Journal of Advances in Biology & Biotechnology

Volume 27, Issue 7, Page 1331-1350, 2024; Article no.JABB.118857
ISSN: 2394-1081

Innovative Soil Management, Soil Amendments and Soil Conservation Strategies for Boosting Horticultural Crops Yields

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jabb/2024/v27i71095

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/118857

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Cite as: *Kumar, Yogendra, Chaitra. K, Divyanshu Sharma, Kavita Devi, Shoaib Adnan, Md Zeeshan Qaiser, Kushal Sachan, and Aniket Kumar Verma. 2024. "Innovative Soil Management, Soil Amendments and Soil Conservation Strategies for Boosting Horticultural Crops Yields". Journal of Advances in Biology & Biotechnology 27 (7):1331-50. https://doi.org/10.9734/jabb/2024/v27i71095.*

Review Article

Received: 28/03/2024
Accepted: 01/07/2024
Published: 02/07/2024

ABSTRACT

Innovative soil management, soil amendments, and soil conservation strategies are pivotal in boosting horticultural crop yields. By integrating cutting-edge techniques, such as precision agriculture and organic amendments, these approaches optimize soil health and fertility, enhancing plant growth and productivity. Soil amendments, including biochar, compost, and green manures, improve soil structure, water retention, and nutrient availability, creating a favourable environment for horticultural crops. Additionally, soil conservation practices like cover cropping, contour ploughing, and agroforestry prevent erosion, maintain soil organic matter, and promote biodiversity. These strategies collectively contribute to sustainable agriculture, ensuring higher yields and long-term soil productivity while mitigating environmental impacts. Through a holistic approach to soil management, horticulturists can achieve robust crop performance and resilience against climatic challenges.

Keywords: Soil; conservation; Biochar; favourable; diversity.

1. INTRODUCTION

The overexploitation of soil by people results in major deterioration and contaminant migration, which is a significant problem because soil is an essential component of terrestrial ecosystems. Despite the fact that agriculture takes approximately 36.5% of the land mass on earth, the ecosystem that is responsible for supporting all forms of life is being significantly harmed by this ongoing deterioration [1]. In order to prevent or reduce the amount of soil particle detachment and the flow of water or air, soil conservation procedures are implemented with the intention of controlling soil erosion. For the purpose of applying control techniques and ultimately leading to soil conservation, it is vital to have a solid understanding of the processes and causes that influence soil erosion [2]. The concept of soil conservation originated as a means of safeguarding an ecosystem from the effects of agricultural production that relied on untested technology that was unable to accommodate the natural requirements of the land. The trend of land degradation that is always developing can only be comprehended by analysing whether the reasons were natural occurrences or the result of irresponsible use [3-5]. The Common Agricultural Policy (CAP) in Europe aims to address conservation by encouraging the implementation of optimal management techniques. These methods include winter cover crops, decreased tillage, plant residues, and grass margins. The traditional methods of increasing productivity, environmental benefits, and profitability are founded on the practices of no-tillage agriculture as well as larger notions of agricultural conservation and sustainable land management. The implementation of these ideas is a component of an ongoing land management practice that encompasses a wide variety of actions, from the implementation of specific soil management techniques such as zero-tillage

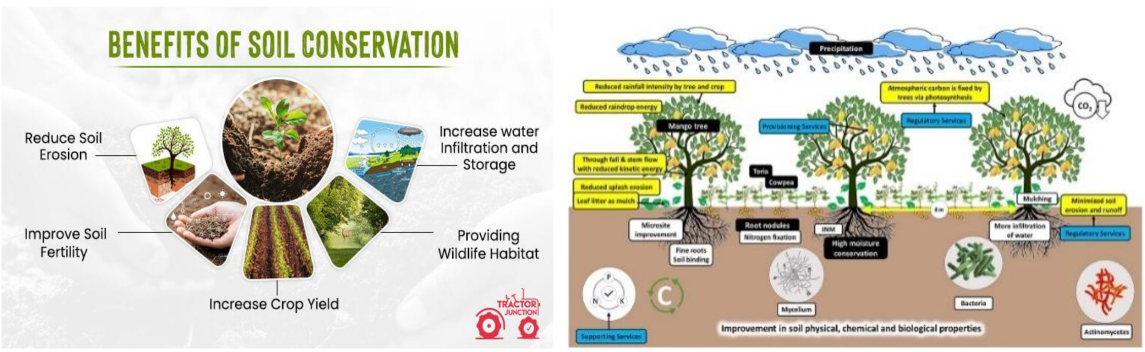

Fig. 1. Benefits of soil conservation

to the enhancement of concepts, principles, and goals related to agricultural conservation and land management for sustainability [6].

2. METHODS TO CONSERVE SOIL IN HORTICULTURAL CROPS

1. Mulching and cover cropping are two efficient ways for controlling top soil because they reduce the amount of soil that is moved and the amount of runoff that occurs. In order to prevent soil erosion and to increase the amount of nitrogen in the soil, mulching, which is the process of applying organic materials over exposed soil, is a vital practice. Peas, which are considered cover crops, have the ability to guard against wind erosion and also contribute to the development of an active microbial community in the soil of the rhizosphere [7].
2. Crop rotation is a traditional and practical method for regulating the biodiversity of agroecosystems. It does this by improving the health of the soil, reducing the number of pests and disease outbreaks, and raising yields. Using this strategy, farmers are able to enhance the structure of the soil, raise the amount of organic matter in the soil, and increase the rooting depth through the cultivation of secondary crops. When it comes to the structure of the soil, root crops are particularly detrimental since they cause widespread breaking throughout the seedbed preparation and harvesting processes [8].
3. During the process of crop rotation, leguminous crops like peas and chickpeas have the potential to contribute to the modification of soil functional microbial populations. It is possible to improve the growth of some soil functional microorganisms by including cover cropping or mulching, zero tillage, and cover cropping or mulching. This can result in an increase in soil microbial diversity and activity, an increase in soil microbial biomass, and an improvement in the cycling of carbon and nitrogen [9].
4. Preservation of soil aggregates, organic matter, and agricultural residues can also be accomplished by the use of conservation tillage, which is another technique. It entails making adjustments to the use of tillage instruments that are less damaging, reducing the amount of tillage done, and leaving crop residue on the surface of the soil in order to minimize erosion [10]. Due to the fact that traditional agricultural techniques have been shown to be extremely harmful to the soil, 24 percent of the world's agricultural area has been degraded as a result of these activities. The practice of tilling the soil is being gradually replaced with a new method that focuses on preserving and enhancing the soil [11].
5. The conservation of soil and the prevention of wind erosion can also be accomplished by the use of contours, terraces, and rides. Ridges can be generated as trap strips that are perpendicular to the direction of the predominant wind or as tall seed beds that are formed throughout the entire field. Ridges are classified as tall listed seed beds. Through the possible reduction in wind speed and the interception of soil particles, these structures have the ability to directly minimize wind erosion at the same time [12]. Indirect wind erosion control effects of terraces and associated contour tillage and cropping methods boost total crop grain and residue productivity by reducing runoff for greater water storage in the soil. Terraces in addition to contour tillage and cropping operations are also beneficial [13].
6. Strip cropping, often known as planting windbreaks, is an additional strategy that may be utilized to save soil and reduce wind erosion. As a barrier, they redirect air flow and lower the speed of wind blowing from the leeward direction. This technique of conservation is effective in challenging settings since irrigation is readily available. In areas where field orientation is not regulated, crops can be grown in strips that are perpendicular to the wind that is blowing at the time. This helps to minimize the wind speed near the surface [14].
7. For the majority of crops and climates, residue management is the strategy that produces the best results when it comes to reducing wind erosion. It is comprised of a number of different tillage procedures that are designed to keep residue from a crop that has been harvested in the past as a surface cover in order to minimize soil erosion [15]. When the residue of the previous crop is left on the surface of the soil, it enhances the soil's ability to store water, increases the amount of rain that penetrates the soil, and decreases the amount of water that evaporates from the

soil. Due to the fact that there is a consistent retrieval of energy from the degrading biomass of leftovers, the microclimate in this location is well adapted for the activities of microorganisms. This results in the mineralization of organic compounds and the breakdown of complicated molecules [15].

3. METHODS TO SOIL MANAGEMENT IN BRIEF MANNER

1. To ensure the continued use of land over the long term and to ensure that future generations continue to benefit from its production, soil conservation methods are very necessary. The technique of conserving soil can be accomplished by a variety of approaches, such as conservation tillage, contour farming, strip cropping, windbreaks, crop rotation, cover crops, buffer strips, and grassed rivers [16].
2. The goal of conservation tillage is to reduce the amount of soil that is eroded by wind and water by covering the ground with plants and reducing the number of times that cultivation is performed. The handling of damp ground can result in compaction, thus it is essential that field activities be performed at the appropriate time. In addition, no-till farming contributes to the preservation of soil by reducing the amount of disturbance caused by crop residue and sowing seeds inside it [17].
3. Planting species along the contour is an effective strategy for conserving soil. This method gathers rainfall behind ridges and reduces runoff, making contour farming an efficient method for soil conservation [18]. It is possible to continue this strategy by planting row crops atop the same furrow year after year. This method enhances the capacity of the furrow to store products. Strip cropping is one of the most cost-effective strategies of conservation that farmers have at their disposal. It serves the purpose of protecting crops from wind by combining high-growing crops with low-growing crops [19].
4. In order to protect crops from the effects of wind and snow, windbreaks are trees or shrubs that are planted in many rows. They eradicate the soil abrasion that crops experience as a result of high winds and create a living habitat for wildlife creatures. Changes in the types of crops planted, the improvement of the structure of the ground via the use of various root systems, the reduction of pest settlements, and the addition of nitrogen to the land through the use of legumes, which are known as nitrogen-fixing plants, are all components of crop rotation [20].
5. Through the production of fodder and grazing material for cattle, the provision of green manure, the assistance in weed control, the retention of moisture, the guarantee of a natural habitat for microbes and small animals, and the maintenance of a nitrogen concentration balance, cover crops contribute to the conservation of soil nutrients. Through the process of stabilizing the ground, insulating water occupants from excessive sunlight, and supplying organic matter and food for small aquatic organisms, buffer strips are able to prevent the wash-off of silt and water [21].
6. There are grass-covered furrows for water streams that are known as grassed waterways. These rivers protect the ground from water erosion and contribute to the conservation of soil over time. The proper planning and construction of these structures allows them to transport water across fields in a secure manner, transfer runoff from large basins located upstream, and have low maintenance costs after the vegetation has established a strong root system [22].
7. In order to develop a water-gathering system for crops, terrace farming is a method of soil conservation that requires the construction of stepped terraces into hills or mountains. This method is frequently used for the cultivation of rice because it allows rainfall to flow from one terrace to the next, so maintaining the soil's health and enhancing the overall quality of the land. In addition, drop inlets and rock chutes are utilized in order to forestall the erosion of riverbanks and riverbeds that is brought about by the movement of water, waves, ice, and precipitation [23].
8. A wide range of soil conservation activities are referred to together as "bank stabilization." The overarching goal of these practices is to avoid erosion of riverbanks and riverbeds that is caused by moving water, waves, ice, and rain.

Typically, gabion baskets, rip rap, and vegetation are utilized in the process of bank stabilization. These methods, which are more cost-effective in the long term once vegetation has been grown, are the three most common options [24].

9. The transport of sediment-laden precipitation into neighbouring water bodies can be slowed down by the use of non-plant physical interventions, which are included in the approaches for controlling sediment. Silt fences, sediment traps, and sedimentation ponds are the three forms of infrastructure that are utilized most frequently for the purpose of sediment control. Maintaining these approaches on a consistent basis and treating the silt in the appropriate manner are both necessary for their success [25].
10. It is essential for contemporary agriculture to practice chemical-free farming since chemical farming has a detrimental effect on the health of ecosystems and hinders the conservation of land. Ploughing leftovers, crop rotation, cultivating green manure, spreading compost and manure, and utilizing microbiological fertilizers are all examples of methodological approaches to soil conservation and nutrient management that do not include the use of chemical substances [26]. Integrated pest management, often known as IPM, is an important component of soil conservation. Its primary objective is to control insects by stopping them from feeding and reproducing, all while addressing the preservation of natural variety and the health of ecosystems [27].
11. In light of the fact that it is impossible to conserve fields that are effective everywhere owing to variances in soil types, geography, and climate, organic farming might be considered an additional method of soil conservation. The use of agricultural leftovers, the cutting of stubble, the rotation of crops over an extended period of time, pasture crops, green and animal manure, and other techniques are characteristics of organic farming [28]. It is usually better to utilize a mix of soil conservation strategies, such as planting fewer shelterbelts on a particular field, lowering the frequency of tillage operations, and increasing the application of green manure to preserve vegetation cover. This is because it is more effective in preserving existing vegetation cover [29].
12. Organically grown soils contain a higher concentration of organic matter compared to soils grown using conventional methods. Additionally, organically grown soils have a more substantial topsoil layer, a greater quantity of polysaccharides, and a lower flexural strength. Research conducted over an extended period of time demonstrates that organic farming is better than conventional farming in terms of preventing erosion and maintaining the fertility of the ground [30].

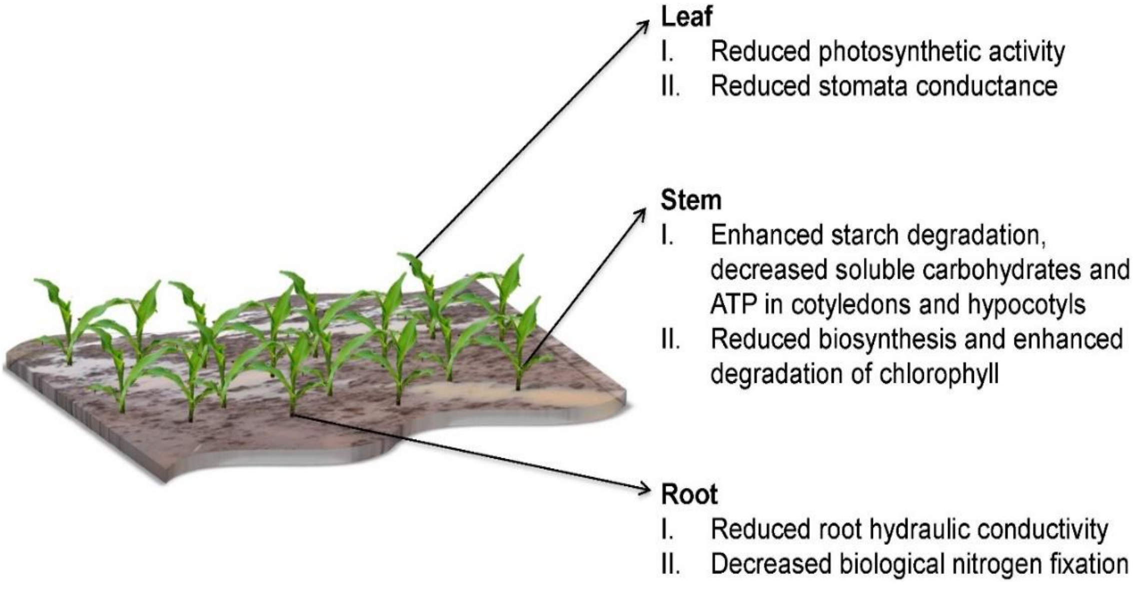

Fig. 2. Conserve soil in horticultural crops

Fig. 3. Soil management in brief manner

4. SOIL MANAGEMENT IN VINES CROPS

Vine production is vital to the global economy, yet improper pest and weed management compromises its ecological functions. Unbalanced soil management can cause compaction, pollution, erosion, soil organic matter depletion, and biodiversity loss, reducing vine quality and quantity [31]. Long-term usage of synthetic fertilizers alters the soil's humic-mineral and microbiological background, causing fertility loss till biological desertification. Higher temperatures impair the long-term viability of wine grape production. High transpiration rates at higher temperatures rapidly decrease soil moisture, influencing whole-plant carbon balance and grape quality [32]. Improved contemporary viticulture requires soil management and sustainable solutions. Vineyard soil chemistry and sustainable management significantly affect wine grape quality. This study evaluates soil management methods and their consequences for viticulture, urging for more scientific research into their sustainability for future development in compliance with current green economy requirements [33].

Soil evaluation must consider soil quality, which is essential for environmental quality, biological production, and plant and animal health. Soil quality is connected with plant development, water regulation, biological population modulation, and nutrient retention in natural and agro-ecosystems [34]. Viticulture uses pH, soil bulk density, primary nutrient availability, and organic matter concentration to assess soil quality. Soil organic matter (SOM) reduces exchangeable sodium (Na), electrical conductivity (EC), salt leaching, water infiltration, water-holding capacity, and aggregate stability, regulating crop yield. Bio indicators assess soil functioning, including nutrient retention, cycling, humus production, organic matter decomposition, soil aggregation, and plant symbiosis and parasitism. Quality soil losses from land soil degradation effect services, resources, and commodities [35]. In viticulture, intensive cultivation can harm water, soil, and vine quantity or quality. Organic matter loss, erosion, fertilizer contamination, and compaction threaten Mediterranean vineyard soil quality. Boost soil fertility, decrease nutrient loss, balance water use, and boost grape quality with innovative management [36]

Vermicompost, limestone, and calcium silicate are investigated as soil additives to increase plant growth and soil quality. Vermicompost and calcium silicate alkalize soil solutions, lowering Cu^{2+} and increasing photosynthetic rates, fine roots, guaiacol peroxidase, and superoxide dismutase activity. Chemical fertilizers may be replaced by these amendments, which improve plant growth, soil quality, and nutrient leaching [37].

Biochar, made by pyrolyzing industry by-products, municipal trash, and agricultural waste, improves soil quality, moisture-holding capacity, pH, cation exchange capacity, crop yield, and fungal and microbial activity. It stores atmospheric biosphere carbon in soil. Biochar decomposes slower than compost because it contains stable carbon. Most soil fertility, yield, and plant growth gains occurred in tropical and subtropical soils [38].

Biochar boosts microbial biomass, enzyme activity, phospho-lipid fatty acids (PLFAs), and bacterial taxa, providing ecosystem benefits. The microbial community is strengthened, enzyme activities, phospho-lipid fatty acids, and bacterial taxa are increased, providing ecosystem benefits [39].

Natural plant biostimulants (PBs) are chemicals or microorganisms that improve plant feeding efficiency, abiotic stress tolerance, and crop quality regardless of nutrient availability. Six non-microbial and three microbial PBs exist. Organic non-microbial PBs such as chitosan, humic and fulvic acids, protein hydrolysates, phosphates, seaweed extracts, arbuscular mycorrhizal fungi, plant growth-promoting rhizobacteria, and trichoderma spp. have many uses [40]. Chitin makes chitosan, while HA and FA are tiny hydrophilic molecules. Partial hydrolysis produces protein hydrolysates (PHs) comprising polypeptides, oligopepetides, and amino acids. Seaweed extracts include about 10,000 species, whereas phosphates are reduced forms of phosphate [41].The symbiosis of arbuscular mycorrhizal fungus (AMF) with soil bacteria makes them popular in horticulture. Seaweed extracts are effective and sustainable for low-input yield stability and abiotic stress resistance. Bioactive phenolic compounds of *Ascophyllum nodosum*, the most common seaweed source for PBs, have been employed to suppress phytopathogens [42]. High salt concentrations harm saprophytic fungus Trichoderma spp. They are important rhizosphere competitors, soil fungicide-resistant, and efficient soil nutrient use and plant development. Trichoderma spp. produces huge amounts of extracellular enzymes to mineralize organic nutrients, minimizing chemical inputs like bio-fertilizers and boosting sustainable agriculture and natural resource conservation [43].

5. SOIL AMENDMENTS FOR HORTICULTURAL CROPS

Soil health is fundamental to the success of horticultural crops, which include fruits, vegetables, nuts, and ornamental plants. As agricultural practices evolve, the importance of soil amendments has become increasingly evident. These amendments—materials added to the soil to improve its physical, chemical, and biological properties—are essential for boosting crop yields and ensuring sustainable farming practices. This article delves into various types of soil amendments, their benefits, application methods, and their impact on horticultural crop production [44].

6. TYPES OF SOIL AMENDMENTS

Soil amendments can be broadly categorized into organic and inorganic types, each offering unique benefits to soil health and crop productivity.

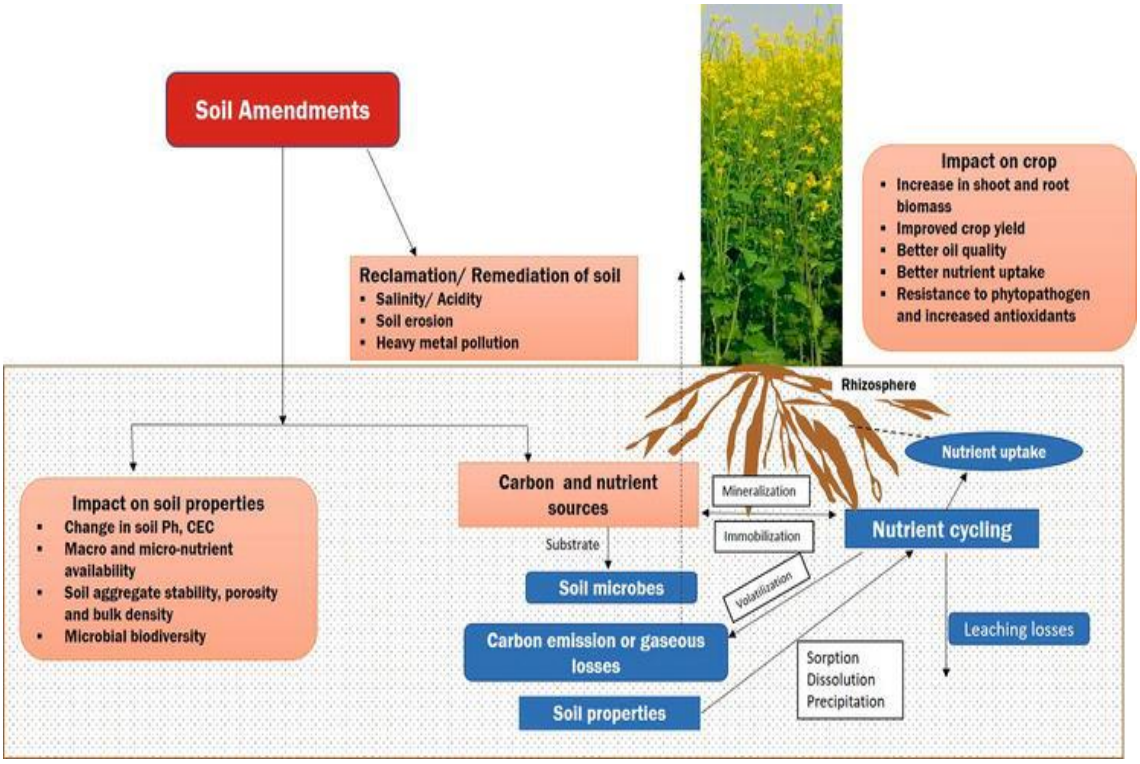

Fig. 4. Soil management in vines crops

Table 1. The soil management practices for various fruit crops, including soil type, pH requirements, and recommended soil amendments

Fruit Crop	Preferred Soil Type	Optimal pH Range	Key Soil Amendments	Additional Notes
Apples	Well-drained loam	6.0 - 6.8	Compost, lime, gypsum	Regularly monitor pH; avoid waterlogged soils.
Blueberries	Sandy or peaty soils	4.5 - 5.5	Sulphur (to lower pH), peat moss, compost	Ensure high organic matter; maintain low pH.
Citrus (e.g., oranges)	Sandy loam	6.0 - 7.5	Compost, gypsum, organic mulch	Avoid saline soils; ensure good drainage.
Grapes	Well-drained loam/sand	5.5 - 6.5	Compost, lime (if pH is low), biochar	Ensure good drainage; avoid heavy clay soils.
Strawberries	Sandy loam	5.5 - 6.5	Compost, organic mulch, balanced fertilizer	Rotate crops to prevent soil diseases.
Raspberries	Well-drained loam	5.5 - 6.5	Compost, manure, organic mulch	Avoid waterlogged areas; ensure good drainage.
Peaches	Sandy loam	6.0 - 7.0	Compost, lime (if pH is low), gypsum	Ensure deep, well-drained soils.
Pears	Well-drained loam	6.0 - 7.0	Compost, balanced fertilizer, lime	Maintain moderate pH; avoid heavy clays.
Cherries	Sandy loam to loamy sand	6.5 - 7.5	Compost, gypsum, lime (if pH is low)	Ensure excellent drainage; avoid waterlogging.
Avocados	Well-drained loam/sand	6.0 - 7.0	Compost, gypsum, organic mulch	Ensure good drainage; avoid saline soils.
Bananas	Well-drained loam	5.5 - 6.5	Compost, balanced fertilizer, organic mulch	Require high organic matter and regular irrigation.
Mangoes	Sandy loam to loam	5.5 - 7.5	Compost, gypsum, balanced fertilizer	Ensure good drainage; avoid waterlogged soils.
Pineapples	Sandy loam	4.5 - 6.5	Compost, balanced fertilizer, organic mulch	Ensure high organic matter; maintain proper drainage.

6.1 Organic Amendments

1. **Compost**

- **Description**: Decomposed organic matter from plant residues, kitchen waste, and manure [45].
- **Benefits**: Enhances soil structure, increases microbial activity, improves nutrient content, and enhances water retention.
- **Application**: Spread as a top dressing or incorporated into the soil before planting [46].

2. **Biochar**

- **Description**: Charred biomass produced through pyrolysis.
- **Benefits**: Increases soil pH, improves nutrient retention, and enhances microbial habitats [47].
- **Application**: Mixed with compost or applied directly to the soil [48].

3. **Green Manures**

- **Description**: Crops grown specifically to be incorporated back into the soil.

- **Benefits**: Adds organic matter, improves soil structure, and supplies nutrients.
- **Application**: Ploughed into the soil before planting the main crop [49].

4. **Animal Manures**

- **Description**: Waste from livestock.
- **Benefits**: Provides a rich source of nutrients, improves soil structure, and increases microbial activity [50].
- **Application**: Applied as raw or composted manure, typically incorporated into the soil [51].

5. **Peat Moss**

- **Description**: Decomposed sphagnum moss harvested from peat bogs.
- **Benefits**: Enhances water retention and aeration in sandy soils [52].
- **Application**: Mixed into soil or used as a component in potting mixes.

6.2 Inorganic Amendments

1. **Lime**

- **Description**: Crushed limestone (calcium carbonate) or dolomitic lime (calcium magnesium carbonate) [53].
- **Benefits**: Raises soil pH, provides calcium and magnesium, and improves soil structure [54].
- **Application**: Applied based on soil test recommendations, typically incorporated into the soil [55].

2. **Gypsum**

- **Description**: Calcium sulphate.
- **Benefits**: Improves soil structure in saline soils, supplies calcium and sulphur [56].
- **Application**: Broadcast on the soil surface or mixed into the soil [57].

3. **Perlite and Vermiculite**

- **Description**: Volcanic glass (perlite) and hydrated laminar minerals (vermiculite) [58].
- **Benefits**: Improve soil aeration and drainage, retain moisture and nutrients.
- **Application**: Mixed into soil or potting mixes.

4. **Sand**

- **Description**: Coarse mineral particles.
- **Benefits**: Improves drainage and reduces soil compaction.
- **Application**: Incorporated into heavy clay soils to improve texture [59].

6.3 Benefits of Soil Amendments

The use of soil amendments offers numerous benefits, which are critical for the productivity and sustainability of horticultural crops [60].

6.4 Enhanced Soil Structure and Aeration

Amendments like compost and biochar improve soil structure by increasing porosity and reducing compaction. This enhances root growth and allows for better air and water movement within the soil, essential for healthy plant development [61].

6.5 Improved Nutrient Availability

Organic amendments gradually release nutrients, providing a steady supply to crops. Inorganic amendments like lime and gypsum adjust soil pH and supply essential minerals, optimizing nutrient uptake by plants [62].

6.6 Increased Water Retention

Materials like peat moss and vermiculite improve the soil's ability to retain moisture, reducing the need for frequent irrigation and protecting plants from drought stress [63].

6.7 Enhanced Microbial Activity

Organic amendments introduce and support beneficial soil microorganisms. These microbes decompose organic matter, fix nitrogen, and enhance nutrient cycling, creating a more fertile and resilient soil ecosystem.

7. APPLICATION METHODS

The effectiveness of soil amendments depends on proper application techniques, tailored to specific crops and soil conditions [64].

Fig. 5. Soil management practices

Table 2. The soil management practices for various vegetable crops, including soil type, pH requirements, and recommended soil amendments

Vegetable Crop	Preferred Soil Type	Optimal pH Range	Key Soil Amendments	Additional Notes
Tomatoes	Well-drained loam	6.0 - 6.8	Compost, balanced fertilizer, lime	Ensure good drainage; rotate crops to avoid diseases.
Carrots	Sandy loam	6.0 - 6.8	Compost, balanced fertilizer, sand (if clayey)	Avoid rocky soils; ensure loose soil for root development.
Lettuce	Well-drained loam	6.0 - 7.0	Compost, balanced fertilizer, organic mulch	Keep soil moist; avoid high temperatures.
Potatoes	Sandy loam	5.0 - 6.0	Compost, balanced fertilizer, sulphur (if pH is high)	Avoid heavy clay soils; ensure good drainage.
Onions	Well-drained loam/sand	6.0 - 7.0	Compost, balanced fertilizer, gypsum	Ensure good drainage; avoid waterlogged soils.
Peppers	Well-drained loam	6.0 - 6.8	Compost, balanced fertilizer, lime	Ensure warm soil; provide consistent moisture.
Beans	Well-drained loam	6.0 - 6.8	Compost, balanced fertilizer, lime	Rotate crops to fix nitrogen and prevent diseases.
Broccoli	Well-drained loam	6.0 - 7.0	Compost, balanced fertilizer, lime	Maintain consistent moisture; avoid acidic soils.
Cucumbers	Sandy loam	6.0 - 7.0	Compost, balanced fertilizer, organic mulch	Ensure good drainage; provide consistent moisture.
Spinach	Well-drained loam	6.5 - 7.5	Compost, balanced fertilizer, lime	Maintain consistent moisture; avoid high temperatures.
Cabbage	Well-drained loam	6.0 - 7.5	Compost, balanced fertilizer, lime	Maintain consistent moisture; avoid acidic soils.
Zucchini	Well-drained loam	6.0 - 7.0	Compost, balanced fertilizer, organic mulch	Ensure good drainage; provide consistent moisture.
Peas	Well-drained	6.0 - 7.0	Compost, balanced	Rotate crops to fix

Vegetable Crop	Preferred Soil Type	Optimal pH Range	Key Soil Amendments	Additional Notes
	loam		fertilizer, lime	nitrogen and prevent diseases.
Beets	Well-drained loam	6.0 - 7.5	Compost, balanced fertilizer, lime	Avoid waterlogged soils; ensure good drainage.
Eggplant	Well-drained loam	5.5 - 6.5	Compost, balanced fertilizer, lime	Ensure warm soil; provide consistent moisture.
Radishes	Sandy loam	6.0 - 7.0	Compost, balanced fertilizer, organic mulch	Ensure good drainage; avoid high temperatures.

Table 3. Soil management practices for various medicinal crops, including soil type, pH requirements, and recommended soil amendments

Medicinal Crop	Preferred Soil Type	Optimal pH Range	Key Soil Amendments	Additional Notes
Aloe Vera	Sandy loam	6.0 - 7.0	Compost, balanced fertilizer, sand (if heavy soil)	Ensure excellent drainage; avoid waterlogging.
Echinacea (Coneflower)	Well-drained loam/sand	6.0 - 7.0	Compost, organic mulch, balanced fertilizer	Ensure good drainage; moderate fertility.
Chamomile	Well-drained sandy loam	6.0 - 7.5	Compost, organic mulch, balanced fertilizer	Light soils preferred; avoid heavy, waterlogged soils.
Lavender	Sandy loam to loamy sand	6.5 - 7.5	Lime (if pH is low), compost, sand (if heavy soil)	Ensure good drainage; avoid waterlogging.
Mint	Moist loam	6.0 - 7.0	Compost, organic mulch, balanced fertilizer	Keep soil consistently moist; avoid dry conditions.
Ginseng	Well-drained loam	5.5 - 6.5	Compost, leaf mold, organic mulch	Shade preferred; ensure rich, moist, well-drained soil.
Turmeric	Well-drained loam	5.5 - 6.5	Compost, organic mulch, balanced fertilizer	Requires warm, humid conditions; ensure good drainage.
Valerian	Well-drained loam	5.5 - 7.0	Compost, organic mulch, balanced fertilizer	Prefers moist, fertile soil; ensure consistent moisture.
Rosemary	Sandy loam to loamy sand	6.0 - 7.5	Compost, sand (if heavy soil), lime (if pH is low)	Ensure excellent drainage; avoid waterlogging.
St. John's Wort	Sandy loam	6.0 - 7.0	Compost, balanced fertilizer, organic mulch	Prefers well-drained soil; avoid heavy, wet soils.
Ashwagandha (Indian Ginseng)	Well-drained sandy loam	6.0 - 7.5	Compost, organic mulch, balanced fertilizer	Prefers dry conditions; avoid waterlogged soils.
Gotu Kola	Moist loam	6.0 - 7.0	Compost, organic mulch, balanced fertilizer	Keep soil consistently moist; prefers partial shade.
Lemon Balm	Well-drained loam	6.0 - 7.5	Compost, organic mulch, balanced fertilizer	Prefers rich, well-drained soil; ensure good drainage.

Medicinal Crop	Preferred Soil Type	Optimal pH Range	Key Soil Amendments	Additional Notes
Feverfew	Well-drained loam/sand	6.0 - 7.5	Compost, balanced fertilizer, organic mulch	Prefers light, well-drained soil; avoid heavy soils.
Arnica	Well-drained loam	6.0 - 7.0	Compost, balanced fertilizer, organic mulch	Prefers well-drained soil; avoid waterlogging.

Table 4. Soil management practices for various flower crops, including soil type, pH requirements, and recommended soil amendments

Flower Crop	Preferred Soil Type	Optimal pH Range	Key Soil Amendments	Additional Notes
Roses	Well-drained loam	6.0 - 7.0	Compost, balanced fertilizer, lime (if pH is low)	Ensure good drainage; provide regular watering.
Tulips	Sandy loam	6.0 - 7.0	Compost, bulb fertilizer, sand (if heavy soil)	Ensure well-drained soil; avoid waterlogging.
Daffodils	Well-drained loam	6.0 - 7.0	Compost, bulb fertilizer, organic mulch	Ensure good drainage; avoid heavy, wet soils.
Lilies	Well-drained loam/sand	6.0 - 6.5	Compost, balanced fertilizer, organic mulch	Ensure good drainage; avoid waterlogging.
Marigolds	Well-drained loam	6.0 - 7.5	Compost, balanced fertilizer, organic mulch	Prefers sunny locations; avoid waterlogging.
Petunias	Well-drained loam	6.0 - 7.0	Compost, balanced fertilizer, organic mulch	Ensure good drainage; provide regular watering.
Pansies	Well-drained loam	5.5 - 6.5	Compost, balanced fertilizer, organic mulch	Prefers cooler temperatures; avoid waterlogging.
Sunflowers	Well-drained loam/sand	6.0 - 7.5	Compost, balanced fertilizer, organic mulch	Ensure good drainage; provide full sun.
Geraniums	Well-drained loam	6.0 - 7.0	Compost, balanced fertilizer, organic mulch	Ensure good drainage; avoid overwatering.
Chrysanthemums	Well-drained loam	6.5 - 7.0	Compost, balanced fertilizer, organic mulch	Ensure good drainage; provide regular watering.
Zinnias	Well-drained loam/sand	5.5 - 7.5	Compost, balanced fertilizer, organic mulch	Prefers sunny locations; avoid waterlogging.
Snapdragons	Well-drained loam	6.2 - 7.0	Compost, balanced fertilizer, organic mulch	Prefers cool conditions; ensure good drainage.
Impatiens	Well-drained loam	6.0 - 6.5	Compost, balanced fertilizer, organic mulch	Prefers shady locations; avoid waterlogging.
Begonias	Well-drained loam	6.0 - 7.0	Compost, balanced fertilizer, organic mulch	Prefers partial shade; ensure good drainage.
Gladiolus	Sandy loam	6.0 - 7.0	Compost, bulb fertilizer, organic mulch	Ensure good drainage; avoid waterlogging.

7.1 Incorporation

This method involves mixing amendments directly into the soil. It is commonly used for compost, animal manure, and inorganic amendments like lime and gypsum. Incorporation ensures that amendments are evenly distributed, enhancing their interaction with the soil and plant roots [65].

7.2 Top Dressing

Applying amendments on the soil surface is suitable for materials like compost and manure. This method gradually improves soil quality as the amendments decompose and leach into the soil with watering [66].

7.3 Mulching

Mulching with organic materials such as straw, wood chips, or grass clippings provides multiple benefits: it conserves moisture, suppresses weeds, and gradually adds organic matter to the soil as it decomposes [67].

7.4 Foliar Application

Some amendments, particularly liquid fertilizers or micronutrient solutions, can be applied directly to plant leaves. This method provides a quick nutrient boost but is generally used in conjunction with soil applications [68].

8. IMPACT ON HORTICULTURAL CROPS

The strategic use of soil amendments has a profound impact on the growth, yield, and quality of horticultural crops.

8.1 Vegetables

Vegetable crops benefit significantly from soil amendments, as these plants often have high nutrient and water requirements. Organic amendments like compost enhance soil fertility and structure, leading to healthier plants and higher yields. Inorganic amendments such as lime can correct soil pH imbalances, ensuring optimal nutrient availability [69].

8.2 Fruits

Fruit crops, particularly perennials like apple, citrus, and berry plants, benefit from long-term soil health improvements provided by amendments. Biochar and compost improve soil structure and nutrient availability, supporting sustained growth and productivity over many years [70].

8.3 Ornamentals

Ornamental plants require well-structured, nutrient-rich soils for vibrant growth and flowering. Amendments like peat moss and vermiculite enhance soil properties, ensuring that ornamental plants receive adequate moisture and nutrients, leading to improved aesthetic qualities [71].

8.4 Nuts

Nut crops, which often grow in orchards, benefit from amendments that improve soil structure and fertility. Gypsum, for instance, can alleviate soil salinity issues, while compost adds organic matter and nutrients essential for healthy tree growth and nut production [72].

9. CHALLENGES AND CONSIDERATIONS

- **Cost**: Adopting advanced soil management techniques and acquiring quality soil amendments can incur significant costs for farmers, especially those with limited financial resources. Cost-effective solutions must be explored to make these practices accessible to a wide range of growers.
- **Knowledge and Education**: Farmers need access to proper education and training on innovative soil management practices. Building awareness about the benefits and methods of soil conservation and sustainable farming is essential for widespread adoption.
- **Adaptation to Local Conditions**: Soil management practices must be tailored to local soil types, climates, and crop varieties. What works well in one region may not be suitable for another, requiring customized approaches based on local conditions.
- **Integration with Existing Practices**: Integrating new soil management practices with existing farming methods can be challenging. Farmers may resist change if they perceive it as disruptive or risky. Encouraging gradual adoption and demonstrating the benefits through pilot projects can help overcome resistance.

- **Monitoring and Evaluation**: Continuous monitoring and evaluation of soil health and crop performance are necessary to assess the effectiveness of soil management practices. This requires investment in monitoring tools, data collection, and analysis to make informed decisions and adjustments as needed.
- **Environmental Impact**: While soil management practices aim to improve agricultural productivity, they must also minimize negative environmental impacts such as nutrient runoff, soil erosion, and pollution. Balancing productivity with environmental sustainability is critical for long-term success.
- **Policy Support**: Government policies and incentives can play a crucial role in promoting innovative soil management practices. Providing subsidies for soil testing, organic amendments, and conservation equipment can encourage adoption and investment in sustainable agriculture.
- **Farm Size and Scale**: The feasibility and impact of soil management practices may vary depending on the size and scale of farming operations. Small-scale farmers may face different challenges than large-scale commercial operations, requiring tailored support and solutions.

10. CONCLUSION

Innovative soil management, soil amendments, and conservation strategies are essential components in bolstering yields of horticultural crops. By employing cutting-edge techniques and sustainable practices, farmers can optimize soil health, enhance nutrient availability, and mitigate environmental degradation, thereby fostering robust crop growth and improving overall productivity. Innovative soil management involves precision agriculture methods, utilizing technology for precise soil analysis and tailored application of fertilizers and amendments. Organic and inorganic soil amendments play a critical role in improving soil structure, fertility, and nutrient balance, providing essential elements for plant growth. Furthermore, soil conservation strategies such as cover cropping, reduced tillage, and contour farming help prevent erosion, maintain soil moisture, and promote soil health, contributing to sustained crop yields and long-term agricultural viability. Through the integration of these innovative approaches, farmers can achieve higher yields, ensure environmental sustainability, and meet the increasing demand for horticultural products in a changing agricultural landscape.

11. FUTURE DIRECTIONS

Future directions for innovative soil management, soil amendments, and conservation strategies in boosting horticultural crop yields involve embracing technological advancements, promoting sustainable practices, and addressing emerging challenges.

1. **Technological Integration**: Continued integration of technology, such as precision agriculture tools, remote sensing, and data analytics, will enable more precise and efficient soil management. Advances in soil sensors and monitoring systems will provide real-time data on soil health, allowing for timely interventions and optimized resource use [73].
2. **Research and Development**: Investing in research and development is crucial for identifying new soil amendments, improving existing practices, and understanding the complex interactions between soil, plants, and the environment. Research should focus on developing bio-based amendments, exploring microbial solutions, and assessing the long-term impacts of soil management practices on soil health and ecosystem resilience [74].
3. **Climate Resilience**: With the increasing impacts of climate change, future soil management strategies must prioritize climate resilience. This includes developing drought-tolerant crops, implementing water-efficient irrigation systems, and adopting practices that enhance soil carbon sequestration to mitigate greenhouse gas emissions.
4. **Education and Outreach**: Enhancing farmer education and outreach programs will promote widespread adoption of sustainable soil management practices. Training programs, demonstration plots, and farmer-to-farmer knowledge sharing initiatives can empower growers with the skills and knowledge needed to implement innovative techniques effectively [75].
5. **Policy Support**: Governments and policymakers should enact supportive policies and incentives to encourage sustainable soil management practices. This includes providing financial incentives for adopting conservation practices,

funding research initiatives, and implementing regulations to mitigate soil degradation and erosion.

6. **Collaborative Partnerships**: Collaborative partnerships between government agencies, research institutions, NGOs, and private sector stakeholders are essential for driving innovation and scaling up successful soil management initiatives. These partnerships can leverage resources, share expertise, and coordinate efforts to address complex soil and agricultural challenges [76].
7. **Circular Economy Approach**: Adopting a circular economy approach to soil management involves minimizing waste, recycling organic materials, and maximizing resource efficiency. This includes utilizing organic waste streams such as crop residues, food waste, and manure to produce compost and bio-based fertilizers, closing the nutrient loop and reducing reliance on synthetic inputs [77].
8. **Global Collaboration**: Soil management is a global issue that requires collective action and collaboration across borders. International cooperation and knowledge exchange platforms can facilitate the sharing of best practices, technologies, and lessons learned to address common challenges and promote sustainable soil management practices worldwide [78].

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/118857