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Review

Farming Practice Variability and Its Implications for Soil Health in Agriculture: A Review

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Abstract: Soil health is essential for sustainable agricultural operations, as it supports farm production and ecosystem services. The adoption of sustainable agriculture practices such as conservation tillage, cover cropping, and crop rotation provides significant benefits for both crop productivity and environmental sustainability. These practices can increase soil biodiversity, nutrient cycling, and organic matter, which increase the resilience of agroecosystems. This narrative review synthesizes the insights of the soil health practices adoption literature, with a focus on common farming practices that can improve soil health and enhance crop yields, reviewing the results of various approaches and pointing out the challenges and opportunities for implementing sustainable agriculture on a larger scale. This paper discusses the effects of various tillage and cropping system approaches on soil health, including no-till and conventional tillage systems, crop rotation, cover cropping, cultivator combinations, and fertilizer application. This study found that conservation tillage is more beneficial to soil health than conventional tillage—which is still debated among scientists and farmers—and that different tillage methods interact differently. In contrast, agricultural yields increase more with intercropping, crop rotation, and cover crops than monocropping. For maintaining soil fertility, this study shows that agricultural yields could be increased by implementing zero tillage. This review identifies the most suitable farming practices for improving soil health while boosting crop production with minimal negative impact on the soil. It also highlights the benefits of these practices in maintaining soil quality.

Keywords: soil health; farming practices; conservation agriculture; no till; yield; soil physical; chemical and biological properties

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1. Introduction

Soil health is a crucial component of agricultural sustainability and environmental management. It encompasses the physical, chemical, and biological properties that enable soil to function effectively as a vital living ecosystem [1]. This complex interplay of soil attributes supports plant growth, regulates water, filters pollutants, and cycles nutrients, all of which are essential for maintaining productive and resilient agricultural systems [2,3]. The concept of soil health extends beyond traditional measures of soil fertility, embracing a holistic view that recognizes the importance of soil biodiversity, organic matter content, and structural integrity [4]. Maintaining soil fertility has become a significant concern in today's world [5]. In recent years, the importance of soil health has gained growing attention from researchers, farmers, and policymakers alike [6]. The increase in interest comes from a rising understanding of soil's vital role in tackling major global issues, such as food security, climate change, and ecosystem degradation [7–9]. The literature shows that the productivity of soil per hectare is very low and constantly decreasing due to unsuitable agricultural practices [6]. It is simplest to care for our soil resources by promoting and maintaining soil health to achieve sustainability. Healthy soils promote water retention and filtration, lower greenhouse gas emissions, increase agricultural yields, and improve the nutritional value of the soil [10]. According to FAO and Smith et al. [11,12], many of the global pressures on agricultural lands are caused by human activity. Examples include erosion, changing land uses, and climate change. Consequently, our current concern is how to manage our agricultural land most effectively in light of these societal issues [13,14]. Current agricultural practices rely heavily on inorganic fertilizers, tillage, and pesticides. Over the years, they have impaired biological activities in the soil and processes such as nutrient cycling, thus affecting nutrient availability in the soil to help farmers optimize agrochemical applications, thus moving from traditional practices (input intensive) to a more land-conservation-centric approach [15,16]. The impact of agricultural practices on soil is not determined by just one factor. Thus, it is critical to investigate all of the variables involved to have a better understanding of the impact of farmers' behaviors on soil health. Despite the large number of published studies on soil health, there is a continuing knowledge gap that prevents a thorough understanding and appropriate management strategies. Research emphasizes the need for accurate indicators to reflect soil health accurately [17]. Furthermore, soil health assessments frequently overlook several soil features [18]. Recently, the global focus on soil health has intensified due to its critical role in sustainable agriculture. By assessing soil health indicators, we gain insights into the underlying processes that contribute to productive and resilient crop systems. Adopting any new technology poses challenges for the adoptee. These challenges increase for innovations with preventative advantages and long-term implications, as is frequently the case with soil health and farming practices [19]. People evaluate innovations depending on their own needs and capabilities, confounding the hunt for relevant soil health indicators [20–22]. Farmers typically need to put in a lot of work, receive concrete incentives, and have the support of local and national governments and public-private partnerships to implement these sustainable techniques [23]. In this review, we investigate and discuss changes in the adoption of farmer practices measures as a sustainable system, with an emphasis on their effects on soil health and their role in supporting appropriate land management while promoting food security. Through a critical examination of recent findings and expert perspectives, we elaborate on the impact of soil management practices on soil health using selected soil indicators from the established literature database and investigate how novel methods and emerging technology might restore and protect soil health, resulting in a more resilient and sustainable agricultural environment for future generations. To achieve this, the following are undertaken:

- We review the literature on factors influencing soil health and how farmers adopt these practices.
- We provided an overview of how different management practices affect soil health and crop yield by evaluating soil biological indices, soil nutrient availability and chemical composition, and soil physical parameters.
- We evaluate how these practices have affected soil health, biodiversity, and yield and assess soil health that has a high possibility of adoption.
- We provide a concise summary of the main findings from the literature.

2. Concept of Soil Health

The terms "soil health" and "soil quality" are used frequently as soil gains more attention in the global policy field. However, it is currently unclear how the two ideas differ, and operational processes for measurement are still being developed [5,24]. This soil capability is referred to in terms of soil health and soil quality. Soil health and soil quality are frequently used synonymously. In actuality, it is difficult to distinguish the two concepts apart, as stated by Lal and Lehmann et al. [4,5]. In this context, Bünemann et al. [25] expressed the definition of soil quality as "the capacity of a soil to function within ecosystem and land-use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health." On the other hand, the ability of soil to function as a living system that supports plant, animal, and human life is referred to as soil health [26]. Others suggest that the notion of soil health goes beyond the conventional definition of soil quality and emphasizes the vital components and capacity for life [5,27]. In the 1990s, soil quality gave rise to the concept of soil health, which was first criticized [24,28]. More recently, the European Union proposed a Soil Monitoring and Resilience Law, aiming to establish a framework for soil health assessment and sustainable management practices by 2050 [29,30]. This shift is evident in various initiatives aimed at promoting soil health, reflecting a growing recognition of its importance for environmental sustainability and agricultural productivity. As the UNFCCC acknowledged soil carbon sequestration as a crucial tactic to lower atmospheric carbon dioxide, the significance of soil health in climate policy increased [31,32]. This initiative addresses the alarming statistic that 60–70% of European soils are unhealthy, emphasizing the need for comprehensive monitoring systems to evaluate soil health indicators across diverse regions [29]. Despite the growing support for soil health, challenges remain in implementing these practices universally, particularly in regions with entrenched agricultural methods. Addressing these challenges requires ongoing education and policy advocacy to ensure sustainable soil management practices, that incorporate the principles of soil health (Figure 1), are adopted globally [26].

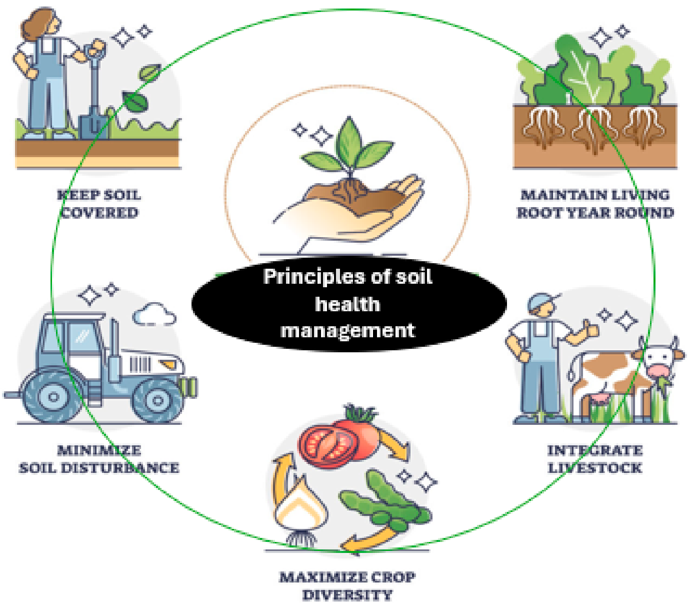

Figure 1. Principles of soil health recommended by USDA-NRCS.

Over the past decade, global interest in soil health has surged, with various government, non-government, and private sector groups working on developing monitoring and assessment protocols [33]. Soil health indicators measure changes in soil properties and functioning for sustainability [34]. Physical, chemical, and biological indicators are used to verify soil status and implement remedial management. Good indicators include bulk density, aggregate stability, and water-holding capacity. Chemical indicators like pH, EC, organic carbon, and nutrient status are established but have slower responses due to rapid changes in microbiological and biochemical properties [35]. Scientists and stakeholders aim to integrate soil health indicators into a single test score or soil health index, and developing such a complex score requires quantitative transformation and weighting [5].

3. Soil Health and Ecosystem Services

Life on Earth is made possible by the vital biological services that soil offers (Figure 2). Through agriculture, medicine, filtration of water, and the provision of essential building materials, soils support human life. Soils regulate climate through the soil carbon cycle [36]. Landscapes and a sense of location in our everyday lives are two ways that soils enhance culture [37]. Ecosystem services are closely linked to soil functioning [38–40]. Soil hosts a vast biodiversity pool comprising species, habitats, and genes critical to ecosystem resilience and stability, particularly under environmental stressors such as climate extremes [41,42]. The production of biomass, including that from forestry and agriculture, is directly facilitated by soils. Soil holds, filters, and regulates chemicals, water, and nutrients. In addition to functioning as stores of prehistoric and geological objects, soils also act as carbon sinks and sources of basic materials. The soil microbial community, for example, plays a pivotal role in maintaining these ecosystem services, as its structure directly influences carbon storage and nutrient cycling processes [43,44]. Soil is vital to human life because it provides and manages a range of ecosystem services [36]. Soil has several advantages, including freshwater, cleaner air, and increased crop production. It is also crucial for lowering poverty and mitigating climate change [45,46]. Soil also serves as a store of prehistoric artifacts and geological objects, adding value beyond ecosystem services. SOC levels in soils, shaped by factors such as plant cover and microbial biodiversity, are higher in younger soils, where ecosystem services strongly depend on soil biodiversity [47,48]. Soil biodiversity, particularly in microbial communities, helps mitigate drought effects on nutrient cycling, supporting plant growth and pathogen control [41]. This resilience is essential as desertification and climate change threaten soil health and ecosystem services [49,50]. Moreover, fertile island effects in desert ecosystems illustrate how specific plant species foster rich microbial communities under harsh conditions, boosting soil health through nutrient cycling [51,52]. In urban environments, soils offer unique ecosystem services by moderating heat, sequestering carbon, and facilitating water regulation, supporting the urban ecosystem's resilience and livability [45,53]. Additionally, soil fauna, including earthworms, arthropods, and nematodes, contribute significantly to nutrient cycling and organic matter decomposition, further reinforcing soil's ecosystem services [54].

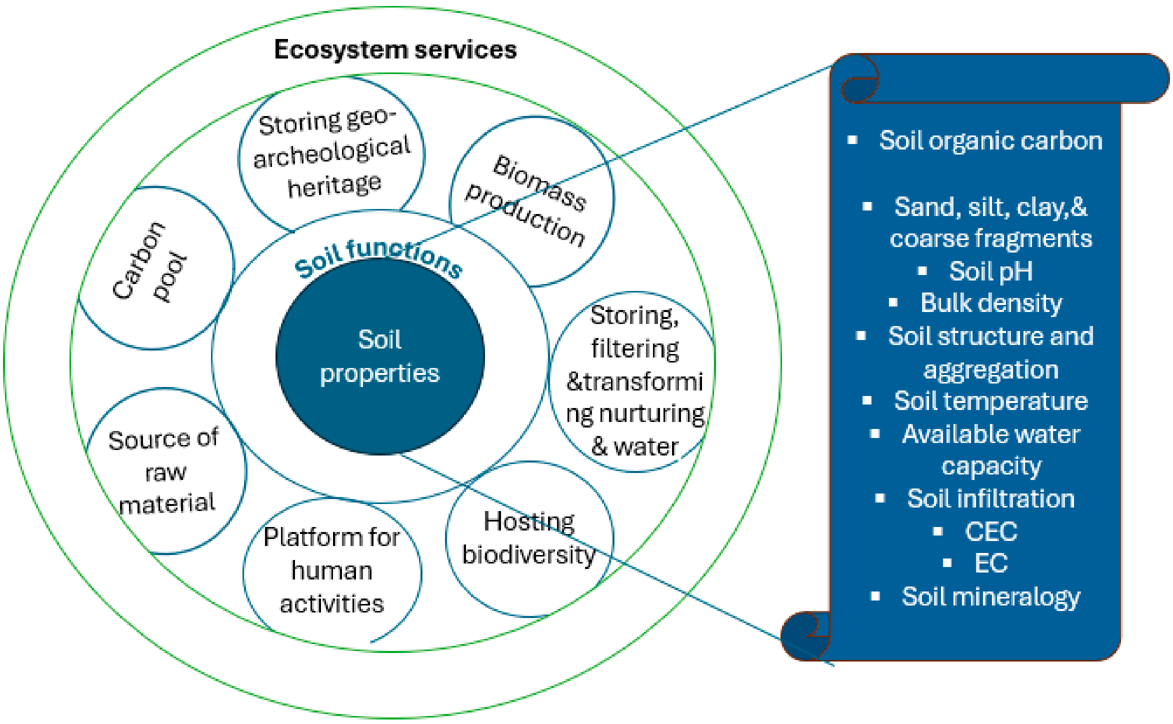

Figure 2. Linking soil health to ecosystem services.

Sustainable soil management within policy frameworks like the European Green Deal underscores the need for healthier soils to meet biodiversity, climate, and pollution targets, which emphasize reducing pesticide use and nutrient losses, as well as fostering organic farming [55]. Additionally, indigenous agricultural practices, such as the "Three Sisters" intercropping method, highlight the cultural and ecological value of traditional knowledge, supporting both soil health and community well-being [56]. Protecting soil biodiversity and managing soils sustainably are thus critical for ecosystem resilience, climate adaptation, and food security—addressing some of the world's most pressing issues [46,57]. These signify some of the most pressing issues facing the world today. The nature, amount, and standard of soil ecosystem services are determined by the same ecological factors that define the characteristics and functions of soil [58].

4. Overview of Global Farming Practices

Global farming practices are highly diverse and shaped by environmental culture and technological factors. Subsistence farming, common in Africa, Asia, and Latin America, relies on traditional methods such as crop rotation and manual labor, while commercial farming, predominant in North America, Europe, and Australia, utilizes large-scale monocropping, chemical fertilizers, and advanced machinery [59–62]. Intensive farming in densely populated areas like China and India employs multiple cropping and extensive irrigation, whereas extensive farming, found in Australia and parts of South America, involves large plots with minimal labor [63]. Muyombano and Espling [64] reported that subsistence farming is predominant in regions like Africa, Asia, and Latin America, where economic constraints and limited resources make it essential for food security. In Africa, over 80% of the rural population depends on subsistence farming, while large portions of Asia and Latin America also rely on smallholder farming [65,66]. In contrast, developed regions like North America, Europe, and Australia exhibit high mechanization rates, with advanced technologies enhancing efficiency and productivity. China presents a unique case, characterized by intensive farming and extensive irrigation, reflecting its focus on maximizing crop yields [66]. This global variation between subsistence-based and mechanized systems underscores the contrasting challenges and opportunities in agriculture across regions, highlighting the need for tailored approaches to sustainable productivity [14]. Organic farming is gaining popularity in Europe and North America, focusing on crop rotation and biological pest control, while agroforestry integrates trees into agricultural systems in tropical regions to enhance sustainability [67]. Traditional farming emphasizes environmental friendliness and soil health but is labor-intensive and less scalable, whereas modern techniques, utilizing genetic modification and advanced irrigation, offer high productivity but can lead to environmental degradation [60]. Geographic factors such as terrain and soil type, climatic conditions like temperature and rainfall, and socioeconomic factors, including economic development, land ownership, and labor availability, all influence farming practices. Balancing traditional and modern methods is crucial for sustainable agricultural development worldwide [60,68,69]. To enhance soil health, customizing or adapting farming practices to local conditions is often needed [70]. Nonetheless, a few general strategies are applied in every climate, soil type, or crop system [71]. In general, a few crucial actions are the focus of various efforts that support soil health:

1. Minimize the possibility of erosion by using conservation measures that shield agricultural areas from precipitation and wind.
2. Cover the soil as much as possible all year or keep continuous living root systems.
3. Minimize compaction and mechanical cultivation.
4. Increase organic matter through natural methods while decreasing or eliminating synthetic fertilizer inputs.
5. Increase crop diversity.
6. Combine livestock with crops. For instance, graze, cover crops, or rotate them gradually.
7. Increase soil biodiversity by reducing or removing pesticides, particularly soil fumigants.

Each of these strategies requires its own book (and there are a few books on all of these topics).

Moreover, nearly all of these techniques are deeply related. Controlling erosion, raising soil organic matter, and sustaining live cover could all be managed with a single approach, such as cover cropping. Describing all of the conservation methods, crop management systems, and specialized technologies that can help improve soil health appears to be practically impossible. However, it is worthwhile to assess at least a few of the most established, well-understood, and easily available soil conservation measures.

5. Major Indicators for Soil Health Assessment

Soil health is crucial for sustainable agriculture and environmental well-being. To optimize soil health, we must manage its biophysicochemical properties effectively. The interactions among inherent and dynamic soil biological, physical, and chemical properties and processes are complex and must be quantified when assessing management effects on soil health. To facilitate such quantifications across land use and management practices, an interpretive framework that provides a wide range of regionally relevant indicator options is needed [18]. Many indices have been developed to evaluate soil health [72]. A widely used tool for assessing the Soil Quality Index (SQI) in agricultural soils is the Soil Management Assessment Framework (SMAF) [73]. These examples include SMAF, which converts measured values into unitless (0–1) scores [74] and integrates multiple biological, chemical, and physical soil health indicators. The SMAF employs integrative measures of ecosystem processes and functions, which are reflected in the SQI based on soil chemical, physical, and biological properties [75]. The SMAF is a three-step framework that assesses soil quality using chemical, physical, and biological indicators. It uses non-linear scoring curves to interpret 13 indicators and integrates them into an overall SQI to evaluate the soil's functioning rate compared with its potential capacity [76]. The SMAF is widely used around the world, while the conceptual framework for indication interpretation was developed using a small dataset. Another method, Comprehensive Assessment of Soil Health (CASH), assesses numerous soil health measurements using cumulative normal distributions of a regional dataset from the northeastern United States [18,25]. To promote science-based soil health evaluations, it is critical to create indexing systems that manage many soil properties and explain important soil health status for various soil types [25]. A new evaluation framework can be created using statistical methods (e.g., minimum dataset, principal component analysis, decision trees, and ANOVA), expert opinion, or expert-based frameworks [77]. To improve science-based soil health assessments, indexing tools should handle multiple soil attributes and describe soil health status for different types. These tools should represent chemical, biological, and physical processes, detect variations in soil functions due to management, be assessable and cost-effective, and reflect the connection between soil functions and management targets. Table 1 presents the leading indications of all three categories.

Soil physicochemical characteristics are important for plant growth and ecosystem health. These characteristics include soil texture, structure, pH, organic matter content, nutrient levels, and microbial activity [78–80]. They influence factors like root penetration, moisture retention, nutrient availability, and soil aeration, all of which are essential for plant development. Furthermore, these qualities have an impact on the soil's overall performance, including its ability to sustain biological productivity, preserve environmental quality, and promote plant and animal health [81]. Understanding and regulating these physicochemical features can help improve soil health, promote sustainable agriculture, and maintain ecological equilibrium. Soil health evaluation integrates physical, chemical, and biological factors, each uniquely impacting overall soil quality. Among these, soil organic carbon (SOC) is especially influential, as it enhances nutrient cycling, microbial activity and, ultimately, crop productivity [18,73]. Physical properties like soil texture, structure, bulk density, and porosity affect water retention, aeration, and root growth, all of which are crucial for plant health [73]. Chemically, nutrient availability—particularly phosphorus and zinc—is essential, with levels dependent on soil management practices [82]. Biological indicators, including soil respiration and microbial counts, reflect biological vitality and the soil's capacity to support plant life [83]. Although SOC is pivotal, maintaining a balanced interaction among all these factors is vital for sustainable soil health, as focusing too heavily on one aspect may lead to unintended degradation in others.

Table 1. Soil biophysicochemical properties and leading indicators of all three categories.

Physical	Chemical	Biological
Soil texture	Soil organic carbon	Enzymatic activity
Soil structure	Soil pH	Mineralization
Soil water characteristics	CEC	Nitrification
Soil depth	Plant nutrients	Nitrogen Fixation
Porosity	Bas saturation	Denitrification
Soil consistency	Soil salinity	Carbon cycle
Water-holding capacity . . .etc.	etc.	Biodiversity
↑	↑	↑
Water Availability	**Nutrient Availability**	**Nutrient Cycling**

6. Main Effects of Farming Practice Management on Soil Health

Farming practice management significantly influences soil health, which is essential for sustainable agriculture and ecosystem balance [84]. Farming practices like conservation tillage, vermicomposting, crop diversification, and organic amendments positively impact soil health by enhancing nutrient cycling, reducing erosion, and improving resilience for sustainable agriculture [10]. Research on soil resilience highlighted that regenerative farming practices resulted in the highest sustainability scores and Soil Quality Index, emphasizing the importance of sustainable soil management practices in preserving soil health and productivity [85]. Directlyadding organic amendments to crop soils can improve soil quality by influencing numerous factors, including soil aeration, structure, drainage, moisture, water-holding capacity, nutrient availability, and microbial ecology. Additionally, different agricultural management practices impact soil nutrient levels and microbial community structure, with organic practices and appropriate fertilization positively influencing soil organic matter, nitrogen content, and microbial diversity [86]. Sustainable soil management practices are essential for addressing soil health issues and ensuring long-term agricultural viability [5]. Soil organic matter (SOM) is a key factor in maintaining soil health, particularly because it acts as a significant reservoir of carbon, containing more organic carbon than global vegetation and the atmosphere combined. This carbon pool is essential for regulating greenhouse gas emissions and soil nutrient retention [87,88]. Additionally, organic matter supports nutrient exchange and pollutant retention, improving plant growth and safeguarding water quality [88]. Microbial diversity and biomass, influenced by soil carbon content, are critical regulators of ecosystem functions. Soil microbial diversity-to-biomass ratios vary significantly across global biomes, with arid environments displaying high diversity-to-biomass ratios, while carbon-rich environments often exhibit lower ratios due to competitive exclusion [89]. Changes in microbial diversity and biomass, driven by land use and climate factors, can lead to shifts in soil function and resilience. Sustainable practices such as cover cropping, crop rotation, no-till systems, and organic amendments maintain higher levels of microbial diversity, which contributes to enhanced nutrient cycling and soil structure stability.

To improve soil health, farmers should adopt various sustainable agricultural practices, such as conservation tillage, composting, crop diversification, crop residue management, organic amendments, fertilizer management, irrigation management, naturally occurring mineral amendments, effective microorganisms, and the use of biopesticides (Figure 3) [84].

Adopting beneficial management practices (BMPs) like cover crops, crop rotations, no till, soil testing, conservation buffers, and organic amendments is crucial for enhancing soil health and resilience on farms [90,91]. Farmers should also focus on engaging in soil health management practices that target both biotic and abiotic components of soils, using multiple strategies in tandem to promote soil health effectively [92]. Furthermore, incorporating balanced fertilization, organic matter incorporation, crop rotation, cover cropping, reduced tillage, and precision nutrient delivery are essential practices for sustainable soil management to address issues like nutrient deficits, soil degradation, and erosion, ensuring the long-term viability of agriculture [1].

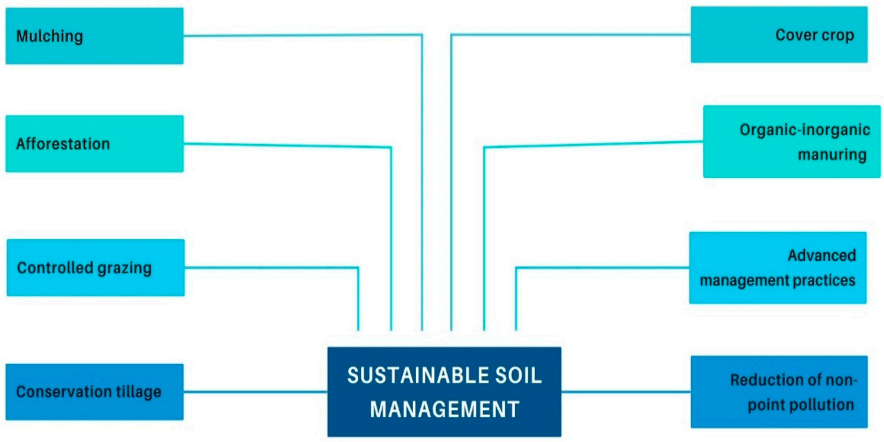

Figure 3. Soil management techniques or control measures for sustainable agriculture.

6.1. Sustainable Practice and Soil Health

Ideal soil health and production are dependent on having optimal physical and chemical soil qualities, which in turn lead to optimal biological soil properties [93]. The chemical, biological, and physical properties of soil that contribute to its ideal functions—such as effective filtration, soil structure, nutrients, and water cycling—are evaluated using soil health indicators (Figure 4). To optimize soil health and production, site-specific management techniques and management strategies aimed at enhancing soil attributes might be based on indicators of soil health.

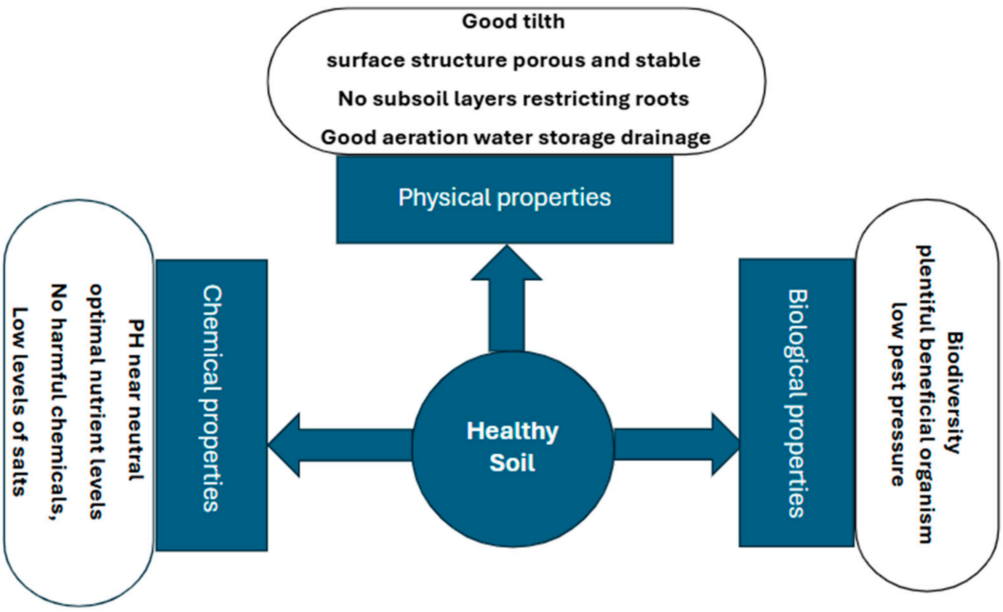

Figure 4. Optimal physical, biological, and chemical properties promote soil health.

6.1.1. Tillage Systems

Tillage has a significant impact on soil health by changing critical physical, chemical, and biological elements that affect soil function and crop productivity (Table 2). Strategic tillage, as discussed in various studies [94–96], offers a targeted approach to address specific soil constraints while minimizing overall soil disturbance. Different tillage systems, such as conventional tillage, no-till, deep tillage, and vertical tillage, have varying effects on soil properties like soil organic carbon content, bulk density, soil moisture, and microbial activity. The choice of tillage method can significantly affect soil health indicators, crop productivity, and nutrient availability [97]. Implementing conservation tillage practices, like zero tillage and cover cropping, can help maintain soil structure, enhance soil biological activity, increase carbon storage, and improve overall soil health for sustainable agricultural production and environmental protection [98]. Soil tillage practices have significant effects on soil structure and soil health. Different tillage methods, such as conventional tillage and zero tillage, impact soil properties like structure, aeration, water utilization, and microbial biodiversity, ultimately influencing soil fertility and crop production [99]. Long-term studies on tillage practices like conventional tillage, minimum tillage, and no tillage show that conservation tillage practices, particularly no tillage or (no till), enhance overall soil quality by increasing soil organic carbon content and improving physical and biological indicators like available soil water, porosity, and coarse pores [95]. The studies reviewed provide evidence that supports an increase in soil texture, aggregate stability, and water retention with reduced tillage and no-tillage practices [100,101]. Research conducted in Manitoba, Canada, demonstrated that no-till and reduced tillage systems positively impacted soil properties, such as bulk density, porosity, and water storage capacities [102]. Permanganate oxidizable carbon (POXC) and wet aggregate stability (WAS) are highly impacted by soil management strategies, according to a Texas A&M Research Farm study. No-tillage systems show greater values of POXC and WAS than conventional tillage systems [103]. Furthermore, a study in Brazil highlighted that no-tillage systems had lower degrees of compaction, higher air capacity, and better water retention characteristics, emphasizing the benefits of reduced soil disturbance for soil quality improvement [104,105]. These findings collectively support the notion that reduced tillage and no-tillage practices can enhance soil texture, aggregate stability, and water retention [101].

A more thorough understanding of how conservation tillage affects the chemical properties of soil (pH, metal cations, nutrient elements, and organic matter) is required to accomplish both environmentally friendly protection and sustainable agricultural expansion. The content of organic matter and organic carbon, nutritional components, and other soil chemical properties can all be markedly increased by conservation tillage and straw stubble covering [106]. Conversely, conventional tillage often leads to unsustainable agricultural productivity, environmental degradation, depletion of soil nutrients, and significant losses of soil and water [21]. Conservation tillage methods, however, can enhance soil nutrient content and adaptability to environmental fluctuations [107]. Conservation tillage techniques, particularly no till, have the potential to improve soil fertility since they preserve the soil structure [108]. Numerous studies have demonstrated how conservation tillage impacts the number and activity of microorganisms [97,109]. No-till farming improved the population and diversity of genomic patterns of the N2 fixing Bradyhizobium in Southern Brazil compared with traditional tillage [105,110]. Mathew et al. [109] observed that bacterial diversity increased in zero tillage conditions compared with conventional tillage. According to Babu et al. [7], soils under conservation agriculture have more superficial layers with greater levels of organic matter content, microbial biomass C, microbial biomass N, and enzyme activities than soils under conventional tillage [111]. The results of several studies are summarized in the table below, which shows the varied effects of different tillage practices on soil health. While conventional tillage can negatively affect soil structure and health over time, studies suggest that conservation and reduced tillage practices often improve soil health indices.

Table 2. Effect of different tillage systems on soil properties: Summary of Recent Global Studies.

Soil Properties Affected	Tillage System	Effect Size	References
Soil organic carbon (SOC)	Conventional tillage	SOC decreased by 20–22%	[7,96]
	Reduced tillage	SOC increased by 12–28%	[95,99]
	No tillage	SOC increased by 35%	[95]
Bulk density (BD)	Conventional tillage	Reduced BD by 6.4%	[1,94]
	Reduced tillage	Increased BD by 13%	[94,102]
	No tillage	Reduced BD by 7–10% compared with CT	[94,102]
Soil erosion	Conventional tillage	Increased erosion by 70% compared with no till	[100]
	Reduced tillage	Reduced soil erosion soil aggregation	[108]
	No tillage	Reduced erosion by 40% compared with CT	[100]
Soil biodiversity	Conventional tillage	Decreased microbial biomass by 10–15%	[109]
	Reduced tillage		
	No tillage	Enhanced microbial diversity by 15–25%	[8,102]

6.1.2. Role of Cover Crops

Cover crop management may improve soil physical, chemical, and biological properties. The benefits can include greater amounts of available soil nutrients and soil organic carbon; decreased soil compaction and increased aggregation; and improved microbial diversity, abundance, and activity (Table 3). Many studies have used soil-quality indices to evaluate the effects of tillage practices and cover crops on soil quality [112–114]. Soil bulk density and soil water penetration are significantly affected by cover crops. Cover crops have been shown in studies to reduce bulk density by 17%, which improves soil water infiltration [115]. In addition, adding cover crops can improve soil water storage capacity by raising soil water content at different soil water pressures, such as 0–33, −33, and −100 kPa, by 23%, 25%, and 28%, respectively, as compared with no cover crop management [115,116]. Furthermore, in the 0–45 cm soil profile, the presence of cover crops can improve soil water retention at wheat sowing by about 1~4%, improving soil water availability for the following crops [117]. These results underline the value of cover crop practices in sustainable soil management strategies by demonstrating its beneficial effects on improved soil water infiltration and a decrease in soil bulk density. The preservation of soil from erosion is the most evident advantage of cover crops. Increased soil organic matter, weed reduction, and nutrient retention are further advantages. Furthermore, through enhancing soil aggregation and moisture conditions, cover crops can change the habitat of living things in the soil [118]. Several chemical properties of soil, including pH, cation exchange capacity, soil organic carbon or organic matter, nutrient concentrations (particularly nitrogen and phosphorus), and electrical conductivity, are affected by the management of cover crops. Various research has explored the influence of cover crops on the soil's C/N ratio as a measure of soil health and fertility [119]. Furthermore, cover crops have been studied for their ability to help mitigate the effects of climate change and global warming by keeping and fixing atmospheric carbon [120] and nitrogen, as well as reducing CO_2 and N_2O emissions to the atmosphere [121]. Nevertheless, most of these cover-crop-induced changes in the chemical properties of the soil are limited to the upper soil surface. The biological properties of soil are highly dynamic, and a number of studies investigated how cover crops might affect the diversity, activity, and abundance of soil organisms like nematodes, earthworms, bacteria, fungi, and protozoa [122,123]. Soil microbial activity has been connected to soil health, since fungal hyphae and bacterial extracellular polysaccharides and hydrophobic substances may lead to enhanced aggregation and nutrient cycling. Soil microbial activity, including fungal hyphae, bacterial polysaccharides, and hydrophobic substances, can increase aggregation, nutrient cycling, and overall soil health [25,124].

Table 3. The effects of different cover crops on soil properties based on the literature.

Cover Crop	Effect on Soil Properties	Reference
Leguminous Crops	Increased nitrogen content improved soil structure and moisture retention	[71,113,125]
Rye	Enhanced soil organic matter, reduced soil erosion, improved water infiltration	[116,118]
Oats	Enhanced soil fertility, increased soil porosity, reduced weed pressure	[115]
Vetch	Significant nitrogen fixation, improved soil structure, increased earthworm activity, improves soil water infiltration	[112,117]
Mixed Cover	Synergistic effects include increased biodiversity and resilience to stresses	[113,117]
Radish	Biodrilling; improvements in soil aeration; increased nutrient uptake	[123,124]
Winter wheat	Enhanced soil health parameters in surface soils	[126]

6.1.3. Role of Crop Rotation

Crop rotation has long been recognized as a useful strategy for maintaining the biodiversity of agroecosystems by improving soil health and preventing pest and disease outbreaks [127]. Many factors affect the value and effectiveness of crop rotations, such as the types of crops used, the length of the rotation, the agronomic history of the farmland, the frequency and series of applications of specific crops, and the properties of the soil [128,129]. Crop rotation is an important factor in determining the physical properties of soil. According to the research of [130], soil bulk densities can change depending on crop rotation and fertilizer levels; long-term fertilization encourages root development and decompaction of the soil, and [15] demonstrated that crop rotation patterns significantly affect soil physicochemical properties, enzyme activities, microbial biomass, and microbial communities, with rotations involving garlic and ryegrass showing distinct modifications to soil properties and microbial compositions. Moreover, a meta-analysis conducted by [131,132] highlighted the advantages of varied rotations for soil physical health and system resilience. It showed that greater crop diversity in rotations decreased bulk density, improved soil aggregation, improved porosity, and saturated hydraulic conductivity. The integration of cover crop mixtures, such as cereal–legume combinations, has also been found to boost weed suppression and improve overall crop resilience through added functional diversity [133]. Therefore, variations in crop rotation between conventional and conservation agricultural systems may also have an effect on soil organic carbon (SOC) levels. Increasing the quantity of residue returned to the soil through plant species rotations and the removal of monocultures are frequently linked to higher SOC stocks in conservation agricultural systems [134]. In certain systems, it has been found that root input is particularly significant. For instance, in a study on a Brazilian Ferrosol, the long-term (17 years) contribution of forage-based NT rotations or cover crops to SOC stocks was found to have a strong correlation with the inclusion of various plant species' roots [135]. Moreover, undersowing diverse cover crops within crop rotations can improve nutrient retention and reduce soil nutrient losses, highlighting the benefit of functional diversity in crop rotations [136]. Additionally, recent studies have shown that intraspecific diversity within crop rotations, such as with wheat varieties, may influence soil nutrient cycling without negatively affecting overall crop productivity, contributing to enhanced ecosystem resilience [137]. Another study in Anhui, China, utilized Fourier transformations and in situ measurements to simulate crop rotation effects, revealing high accuracy in estimating organic carbon in topsoil [138]. Cover crops used in rotation not only improve soil structure but also help regulate the nematode community, promoting beneficial free-living nematodes while suppressing parasitic species [139]. Furthermore, crop rotations that incorporate cover crops can optimize multifunctionality in dryland systems, enhancing soil nutrient cycling, soil water conservation, and weed suppression in comparison to fallow periods [140]. Companion planting and diverse cover crops also foster beneficial microbial interactions and soil enzyme activity, further supporting crop health in continuous cropping systems [141].

6.1.4. Mulching Management

Mulch can be made from a wide range of materials and is generally categorized into two main types: organic mulch (such as straw, crop residues, forest residues, wood chips, pine bark, branches, leaves, litter, dry grass, and hydro-mulch) and inorganic mulch (such as rock fragments, gravel, stones, pebbles, volcanic ash, plastic film, cinder, and other inorganic synthetics). It can improve soil health by retaining moisture, regulating temperature, suppressing weeds, preventing erosion, increasing fertility and plant nutrition, and preventing pests and diseases [142]. Traditionally, the most frequently used mulch materials for soil and water conservation are straw mulch, wood-based mulch, and rock fragments [143,144]. Mulching increases the hydraulic roughness of soil surfaces and entraps more water, which decreases surface water flow and transport capacity [145,146]. For instance, Kachala grass and sludge pellet mulch improve soil moisture retention, organic matter content, nutrient availability, enzyme activity, and temperature, respectively. The choice of mulch thickness also impacts soil quality. Recent studies have further demonstrated the multifaceted benefits of mulching. For instance, live mulch-based conservation tillage significantly improves soil properties and boosts productivity, as shown in maize systems in the Indian Himalayas. This practice not only reduced bulk density but also increased water-holding capacity and nitrogen availability, promoting a favorable soil environment for maize growth [147]. Another study on the effect of straw mulching on cotton production emphasized its role in enhancing soil moisture and nutrient retention, especially during dry years, ultimately promoting greater crop yields [148]. Furthermore, in semi-arid regions of Pakistan, black plastic mulch was shown to enhance wheat growth by improving water retention, photosynthetic rate, and leaf turgor potential under partial root-zone drying irrigation [149]. Straw mulching has also shown efficacy in improving soil moisture conservation and nutrient cycling. A study in Liaoning, China, demonstrated that straw mulching combined with autumn mulching significantly enhanced water-use efficiency and yield in spring maize, especially in semi-arid conditions [150]. Similar findings were noted in semi-arid regions of India, where residue mulching in zero-tillage systems buffered soil temperatures and reduced moisture stress, thus enhancing crop growth and minimizing energy inputs in the pigeon pea-wheat cropping system [151]. Additionally, studies have noted that different straw-returning practices, such as biochar application and surface straw covering, increase soil organic carbon, available phosphorus, and potassium levels, further contributing to crop health and soil sustainability [152]. In rice paddy systems, different rates of straw return significantly impacted soil structure, organic carbon content, and crop productivity, with partial straw incorporation proving effective in enhancing soil fertility while minimizing the risk of nutrient runoff [153]. Collectively, these findings underscore the value of strategic mulching and straw return techniques in diverse agroecosystems to sustain soil health and crop productivity.

6.1.5. Organic Amendments

An effective method of restoring soil organic matter content and enhancing soil quality is the practice of applying organic amendments to crop soils [18,154]. In fact, organic amendments of various compositions and origins (such as sewage sludge, compost, manure, animal slurry, etc.) can boost the soil's organic matter content and provide important nutrients, both of which are beneficial to soil health [10,155]. Organic matter inputs impact soil physicochemical properties, microbiota, microbial biomass, diversity, community structure, and activities, affecting crop production and plant health [6,16,72]. Organic farming uses livestock manure, natural plant residues, and diverse plant species to close nutrient cycles, minimizing external inputs and promoting soil fertilization. Its advantages include improved soil health and reduced environmental impact, leading to widespread adoption in Europe. Organic practices focus on enhancing biodiversity and sustainable practices [10]. Organic nutrient sources like green manures, sewage sludge, press mud, farmyard manure, and poultry litter promote soil health, reduce chemical dependency, and create an economically, environmentally, and socially sustainable agricultural system [69]. For instance, crop residues and green manures are excellent plant-based SOM sources, offering erosion control, weed suppression, and fertility enhancement [156]. Additionally, animal manure provides essential nutrients, enhances soil structure, and supports microbial health [157]. Biosolids from wastewater treatment offer nutrient-rich additions for soil fertility and carbon sequestration [158]. Studies have shown that organic amendments, such as farmyard manure and municipal solid waste compost, significantly improve soil organic carbon (SOC), nutrient retention, and crop productivity, particularly in nutrient-poor soils [159]. In dryland Mediterranean agriculture, composted sewage sludge and pig slurry have been effective in increasing nutrient availability without excessive nitrate buildup, which is critical in semi-arid conditions [160]. In Afghanistan, a combined organic and chemical fertilization approach has been shown to increase soil carbon, nitrogen, and active carbon, ultimately enhancing soil quality and long-term fertility [161]. For arid regions, composted organic waste and farmyard manure have been found to improve soil water retention and aggregate stability, which are essential for sustainable crop production [159]. One study highlighted the impact of organic amendments on saline–sodic soils, where organic materials like lignite humic acids and crop residue incorporation improved soil microbial diversity, soil pH, and nutrient availability, ultimately increasing crop yields [162]. Compost, produced from organic waste, enhances soil aeration, water retention, and microbial activity. In semi-arid vineyard ecosystems, organic amendments such as compost and manure were found to increase soil fertility and grape yield while simultaneously mitigating greenhouse gas emissions, particularly when applied in drip-irrigated systems [163]. Anaerobic digestion of organic waste yields digestates, which are useful as fertilizers, while also reducing pathogens and pollutants [164]. A meta-analysis has also revealed the differential greenhouse gas (GHG) emissions associated with various manure types, with poultry manure having a higher global warming potential due to increased CO_2, CH_4, and N_2O emissions compared with pig and cattle manure [165,166]. Organic amendments, such as manure and straw, are effective in sequestering SOC, with manure showing higher SOC increases in nitrogen-deficient soils, while straw is more effective in nitrogen-enriched soils [160]. These findings emphasize the importance of tailored amendment strategies that consider soil nutrient status for optimal soil carbon sequestration. Nonetheless, in many cases, organic amendments may contribute to the accumulation of contaminants in the soil, potentially leading to toxicity issues [155]. To mitigate these risks, incorporating stabilized organic materials, like mature compost, has been shown to reduce nitrogen and phosphorus runoff, thereby enhancing nutrient retention and reducing environmental impacts [156]. The benefits of organic amendments are clear, though careful management is required to maximize soil health outcomes and mitigate possible negative effects.

6.1.6. Role of Fertilizer Application

The type of fertilizer applied significantly impacts soil physical properties, which in turn influences overall soil health. Organic fertilizers enhance soil organic carbon (OC) levels, leading to improved nutrient availability and better soil structure (Table 4). This increase in OC is associated with a notable rise in aggregate stability (AS) and a decrease in soil bulk density (BD), which together enhance soil porosity and aeration, crucial for root development and microbial activity [167]. Moreover, the application of organic fertilizers has been shown to improve soil physical quality, as indicated by a higher Dexter index, reflecting better conditions for plant growth [16,168]. These changes also affect the soil's ability to retain moisture, as evidenced by variations in available water content (AWC) between different fertilization treatments [169]. Recent studies have highlighted that biobased mineral fertilizers (BBMFs) from organic waste are promising alternatives to conventional mineral fertilizers, supporting soil health through similar biomass productivity in crops like maize, without significantly altering soil microbiome composition [170,171]. BBMFs promote beneficial plant-growth-promoting bacteria, contributing to nutrient cycling and soil structure maintenance, which are essential for long-term soil productivity [172]. Additionally, integrated fertilizer approaches that combine organic, biological, and mineral fertilizers have shown positive effects on crop yield and nutrient cycling in soils, enhancing both bacterial and fungal community interactions [173]. In forest plantations, the use of organic and microbial fertilizers has been shown to enrich rhizosphere microbial diversity, particularly favoring bacteria over fungi. This diversity contributes to improved nutrient cycling and stress resistance within the soil, which is essential for maintaining healthy forest soils [174]. Furthermore, the combined use of organic and inorganic fertilizers enhances microbial interactions and modifies key taxa in the rhizosphere, facilitating efficient nutrient uptake and improved soil properties [175]. Similarly, fertilization in arugula cultivation with a mix of biological, inorganic, and organic fertilizers leads to increased yield and beneficial shifts in soil microbiota, underscoring the importance of integrated fertilization strategies for optimizing plant health and productivity [176].

The cumulative effect of these improvements leads to reduced erosion, enhanced water retention, and overall healthier soil ecosystems, demonstrating the critical role of fertilizer type in sustainable soil management practices. Thus, the strategic use of organic fertilizers not only bolsters soil physical properties but also fosters long-term soil health and productivity. Additionally, research on phosphorus fertilization in crops like oilseed flax has shown that moderate P levels improve plant growth and soil microbial health, highlighting the importance of tailored fertilization to balance crop needs and soil microbiota sustainability [177]. While mineral and organic fertilizers both have unique benefits, biobased and integrated approaches hold potential for aligning productivity with environmental sustainability, reducing reliance on non-renewable resources [178].

Long-term studies on nitrogen fertilization reveal that high N levels without proper management can lead to soil acidification, reduced aggregate stability, and potentially harmful environmental impacts, especially in fine-textured soils with shallow groundwater [179]. For instance, ammonium-based fertilizers were associated with increased microaggregate formation but reduced stability in larger aggregates, while lime co-application counteracted the acidifying effects, thereby restoring macro-aggregation and enhancing carbon storage in stable soil fractions [180]. Another study showed that the effects of fertilization on soil microbial communities outweigh those of crop rotation, with composted manure increasing bacterial diversity and resilience in agroecosystems compared with synthetic NPK or straw-based amendments [181].

Furthermore, integrated N management in grasslands has demonstrated an increase in SOC sequestration when organic amendments are combined with synthetic N, promoting long-term carbon storage within soil aggregates [182]. Long-term monitoring also revealed the benefits of optimizing N application rates and timings to minimize nitrate leaching, thereby mitigating potential groundwater contamination risks associated with intensive fertilization [183].

Table 4. Comparison between inorganic and organic fertilizer.

Basic	Organic	Inorganic
Meaning	It is a natural material derived from decaying plant and animal waste that can be applied to the soil to improve its fertility	It is a chemical or man-made material that can be put to soil to increase productivity and improve fertility
Preparation	Prepared in fields	Factory-produced materials
Humus	It supplies the soil with humus	It does not provide the soil with humus
Nutrients	Plant nutrients are quite limited	Reich in plant nutrients
Side effect	It does not have any adverse impacts and, in fact, makes the soil better physically	It harms organisms, distorts the ecosystem of the land, and contaminates groundwater
Safety	Safe	Harmful
Cost	Cost effective	Expensive
Example	Compost, green manure, biochar	Nitrogen fertilizers, phosphorous fertilizers, potassium fertilizers, sulfur, calcium, and magnesium fertilizers, and micronutrient fertilizers

6.1.7. Agroforestry System

Agroforestry is a multipurpose practice in which trees and shrubs are purposefully incorporated with crops or cattle as part of our food chain. Agroforestry is a sustainable farming method that has been recognized for around 50 years [184]. The idea of integrating trees into the agricultural landscape dates back to the beginning of land cultivation. Agroforestry has been shown to have numerous benefits. These include mitigating nutrient and pesticide runoff, storing carbon, improving soil quality, controlling erosion, improving wildlife habitat, reducing fossil fuel consumption, and promoting resilience in the context of an unpredictable agricultural future [185]. The addition of organic matter from tree litter and pruning further aids in restoring soil fertility, creating a more robust ecosystem for plant growth [186]. Moreover, the presence of nitrogen-fixing trees and shrubs in agroforestry systems enhances nitrogen inputs, which is crucial for improving soil fertility. For instance, species like Leucaena leucocephala can fix substantial amounts of nitrogen, contributing to the overall nutrient availability in the soil [187]. This combination of practices not only supports the health of the soil but also promotes biodiversity and resilience in agricultural landscapes, making agroforestry a vital strategy for sustainable land management [188]. Through these interconnected processes, agroforestry emerges as a powerful tool for enhancing soil health and agricultural productivity. The primary source of nutrients and organic carbon (OC) in agroforestry systems is the buildup of litter from the shedding of leaves and twigs (Figure 5). Both directly and indirectly, soil organic carbon (SOC) affects how efficiently nutrients are used in agriculture. Since soil with a high organic matter content and an active deep root system will absorb and make more nutrients available, the efficiency of using those nutrients will be improved. Furthermore, mycorrhizae are likely provided by the enhanced microbial diversity brought about by the addition of OM, which releases P and makes it available to crops [189]. Despite its many positive effects on the environment and the economy, agroforestry has several significant challenges that impact its adoption and effectiveness. One key challenge is resource competition, as trees in agroforestry systems may compete with crops for critical resources such as light, water, and nutrients [187,189]. This competition can negatively affect crop yields, thereby reducing agricultural productivity, especially in regions with limited resource availability [24]. Another significant challenge is the management complexity inherent in agroforestry practices. Implementing effective agroforestry systems often requires specialized knowledge and skills, such as understanding tree–crop interactions, selecting appropriate species, and managing soil health. This complexity can act as a considerable barrier for farmers, particularly those without access to the necessary training or resources, complicating widespread adoption.

6.2. Impact on Yield, Yield Stability, and Farm Profitability

Yield production is closely linked to soil health, as healthy soil is fundamental for sustaining agricultural productivity. Implementing soil health principles, such as maintaining soil cover, minimizing disturbance, and maximizing living roots, can significantly enhance soil quality and, consequently, crop yields [190]. Regular soil health assessments using various tools can help farmers identify specific areas needing improvement, ensuring that management practices are effectively tailored to local conditions [191]. One critical aspect of soil health is soil organic matter (SOM), which consists of decomposed plant and animal residues. SOM improves soil structure, enhances water retention, and increases nutrient availability, all of which are vital for optimal crop growth [192]. Additionally, soil aggregate stability plays a crucial role in preventing erosion and maintaining soil structure, further supporting yield production [193]. Moreover, soil microbial activity is essential for nutrient cycling, as microorganisms break down organic matter and release nutrients that plants can absorb [10,194]. By fostering a diverse and active microbial community, farmers can create a resilient soil ecosystem that supports higher yields and sustainable agricultural practices. Thus, improving soil health through these interconnected strategies is key to enhancing yield production.

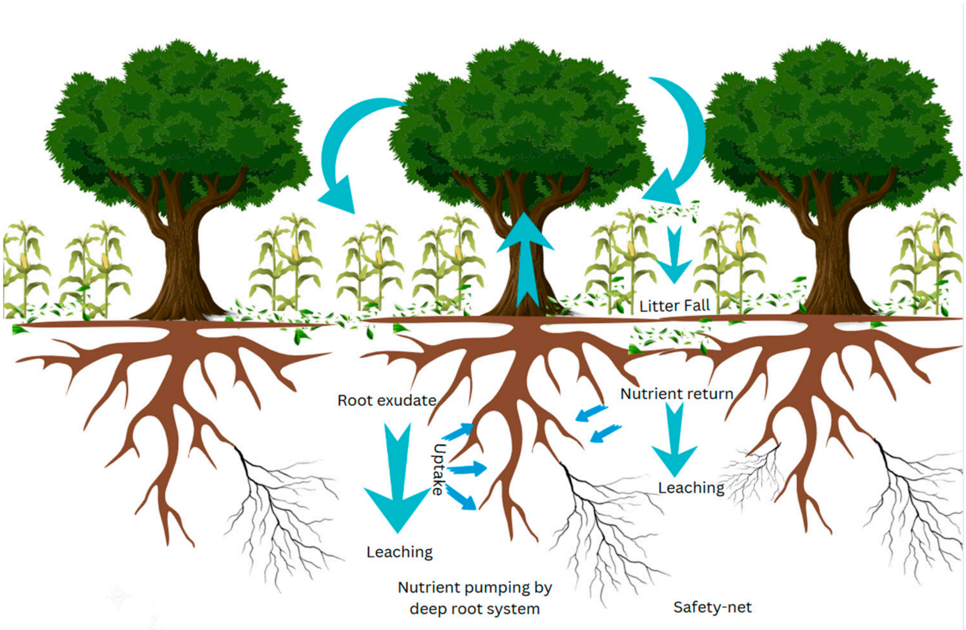

Figure 5. Pumping and cycling of nutrients through the building of a "safety net" by enhancing organic matter inputs, accessing deep soil nutrients, and improving soil structure, through carful management is required to balance resource competition in agroforestry system, by [189].

7. Yield Stability

How do farming practices influence the stability and resilience of annual crop yield across years? Results from a meta-analysis reveal that yield stability across NT and CT fields was similar, with some indication of reduced stability for NT compared with tillage in humid versus dry climates [195]. Key to maintaining soil health are alterable properties such as soil organic matter content, root and microbial density, and microporosity, all of which can be managed to sustain high productivity [196]. Moreover, soil carbon (C) sequestration plays a significant role in improving soil health and is recognized as a cost-effective method to offset emissions, further contributing to yield stability [87,195]. The management practices that favor carbon sequestration, such as no-till farming and the incorporation of organic amendments, not only enhance soil quality but also mitigate the adverse effects of climate change on food security [87]. Ultimately, maintaining biological diversity and activity within the soil is crucial for enhancing these alterable properties, which in turn supports overall soil health and yield stability [196]. Thus, a holistic approach to soil management is essential for sustainable agricultural productivity. The advantages of soil health practices, such as cover crops, for yield stability, may also not appear in certain systems until the medium to long term. According to some authors, "many of the ecosystem services that cover crops provide may improve resilience with positive feedback to yield stability, reduced external input requirements, and profitability" [113,197].

8. Knowledge Gaps

As part of this review paper, we conducted a thorough literature study and, as a result, found various knowledge gaps, which are shown graphically in (Figure 6) and addressed below. One of the most pressing areas is the dynamics of soil organic carbon (SOC). While research has shown that conservation tillage and crop rotation positively influence SOC levels, the specific mechanisms that drive SOC loss or accumulation are still not well understood. Further studies are needed to elucidate how different land management practices, such as varying tillage systems and cropping intensities, can optimize carbon sequestration while maintaining or improving soil fertility [198].

Another key gap relates to soil compaction. Agricultural activities can lead to compaction, which negatively impacts soil structure, water infiltration, and root growth. However, research on effective strategies to mitigate compaction and its long-term impact on soil health remains scarce. More empirical data are needed to assess how specific management practices, such as reduced tillage or the use of cover crops, can alleviate compaction issues without compromising agricultural productivity [198].

Soil salinity is another area in need of more research. Soil salinization, exacerbated by irrigation practices and poor land management, continues to affect agricultural productivity in many regions. Understanding how different crops and irrigation techniques influence salinity levels is crucial for developing sustainable solutions to this growing concern. More studies should focus on how specific management interventions can prevent or reverse salinization without harming the soil's overall health [199].

Lastly, the integration of soil data into land management remains a significant challenge. While numerous soil health indicators are available, their practical application in farm management decisions is often limited by a lack of clear, actionable guidance. Research into creating easy-to-use tools and frameworks for integrating soil health data into farming decisions would help bridge this gap, enabling farmers to manage soil health more effectively and sustainably [200].

However, due to the paucity of empirical research comparing the benefits of farming practices against soil health, this review paints a complicated picture to give an evidence base clearly outlining the benefits of each. A significant factor contributing to this complexity is the differential interactions of various tillage methods with soil health parameters such as organic matter content, microbial activity, and nutrient cycling. These interactions are not uniform and depend heavily on localized conditions, including soil type, climate, and cropping systems, which are further compounded by the lack of a globally agreed upon definition of soil health and soil quality, making the evaluation of the purported benefits challenging for researchers. Such information, as provided in this article, on a local or broader scale, can help identify areas with the greatest potential to enhance soil health, prioritize efforts, and invest resources effectively.

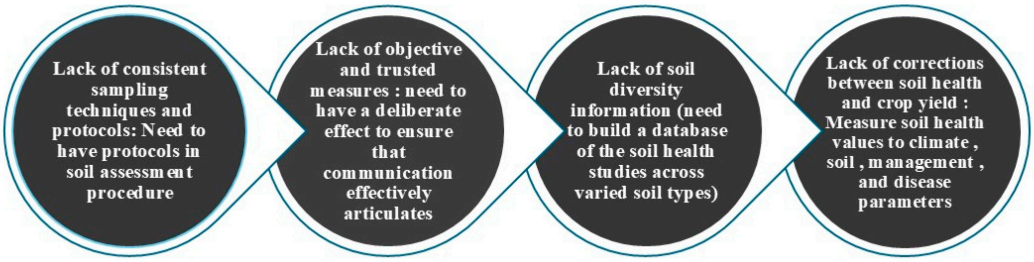

Figure 6. Knowledge gaps exist in our current understanding of soil health.

Moreover, soil health is influenced by numerous interconnected factors, such as microbial diversity, organic matter content, and nutrient cycling, which vary significantly across ecosystems, climates, and soil types. The role of tillage is especially complex, as different tillage methods influence these factors in distinct ways. For instance, conservation tillage may promote carbon sequestration and microbial activity, while conventional tillage may impact short-term nutrient availability. Understanding these differential effects is critical for optimizing practices in specific regions. This complexity further underscores the importance of localized data and region-specific evaluations, as the effectiveness of certain practices may differ depending on the unique characteristics of each area. By compiling and analyzing data on a local or broader scale, the information presented in this review can serve as a valuable tool for identifying regions with the highest potential for soil health enhancement. It can also aid in prioritizing soil conservation and restoration efforts, allowing stakeholders to allocate resources more strategically. Such insights can inform policy development, guide sustainable agricultural practices, and encourage targeted investments that address specific soil health needs, thereby supporting both agricultural productivity and environmental resilience in the long term.

9. Future Perspectives

Despite advancements, challenges remain, such as the need for improved methods to quantify soil health beyond chemical indicators, focusing on biodiversity and ecosystem services [5]. Addressing these challenges is crucial for achieving long-term soil health and agricultural sustainability. As research highlights, a multifaceted approach is essential for enhancing soil health, which is critical for agricultural productivity and ecosystem sustainability. The concept of soil health addresses a significant requirement for sustainable development among stakeholders by increasing awareness of the significance of soil in contemporary society. It has also grown into a compelling and effective audience for farmers, land managers, local governments, and leaders. Soil health is adaptable to various contexts, making it a valuable idea for stakeholders. In particular, communicating how different tillage methods interact with soil health and ecosystem services, such as water regulation and carbon sequestration, can help stakeholders tailor their practices to achieve specific goals. Soil health can be linked to broader sustainability goals and inspire innovative soil management, making it a widely accepted goal among the public.

Scientists are developing techniques to evaluate soil health, focusing mostly on agricultural productivity and neglecting biotic and abiotic diversity. Rather than viewing soil health as only a measurable attribute, researchers should embrace it as an underlying principle to which they may add information. This approach is particularly important when assessing tillage practices, as the varying effects of these methods on soil structure, microbial dynamics, and nutrient cycling can have long-term implications for sustainability. It takes cooperation from all parties concerned, especially a shared understanding between scientists and stakeholders, to allow the soil health concept to fulfill its potential as a unifying idea that links soil functions.

In conclusion, we require clear and objective measures to assess soil health across various soil types globally. These measures are essential for supporting agricultural, environmental, and cultural goals. Farmers and ranchers need reliable soil health indices to guide their practices and communicate effectively about this intricate system. Similar to health indicators in medicine, these indices serve as valuable models. They should be straightforward and applicable within specific contexts, such as climate change. Additionally, indices that capture the differential effects of tillage methods can help refine recommendations for specific scenarios, ensuring both short-term productivity and long-term sustainability. However, as scientific knowledge evolves and thresholds for soil health indices change, we must proceed cautiously to maintain trust among consumers and policymakers.

10. Conclusions

In this review, we explored the variability of farming practices and their complex implications for soil health in agriculture. Sustainable farming practices are critical to maintaining and enhancing soil health, which is necessary for agriculture's long-term sustainability. These practices, including minimum tillage, residue retention, and cover cropping, can improve soil carbon and crop yield and restore soil function by overcoming nutritional limitations, improving physical and biological properties, and promoting general soil and crop resilience. Maintaining soil health needs a comprehensive strategy that considers the soil's biological, chemical, and physical properties, as well as its complex relationships among them. We can ensure the health and productivity of our soil for future generations by implementing soil conservation methods and promoting sustainable land use practices. This review examined the role of soil health in different farming systems and identified factors to consider when assessing soil health components in sustainable agricultural systems. Also, it studied various technological approaches for sustainable farming practices, using information and numerical data from peer-reviewed journal publications. While this methodological technique has advantages, it also limits the research to a small set of selected outcomes that may not be typical of the entire research landscape (a problem known as publication bias). Soil health assessment is complex and requires clearer evidence due to limited empirical research. It is difficult for researchers to come up with a definition of soil health that is widely accepted. Areas for improving soil health, establishing conservation priorities, and directing resource allocation can all be accomplished with targeted insights.

This study investigates the current understanding of soil health, namely the quality of soil and the components associated with its healthy state. Soil health considers farming practices that influence soil health, such as no till, reduced till, crop rotation, cover cropping, and agroforestry. Soil amendments tended to improve soil physical, chemical, and biological properties to the greatest extent, while the incorporation of cover crops reduced nitrate leaching, increased soil carbon levels, and suppressed weeds. Despite progress, significant knowledge gaps remain. A key area is the dynamics of soil organic carbon (SOC), where the mechanisms driving SOC loss or accumulation are not well understood. Further research is needed to optimize carbon sequestration through various land management practices. Soil compaction also remains underexplored, with limited strategies to mitigate its impact on soil structure and root growth. Practices like reduced tillage and cover cropping show potential, but more data on their long-term effectiveness are needed. Soil salinity is another major concern, particularly in irrigated areas where it affects productivity. Research should focus on understanding how different crops and irrigation techniques influence salinity and develop management practices that prevent further soil degradation. Additionally, integrating soil data into land management remains a challenge, as translating these indicators into actionable strategies is often difficult for farmers. Developing user-friendly tools is crucial for better soil health management.

To ensure the agroecosystems' long-term production and environmental sustainability, new tools and techniques for evaluating and directing soil management decisions must be developed in order to measure the quality and health of the soil.

Future research should prioritize developing and refining farming practices tailored to diverse agroecological zones, leveraging modern technologies, and advocating for policies that support local and global agricultural systems. Such research should focus on advancing sustainable agricultural techniques and crafting innovative soil health management strategies to address the interconnected challenges of global food security and climate change.

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