and diminished food supply (Mulazzani et al., 2020). The rehabilitation of agricultural lands and the expansion of land conversion for farming, alongside sustainable food production, are global challenges that necessitate a quantitative, comparable instrument for program evaluation. A dependable indicator must include soil types, applications, climate zones, and more aspects. Numerous efforts have been undertaken to identify 'excellent' soil (Bünemann et al., 2018). The physical, chemical, and biological attributes of soil functionality encompass tilth, fertility, and quality. The most recent initiative to characterize and assess soil that fosters advantageous agricultural and environmental results is termed 'soil health,' emphasizing the comprehensive integration of soil biota and biotic processes. Soil biota was significant prior to modern soil research, although three variables render soil health particularly crucial in the present day (Creamer et al., 2022).

A variety of microbiological soil health indicators are commercially accessible and extensively utilized. Secondly, there is a necessity for soil health indicators that encompass a broader range of agricultural systems beyond the usually studied row crops (Hussain et al., 2022). There is keen interest in assessing soil health in rangelands, while indicators for row crops may be inapplicable. The context will also influence the interpretation of values. In precision agriculture, there is a desire for rapid, management-focused soil testing (Azuazu, 2023). Numerous existing approaches were designed for research purposes rather than for providing management recommendations or assessments related to plot-to-ecosystem dynamics, where causal relationships to outcomes are essential. Consequently, these biological markers may prove ineffective for evaluating soil health or for the selection and oversight of soil health initiatives (Dahiya et al., 2022).

2. Factors Affecting Soil Health

2.1 Environmental Factors

Following are the Environmental factors affecting soil health

2.1.1. Climate

The climate significantly influences soil health. Temperature and precipitation patterns affect soil formation, organic matter breakdown, and nutrient cycling. In areas characterized by elevated temperatures and substantial precipitation, soils are generally more eroded and leached, leading to reduced nutrient availability. Conversely, dry and semi-arid regions often feature soils with high salt concentrations resulting from inadequate leaching. Seasonal variations in temperature and humidity affect microbial activity and the decomposition rates of organic compounds, hence influencing soil structure and fertility (Zifcakova, 2020).

2.1.2. Topography

Topography, characterized by the physical features of the landscape, influences soil health by affecting water drainage, erosion, and soil depth. Sloped landscapes are more vulnerable to erosion, which can deplete nutrient-rich topsoil and reduce soil fertility. In contrast, flat or gently sloping terrains demonstrate enhanced water retention and less erosion, hence promoting more resilient soils. Topography affects the distribution of organic matter and nutrients, as lower areas often collect larger quantities of organic material and nutrients due to runoff from higher elevations (Lintern et al., 2018).

2.2 Human Activities

Following are the human activities affecting soil health:

2.2.1. Fertilizers

The utilization of organic and inorganic fertilizers is crucial for preserving soil fertility and improving crop yield. Nonetheless, the excessive or inappropriate use of fertilizers can adversely affect soil health. Excessive usage of inorganic fertilizers can lead to detrimental salt accumulation, nutritional imbalances, and soil acidification. Manure and compost are examples of organic fertilizers that enhance the soil's structure, boost its organic matter content, and promote microbial activity. Regular soil testing and judicious fertilizer application are essential for preserving soil health and avoiding nutrient toxicity or depletion (Pasko & Lebedeva, 2024).

3.2.2. Pesticides and Herbicides

Pesticides and herbicides can harm soil health even though they are frequently used in agriculture to manage weeds and other pests. These substances can reduce soil biodiversity by negatively affecting beneficial microorganisms, insects, and earthworms. Frequent pesticides in soil can cause prolonged pollution and can even damage the organisms that are not the desired goals. Integrated pest management (IPM) systems add chemical, cultural and biological control techniques to reduce the negative effects of pesticides on soil fertility (Deguine et al., 2021).

2.2.3. Irrigation Practices

In many places, irrigation is necessary for agricultural production, yet improper irrigation technology may deteriorate soil quality. Over-irrigation can lead to loss of nutrients, soil erosion and waterlogging. Inadequate water may result in soil salinization and low agricultural productivity, while effective irrigation techniques such as drip irrigation and sprinkler systems maintain ideal soil moisture, reduce water loss, and prevent the decline of soil. Regular assessment of soil moisture levels and to maintain soil health is necessary to modify the irrigation program as per crop requirements (Pereira et al., 2020).

2.3 Biological Factors

The following are the organic substances that affect soil health:

2.3.1. Pests and Diseases

Soil health and agricultural production can be greatly affected by pests and diseases that are present in the soil. Attacking the roots of plants by nematodes, fungus, bacteria, viruses and other diseases can obstruct the plant's ability to absorb the nutrients of the plant, causing stress or even death The harmful effects of pests and diseases caused in the soil can be reduced by cultivating crop types, rotating crops and using biological control agents. Maintaining a diverse and strong soil microbial population improves plant health and disease control (Panth et al., 2020).

2.3.2. Organic Matter

Because it improves soil composition, moisture retention and access to nutrients, organic matter that is made of disintegrated plant and animal residue is essential for soil health. It also keeps resources available to soil bacteria, promoting a vibrant and diversified population. Cover cropping, crop rotation, and organic additions enhance soil organic matter and health Comprehending the determinants influencing sustainable soil management initiatives is essential for soil vitality. Soil fertility and productivity are influenced by pests, diseases, and soil microbes. Soil health practices can enhance crop yields, promote environmental sustainability, and extend the longevity of agricultural systems (Shah & Wu, 2019).

3. Soil Microorganisms and their Role

Urgent restoration is required due to intensive agriculture, which has employed chemical fertilizers, herbicides, and insecticides, thereby modifying soil structure and microbial composition in recent decades. Intensive agriculture leads to soil and environmental pollution, as well as physical and physiological challenges. Excess chemical fertilizers persist in the soil in a useless form, hindering plant absorption (Amin & Jilani, 2024). Precipitation following the application of chemical fertilizers in agricultural regions can contaminate water and induce algal blooms. Organic fertilizers and organic agriculture were established to mitigate the adverse effects of chemical fertilizers. Compost, farmyard manure, green manures, and bio-fertilizers constitute organic fertilizers (Bergstrand, 2022).

Organic fertilizers enhance physical and chemical characteristics, include the mitigation of sodicity, reduction of bulk density, and augmentation of water infiltration rates, enhancement of porosity and aeration, and promotion of saline water leaching. Humus enhances the biological properties of soil, fostering beneficial microorganisms (Costantini & Mocali, 2022). Organic amendments enhance soil carbon and nitrogen levels, hence augmenting agricultural production, sustainability, and profitability. Agriculture has consistently fulfilled global food requirements. With the increase in population, agriculture must meet this demand (Timsina, 2018).

Furthermore, constant cultivation depletes essential nutrients from the soil, leading to reduced yield and quality of the produce. Chemical fertilizers and insecticides have been utilized to alleviate these detrimental effects (Pahalvi et al., 2021). However, its extended use has led to considerable health and environmental problems, damaging ecosystems and promoting insect resistance. To reduce chemical usage, bio-fertilizers and bio-pesticides offer an environmentally friendly approach to improve crop yields (Kumar et al., 2024).

Using bio-fertilizers or bio-pesticides to boost agricultural output is novel. Biogenic fertilizers are effective and sustainable biotechnological alternatives to chemical fertilizers for increasing agricultural productivity, soil fertility and plant development (Divya, 2022). In contrast, bio-pesticides are essential to crop protection when utilized in bio-intensive integrated pest control with conventional pesticides. Numerous pests and phytopathogens damage crops, causing significant economic losses. Some of the most prevalent biofertilizers and bio pesticides are *Bacillus,* it can use numerous direct and indirect paths during plant development. Their direct procedures involve obtaining nitrogen, phosphate, potassium, and minerals or modulating plant hormone concentrations. Indirect strategies include plant pathogen resistance or antagonistic chemical production. *Bacillus thuringiensis* is a popular biopesticide (Hashem et al., 2019).

4. Nutrient Management

Due to increasing land scarcity and water restrictions, most agricultural techniques depend on chemical fertilizers and the production of innovative high-yield crop varieties. Both components are, however, prohibitively expensive and will result in heightened pressure and increased financial obligations, finally culminating in a rise in overall expenditures. Simultaneously, the price of fertilizers rises each year, driven by the greater amounts needed in the second and third seasons compared to the first season, to maintain yield output at a financially sustainable level (Kallianiotis, 2022). Despite the increase in fertilizer application, some of the applied fertilizers and native soil nutrients have already been used by both current and prior crops, especially in intensive agricultural practices where two to three crops are cultivated each year. Moreover, the use of inorganic fertilizers is not a feasible option for many farmers worldwide (Comer et al., 2019).

4.1. Precision Nutrient Application Techniques

Precision nutrient application techniques are sophisticated methods and technology employed in agriculture to accurately and efficiently deliver fertilizers and other vital nutrients to crops. These strategies aim to enhance nutrient delivery by utilizing real-time data, field variability, and particular crop requirements. The goal is to increase agricultural output, decrease nutrient loss, and promote sustainable farming practices (Mikula et al., 2020).

The following are some specific ways to use accurate nutrition:

4.2. Variable Rate Technology (VRT)

According to the exact agricultural sector conditions, the variable rate technology (VRT) is used to modify the number of inputs such as seeds, fertilizers, and herbicides. The VRT increases resource usage by customizing the input application at specific field locations. Conversely, uniform application methods spread the input equally into the area, causing both over- and under-applications as well as disability. Sensors, data analytics, GPS, GIS, and sometimes machine learning technologies are all integrated with VRT (Mishra et al., 2021). These devices, which display topography, moisture content, fertilizer application, soil composition and other variables, can be used by farmers to designate their fields. The VRT system can assess these maps and real-time sensor data to make intelligent adjustments in input rates. In contemporary agriculture, convertible rate technology (VRT) increases crop growth, stability, economic viability and nutrition efficiency. Variable Rate Technology (VRT) systems enable farmers to apply fertilizers and nutrients more efficiently by adjusting application rates in real time based on soil nutrient levels, historical crop yields, and other relevant factors.

This accuracy reduces nutrients runoff and leaks in aquatic houses by reducing the overflow of nutrients in productive areas, preserves water quality and ecological integrity (Fabiani et al., 2020).

4.3. Sensor-based Techniques

Monitor is used by the agricultural sensor system to collect data on crops, soil and climate in real time. These sensors provide important information to farmers for resource allocation, input management and crop management. Accurate agriculture requires sensor-based methods to monitor and adapt to the region's condition. Tools are used to detect soil moisture, humidity and mineral concentrations. With this information, farmers can increase crop growth through better drainage and distribution of nutrients. To assess the state of agriculture, weather sensors measure temperature, air speed, humidity and solar radiation (Kanwalet al., 2023). The spectral analysis of crop health sensors is used to find early indicators of stress, disease and nutritional deficit. Nutrient sensors assess the content of nutrients to prevent the imbalance of nutrients and guarantee the appropriate fertilizer application. Satellites or drone take photographs of agricultural sectors to assess crop conditions, growth patterns and stress. The maps of these photos can then be made for specific treatments. The precise agricultural nutrient concentrations, soil moisture content and other variables use the sensor to assess. Farmers can use real -time data from these sensors to inform their decisions about fertilizer and irrigation. Soil nutrient sensors monitor the amount of nitrogen, phosphorus and potassium (Welekar et al., 2023). These sensors evaluate soil nutrients using ion-selective electrodes, optical spectroscopy and electrical conductivity measurements. Measuring the amount of nitrogen in the soil using ion-selective electrodes. Researchers found that these sensors offer accurate and real -time measurements of soil nitrate concentrations, allowing farmers to accommodate nitrogen application rates (Asadzadeh et al., 2020).

5. Practices to Improve Soil Health

5.1. Organic Farming

To maintain plant health, organic farming uses organic nutrient mobilization, animal cow dung, crop rotation, mineral-grade rock and external organic waste. Human health, ecosystems and soils are all protected by organic farming. It uses biological processes along with biodiversity. Organic farming connects science, innovation and tradition to improve the quality of life, equity and community welfare (Nengparmoi et al., 2023).

By improving agroecosystem, organic farming makes it more flexible for climate change. It establishes drought and temperature ups and downs without soil erosion, environmentally viable agricultural systems. Organic farming advocates for environmentally sustainable management, conservation, and restoration practices. In comparison to conventional agriculture, organic farming is cost-effective. It aids farmers and communities in adapting to climate change. Organic farming aligns with multiple adaptation criteria (Taylor et al., 2021).

5.2. Crop Rotation

Crop rotations may increase soil organic carbon in biologically simple grain-centric agroecosystems. Functional diversity was expected to better predict crop rotation effects on soil organic carbon concentrations than species diversity. The carbon (C) input via functional diversity may increase or reduce soil organic carbon (SOC). Nitrogen (N) fertilizer inputs, soil carbon input, crop rotation species, functional diversity, and soil organic carbon (SOC) concentrations (g C kg/soil) were collected from 169 cropping systems and 27 cropping system locations. Classified agricultural rotations into categories of grain-exclusive, cover crop, and perennial crop (Francaviglia et al., 2023).

Cover cropped and perennial cropped rotations increased carbon input by 42% and 23%, respectively, and elevated soil organic carbon concentrations by 6.3% and 12.5% in comparison to grain-only rotations. Rotations of cereal and legume grains diminished overall carbon intake (<16%), root carbon (<12%), and soil organic carbon (<5.3%) in comparison to cereal-only rotations. The diversity of species did not influence soil organic carbon in grain-only rotations (King & Blesh, 2018). In monoculture crop cycles, nitrogen fertilizer rates limit functional diversity effect on soil organic carbon. Minimal nitrogen fertilizer applications (≤75 kg N·ha−1·yr−1) led to diminished soil organic carbon loss in cereal and legume grain rotations relative to higher nitrogen fertilizer applications. Improved functional crop rotation and augmented carbon input raise soil organic carbon levels. Diverse perennial and cover crop rotations increased carbon input and soil organic carbon levels by exploiting unproductive temporal niches (Zou et al., 2024).

5.3. Cover Cropping

The misuse of traditional agricultural technology, including heavy machinery for tillage, chemical inputs for fertilizers, pesticides, and herbicides, monoculture practices, and groundwater depletion for irrigation, has resulted in significant environmental damage, notably the deterioration of soil quality. Soil loss is the most obvious feature of degraded landscapes, which also include erosion, salinization, water contamination, and soil compaction (Osipitan et al., 2019). Natural-based solution (NBS) agriculture is advocated in preference to conventional methods. Diversify species, apply agricultural waste as soil cover, and reduce mechanical soil disturbance (Preti et al., 2022).

6. Relationship Between Soil Health and Yield, Case Studies and Examples

In temperate regions, plow-till (PT) management warms spring soil, improves soil physical conditions for plant development momentarily, integrates surface debris, and evaporates water. Excessive tillage can harm the ecology and soil over time. PTs promote subsurface compaction, decrease macro porosity and aggregate stability, and crust the soil surface following tillage. The PT may lessen erosion, soil water infiltration, and root growth. PT systems suffer from soil erosion, which lowers agricultural productivity, sedimentation in streams and lakes, and soil depth. Soil biology is harmed by intensive tillage (Nunes et al., 2018).

The United States used low tillage in the 1930s to fight wind and water erosion, which was driving notable erosion during the Dust Bowl. In temperate areas, switching from PT to NT could help to improve soil quality, lower soil erosion, and benefit the environment and the economy. No-till (NT) may also diminish organic matter (OM) mineralization by influencing soil processes and inhibiting residue assimilation. No-till (NT) strategies may enhance soil pore continuity and connectivity, hence influencing air diffusivity and permeability, whereas conservation management techniques might promote the production and preservation of water-stable aggregates (Bolles & Forman, 2018).

7. Sustainable Farming Techniques

7.1. Conservation tillage

Conservation, non-inversion, or limited tillage improves soil stability and structure. Preparing a cash crop seedbed requires inverting the soil to more than 20 cm with a moldboard plow before secondary cultivation. Conservation tillage includes planting directly into the previous crop's residue or gently disturbing the soil (e.g., shallow non-inversion tillage to a depth of less than 10 cm using discs or tines) (Lal et al., 2020). Conservation tillage improves soil structure by enhancing drainage, water retention, microbial and earthworm activity, erosion, and organic matter. Non-inversion tillage boosts agriculture's finances by reducing fuel and labor costs for energy-intensive deep soil inversion operations. Tillage intensity reduction is not always beneficial. In the absence of soil inversion, surface soil compaction, weed and insect pests, and surface runoff-released nutrients can affect freshwater habitats. Conservation tillage may reduce crop yields due to poor seedbed preparation (Seitz et al., 2019).

7.2. Integrated Pest Management (IPM)

Cost-benefit analysis guides IPM pest control decisions. IPM programs are cost-effective when control costs less than pest-related market value loss. IPM avoids needless chemical applications and uses nonchemical control approaches whenever possible to reduce pesticide consumption. To meet consumer and regulatory demands for pesticide reduction, the food industry will need to adopt IPM programs more. Cost–benefit analysis for IPM programs uses economic injury levels. pest density that reduces market value more than pest control costs is an EIL (Rahman et al., 2024).

8. Challenges in Maintaining Soil Health

Energy-intensive mining, agriculture, and deforestation deteriorate soil, air, and land, negatively impacting economies. Mining produces significant amounts of predominantly inert and amorphous crushed rock that often contains hazardous elements like lead, arsenic, and cadmium inside metal sulfides, along with calcium, magnesium, and metal sulfates and carbonates (Li et al., 2016). Mining overburden and tailings are deposited near to extensive open pits. In modern agriculture, commercial fertilizers, insecticides, and animal waste negatively impact soil, air, and water quality. Deforestation degrades land and water quality by intensifying soil erosion, sedimentation, and the depletion of nutrient-dense topsoil. Invasive alien plant species threaten our land by increasing fire risks and inducing soil degradation. Metals, salts, and acid or acid genic minerals generated or concentrated during these processes affect soil salinity and acidity. Such compounds may be released into the atmosphere or aquatic ecosystems (Lehmann et al., 2020).

8.1. Soil Erosion

Modern soil erosion harms the ecology and economy worldwide. Accelerated soil erosion dominates global degradation. The ratio of sensitive to unsusceptible soils cape units determines the watershed's mean soil quality index for erosional processes. Soil quality affects productivity and environmental regulation. Soil resilience mitigates major degradative processes. Biophysical and socioeconomic factors complicate erosion's impact on soil quality and vice versa. Based on productivity and environmental regulatory soil depth, erosion influences soil quality (Borrelli et al., 2021).

9. Future Perspectives

UN estimates put the global population at 8.5 billion by 2030, 9.7 billion by 2050, and 10.4 billion by 2080. Sustainable food must be provided annually. To maintain sustainability, corn production must rise from 2.1 billion tons to 3 billion tons and animal production from 200 million tons to 470 million tons. If not, this will lead to the largest economic disaster in history, making people begging for food with empty bowls or bags. Sustainable agriculture techniques include agroecology, nature-inclusive agriculture, permaculture, biodynamic, organic, conservation, regenerative, carbon, climate-smart, minimal external input, circular, ecological intensification, and sustainable intensification. These strategies are more alike than farming (Willett et al., 2019). Rotating crops, variety, cover crops and perennials, lowering or eliminating tillage, IPM, livestock-crop integration, INM, precision agriculture, and agroforestry are sustainable agricultural methods. New farming practices are needed for ecological sustainability and food security for a growing population. Only a global shift toward sustainability can preserve nature and its benefits to humans. Since providing adequate food at cheap prices and protecting the environment are essential to our survival, implementing these methods is the most important thing we can do for our future (Ives et al., 2018).

Conclusion

In conclusion, soil health is essential for sustaining long-term agricultural productivity and promoting plant growth. The soil's physical, chemical, and biological characteristics are essential for sustaining plant life, controlling water flow, and preserving an ecosystem's general health. Increasing crop performance is mostly due to important characteristics such as soil structure, texture, pH, availability of nutrients and microbial appearance. Additionally, healthy soil promotes necessary functions including pollination, carbon storage, insect control and water management - which are all associated with high yields. Examples of permanent methods that help maintain soil health and reduce the effects of climate change on agriculture include crop rotation, protection tiling and use of organic fertilizers. To collect important information on soil conditions, contemporary technologies such as remote sensing and soil monitoring can be employed. Maintaining global food systems and ensuring agricultural productivity requires the ongoing study in soil ecosystem services and biodiversity. Finally, it is necessary to preserve soil health for future food and environmental protection.

References

Amin, F., & Jilani, M. I. (2024). Environmental, Microbiological and Chemical Implications of Fertilizers use in soils: A review. *International Journal of Chemical and Biochemical Sciences*, *25*(18), 56-73. https://www.iscientific.org/wp-content/uploads/2024/02/6-IJCBS-24-25-18-6.pdf

Asadzadeh, A., Arashpour, M., Li, H., Ngo, T., Bab-Hadiashar, A., & Rashidi, A. (2020). Sensor-based safety management. *Automation in Construction*, *113*, 103128. https://doi.org/10.1016/j.autcon.2020.103128

Azuazu, I. N. (2023). *Enhancing natural attenuation for oil-contaminated soils using a combination of low-carbon bioengineered approaches* Cranfield University. https://dspace.lib.cranfield.ac.uk/handle/1826/22694

Bergstrand, K.-J. (2022). Organic fertilizers in greenhouse production systems–a review. *Scientia Horticulturae*, *295*, 110855. https://doi.org/10.1016/j.scienta.2021.110855

Bolles, K. C., & Forman, S. L. (2018). Evaluating landscape degradation along climatic gradients during the 1930s dust bowl drought from panchromatic historical aerial photographs, United States Great Plains. *Frontiers in Earth Science*, *6*, 153. https://doi.org/10.3389/feart.2018.00153

Borrelli, P., Alewell, C., Alvarez, P., Anache, J. A. A., Baartman, J., Ballabio, C., Bezak, N., Biddoccu, M., Cerdà, A., & Chalise, D. (2021). Soil erosion modelling: A global review and statistical analysis. *Science of the total Environment*, *780*, 146494. https://doi.org/10.1016/j.scitotenv.2021.146494

Bünemann, E. K., Bongiorno, G., Bai, Z., Creamer, R. E., De Deyn, G., De Goede, R., Fleskens, L., Geissen, V., Kuyper, T. W., & Mäder, P. (2018). Soil quality–A critical review. *Soil Biology and Biochemistry*, *120*, 105-125. https://doi.org/10.1016/j.soilbio.2018.01.030

Comer, B. M., Fuentes, P., Dimkpa, C. O., Liu, Y.-H., Fernandez, C. A., Arora, P., Realff, M., Singh, U., Hatzell, M. C., & Medford, A. J. (2019). Prospects and challenges for solar fertilizers. *Joule*, *3*(7), 1578-1605. https://www.cell.com/joule/fulltext/S2542-4351(19)30213-2

Costantini, E. A., & Mocali, S. (2022). Soil health, soil genetic horizons and biodiversity#. *Journal of Plant Nutrition and Soil Science*, *185*(1), 24-34. https://onlinelibrary.wiley.com/doi/full/10.1002/jpln.202100437

Creamer, R., Barel, J., Bongiorno, G., & Zwetsloot, M. (2022). The life of soils: Integrating the who and how of multifunctionality. *Soil Biology and Biochemistry*, *166*, 108561. https://doi.org/10.1016/j.soilbio.2022.108561

Dahiya, U. R., Das, J., & Bano, S. (2022). Biological indicators of soil health and biomonitoring. In *Advances in Bioremediation and Phytoremediation for Sustainable Soil Management: Principles, Monitoring and Remediation* (pp. 327-347). Springer. https://link.springer.com/chapter/10.1007/978-3-030-89984-4_21#citeas

Deguine, J.-P., Aubertot, J.-N., Flor, R. J., Lescourret, F., Wyckhuys, K. A., & Ratnadass, A. (2021). Integrated pest management: good intentions, hard realities. A review. *Agronomy for Sustainable Development*, *41*(3), 38. https://link.springer.com/article/10.1007/S13593-021-00689-W#citeas

Divya, B. S. (2022). Chapter-2 Biofertilizers: Their Role, Uses and Different Methods of Application. *Chief Editor Dr. Neeraj Kumar*, 13.

Doran, J. W., Jones, A. J., Arshad, M., & Gilley, J. (2018). Determinants of soil quality and health. In *Soil quality and soil erosion* (pp. 17-36). CRC Press. https://www.taylorfrancis.com/chapters/

Fabiani, S., Vanino, S., Napoli, R., Zajíček, A., Duffková, R., Evangelou, E., & Nino, P. (2020). Assessment of the economic and environmental sustainability of Variable Rate Technology (VRT) application in different wheat intensive European agricultural areas. A Water energy food nexus approach. *Environmental Science & Policy*, *114*, 366-376. https://doi.org/10.1016/j.envsci.2020.08.019

Francaviglia, R., Almagro, M., & Vicente-Vicente, J. L. (2023). Conservation agriculture and soil organic carbon: Principles, processes, practices and policy options. *Soil Systems*, *7*(1), 17. https://doi.org/10.3390/soilsystems7010017

Gao, H., Sabo, J. L., Chen, X., Liu, Z., Yang, Z., Ren, Z., & Liu, M. (2018). Landscape heterogeneity and hydrological processes: a review of landscape-based hydrological models. *Landscape Ecology*, *33*, 1461-1480. https://link.springer.com/article/10.1007/s10980-018-0690-4#citeas

Gupta, A., Singh, U. B., Sahu, P. K., Paul, S., Kumar, A., Malviya, D., Singh, S., Kuppusamy, P., Singh, P., & Paul, D. (2022). Linking soil microbial diversity to modern agriculture practices: a review. *International Journal of Environmental Research and Public Health*, *19*(5), 3141. https://doi.org/10.3390/ijerph19053141

Hashem, A., Tabassum, B., & Abd_Allah, E. F. (2019). Bacillus subtilis: A plant-growth promoting rhizobacterium that also impacts biotic stress.

Saudi journal of biological sciences, *26*(6), 1291-1297. https://doi.org/10.1016/j.sjbs.2019.05.004

Hussain, Z., Deng, L., Wang, X., Cui, R., & Liu, G. (2022). A review of farmland soil health assessment methods: Current status and a novel approach. *Sustainability*, *14*(15), 9300. https://doi.org/10.3390/su14159300

Ives, C. D., Abson, D. J., Von Wehrden, H., Dorninger, C., Klaniecki, K., & Fischer, J. (2018). Reconnecting with nature for sustainability. *Sustainability science*, *13*, 1389-1397. https://link.springer.com/article/10.1007/S11625-018-0542-9#citeas

Janzen, H. H., Janzen, D. W., & Gregorich, E. G. (2021). The ‘soil health’metaphor: illuminating or illusory? *Soil Biology and Biochemistry*, *159*, 108167. https://doi.org/10.1016/j.soilbio.2021.108167

Kallianiotis, I. (2022). Tax Reform Imperative: Alleviating Financial Burden and Fostering Middle-Class Prosperity in the US Economy. *Journal of Business and Economic Options*, *5*(1), 48-57. http://resdojournals.com/index.php/jbeo/article/view/208

King, A. E., & Blesh, J. (2018). Crop rotations for increased soil carbon: perenniality as a guiding principle. *Ecological Applications*, *28*(1), 249-261. https://doi.org/10.1002/eap.1648

Kumar, A., Saharan, B. S., Parshad, J., Gera, R., Choudhary, J., & Yadav, R. (2024). Revolutionizing Indian agriculture: the imperative of advanced biofertilizer technologies for sustainability. *Discover Agriculture*, *2*(1), 24. https://link.springer.com/article/10.1007/s44279-024-00037-y#citeas

Lal, R., Eckert, D., Fausey, N., & Edwards, W. (2020). Conservation tillage in sustainable agriculture. In *Sustainable agricultural systems* (pp. 203-225). CRC Press. https://www.taylorfrancis.com/chapters/

Lehmann, J., Bossio, D. A., Kögel-Knabner, I., & Rillig, M. C. (2020). The concept and future prospects of soil health. *Nature Reviews Earth & Environment*, *1*(10), 544-553. https://www.nature.com/articles/s43017-020-0080-8#citeas

Lintern, A., Webb, J., Ryu, D., Liu, S., Bende-Michl, U., Waters, D., Leahy, P., Wilson, P., & Western, A. (2018). Key factors influencing differences in stream water quality across space. *Wiley Interdisciplinary Reviews: Water*, *5*(1), e1260. https://wires.onlinelibrary.wiley.com/doi/full/10.1002/wat2.1260

Mikula, K., Izydorczyk, G., Skrzypczak, D., Mironiuk, M., Moustakas, K., Witek-Krowiak, A., & Chojnacka, K. (2020). Controlled release micronutrient fertilizers for precision agriculture–A review. *Science of the Total Environment*, *712*, 136365. https://doi.org/10.1016/j.scitotenv.2019.136365

Mulazzani, L., Manrique, R., Stancu, C., & Malorgio, G. (2020). Food security and migration in Africa: A validation of theoretical links using case studies from literature. *New Medit*, *19*(2), 19-36. https://cris.unibo.it/handle/11585/775677

Nengparmoi, T., Devi, N. M., Naveen, K., & Devi, O. R. (2023). Chapter-19 Organic Farming-Concepts. *Dr. Chandana Behera*, 351. https://www.researchgate.net/profile/Okram-Devi-2/publication/370962767_Organic_farming-Concepts/links/64e7a5ac40289f7a0fb16587/Organic-farming-Concepts.pdf

Nunes, M. R., van Es, H. M., Schindelbeck, R., Ristow, A. J., & Ryan, M. (2018). No-till and cropping system diversification improve soil health and crop yield. *Geoderma*, *328*, 30-43. https://doi.org/10.1016/j.geoderma.2018.04.031

Osipitan, O. A., Dille, J. A., Assefa, Y., Radicetti, E., Ayeni, A., & Knezevic, S. Z. (2019). Impact of cover crop management on level of weed suppression: a meta-analysis. *Crop Science*, *59*(3), 833-842. https://acsess.onlinelibrary.wiley.com/doi/abs/10.2135/cropsci2018.09.0589

Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., & Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. *Microbiota and Biofertilizers, Vol 2: Ecofriendly tools for reclamation of degraded soil environs*, 1-20. https://link.springer.com/chapter/10.1007/978-3-030-61010-4_1#citeas

Panth, M., Hassler, S. C., & Baysal-Gurel, F. (2020). Methods for management of soilborne diseases in crop production. *Agriculture*, *10*(1), 16. https://doi.org/10.3390/agriculture10010016

Pasko, O. A., & Lebedeva, N. A. (2024). *Ecological Aspects of Soil and Land Preservation*. IGI Global. https://books.google.com.pk/books?id=DnkVEQAAQBAJ&lpg=PP1&ots=6GeRtSIV5H&dq=Pasko%2C%20O.%20A.%2C%20%26%20Lebedeva%2C%20N.%20A.%20(2024).%20Ecological%20Aspects%20of%20Soil%20and%20Land%20Preservation.%20IGI%20Global.&lr&pg=PP1#v=onepage&q=Pasko,%20O.%20A.,%20&%20Lebedeva,%20N.%20A.%20(2024).%20Ecological%20Aspects%20of%20Soil%20and%20Land%20Preservation.%20IGI%20Global.&f=false

Pereira, L., Paredes, P., & Jovanovic, N. (2020). Soil water balance models for determining crop water and irrigation requirements and irrigation scheduling focusing on the FAO56 method and the dual Kc approach. *Agricultural Water Management*, *241*, 106357. https://doi.org/10.1016/j.agwat.2020.106357

Pervaiz, Z. H., Iqbal, J., Zhang, Q., Chen, D., Wei, H., & Saleem, M. (2020). Continuous cropping alters multiple biotic and abiotic indicators of soil health. *Soil Systems*, *4*(4), 59. https://doi.org/10.3390/soilsystems4040059

Preti, F., Capobianco, V., & Sangalli, P. (2022). Soil and Water Bioengineering (SWB) is and has always been a nature-based solution (NBS): A reasoned comparison of terms and definitions. *Ecological Engineering*, *181*, 106687. https://doi.org/10.1016/j.ecoleng.2022.106687

Rahman, A., Khalid, S., Qadeer, S., Naqqash, R. M., & Khalid, N. (2024). Cost-Benefit Analysis of Smart Pest Control Technologies. In *Revolutionizing Pest Management for Sustainable Agriculture* (pp. 133-160). IGI Global. https://www.igi-global.com/book/revolutionizing-pest-management-sustainable-agriculture/334858

Seitz, S., Goebes, P., Puerta, V. L., Pereira, E. I. P., Wittwer, R., Six, J., van Der Heijden, M. G., & Scholten, T. (2019). Conservation tillage and organic farming reduce soil erosion. *Agronomy for Sustainable Development*, *39*, 1-10. https://link.springer.com/article/10.1007/s13593-018-0545-z#citeas

Shah, F., & Wu, W. (2019). Soil and crop management strategies to ensure higher crop productivity within sustainable environments. *Sustainability*, *11*(5), 1485. https://doi.org/10.3390/su11051485

Taylor, A., Wynants, M., Munishi, L., Kelly, C., Mtei, K., Mkilema, F., Ndakidemi, P., Nasseri, M., Kalnins, A., & Patrick, A. (2021). Building climate change adaptation and resilience through soil organic carbon restoration in Sub-Saharan rural communities: challenges and opportunities. *Sustainability*, *13*(19), 10966. https://doi.org/10.3390/su131910966

Timsina, J. (2018). Can organic sources of nutrients increase crop yields to meet global food demand? *Agronomy*, *8*(10), 214. https://doi.org/10.3390/agronomy8100214

Toor, G. S., Yang, Y.-Y., Das, S., Dorsey, S., & Felton, G. (2021). Soil health in agricultural ecosystems: current status and future perspectives. *Advances in Agronomy*, *168*, 157-201. https://doi.org/10.1016/bs.agron.2021.02.004

Wang, X. (2022). Managing land carrying capacity: Key to achieving sustainable production systems for food security. *Land*, *11*(4), 484. https://doi.org/10.3390/land11040484

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., & Wood, A. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The lancet*, *393*(10170), 447-492. https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(18)31788-4/abstract

Zifcakova, L. (2020). Factors affecting soil microbial processes. *Carbon and Nitrogen Cycling in Soil*, 439-461. https://link.springer.com/chapter/10.1007/978-981-13-7264-3_13#citeas

Zou, Y., Liu, Z., Chen, Y., Wang, Y., & Feng, S. (2024). Crop Rotation and Diversification in China: Enhancing Sustainable Agriculture and Resilience. *Agriculture*, *14*(9), 1465. https://doi.org/10.3390/agriculture14091465