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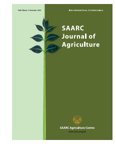

Research Article

Approaches to Sustainable Agriculture: A Retrospective Analysis for Soil Health Improvement

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Abstract

Gaining insight into farmers' viewpoints is essential for attaining sustainable development goals in agriculture. By actively involving farmers and integrating their perspectives, it is possible to foster novel strategies that enhance soil quality and bolster the agricultural ecosystem. it is possible to improve soil health and reduce reliance on outside inputs by using regenerative farming methods that are based on agroecological principles and precision farming technologies. Engaging in collaboration with researchers, policymakers, and agricultural communities is crucial to jointly develop creative artificial intelligence (AI), which has the potential to enhance economic expansion, reduce inefficiencies, and provide nutrients directly to plant roots. This transformation revolves around the recognition of solutions that effectively tackle the sustainable development goals (SDGs) and advance the improvement of soil health. The study regenerated with previous understanding and recommended that farmers investigate the intricate correlation between bacteria and nutrients to discover more effective approaches to soil management. several natural alternatives include cyanobacteria, biofertilizers, plant growth-promoting rhizobacteria (PGPR), and livestock manure. Optimal soil health is crucial for the overall functioning and sustainability of entire ecosystems. The study emphasized the significance of prioritizing farmers' practices and adopting their perspectives to comprehend the real-time decision-making process. Furthermore, the study suggested some effective recommendations, that farmers should receive to practice land tilling, smart farming adoption, residues and weed management. These potential strategies significantly enhance agricultural productivity.

Keywords: Biofertilizers; Environmental health; Nanotechnology; Sustainable agriculture; Soil health; Synthetic fertilizers

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Background

It is crucial to safeguard our land from harmful practices. The soil is considered a living entity, and its natural organic matter has seen a degradation of 40% (Bossio et al., 2010). This is a serious issue that requires immediate attention. The preservation of soil is currently of utmost importance, since it is crucial to halt any further deterioration of this key natural asset. Soil is an intricate combination of organic and inorganic substances that facilitate plant growth and serves as a habitat for many species. It encompasses plant residues, decaying organic matter, minerals, rocks, and various chemical compounds. Livestock manure contributes organic nutrients, while insects and microorganisms play pivotal roles in nutrient cycling and soil health. Synthetic fertilizers alter soil composition by introducing concentrated nutrients, affecting pH and microbial activity. Excessive use of synthetic fertilizers can harm beneficial soil microorganisms and lead to a decline in soil organic matter. Understanding this intricate interplay is crucial for sustainable soil management (Dinel et al., 2017). Since the advent of intensive agriculture, farmers have discontinued the use of natural manure. Instead, farmers have exclusively depended on synthetic chemicals, leading to the full deterioration of the soil.

Soil degradation includes processes such as erosion, salinization, acidity, compaction, and loss of cover (Gomiero, 2016). Regrettably, the act of providing sustenance to an excessively large population and the pursuit of economic incentives are having detrimental effects on our environment and putting significant pressure on the balance of the soil. An urgent and comprehensive endeavour is required to protect the inherent characteristics of our soil for the benefit of future generations.

Causes for Soil Degradation

Soil degradation is a growing concern in agricultural practices, mainly due to the excessive use of chemical fertilizers and less use of organic manure. These fertilizers, while initially increasing crop yields, often lead to a decline in natural fertility and overall soil health over time (Aulakh and Sidhu, 2015). Chemical fertilizers provide nutrients to plants but do not address the long-term health of the soil ecosystem. As a result, the repeated use of chemical fertilizers can disrupt the balance of nutrients and microorganisms in the soil, leading to reduced organic matter content and diminishing natural fertility (Jacoby et al., 2017).

a. Use of synthetic fertilizers

The extensive use of synthetic fertilisers, necessitated by the critical need to close the supply-and-demand mismatch in agricultural production, has been prompted principally by economic factors. Chemical fertilisers are undoubtedly a significant step toward addressing the nutrient shortage, however it involves a serious risk to the environment and resource depletion facing humanity (Kaur et al., 2014). Due to their hasty and practical nature, farmers adopt these techniques without being cognizant of their potential long-term repercussions. Sadly, the consequences of the intensive fertiliser use of the present day reach far beyond economic benefits; they have significant effects on both human health and the environment (Tripathi et al., 2020).

b. Soil erosion and faulty land use

Natural processes such as wind, water, and climatic events cause fine soil particles to separate and move, a process known as soil erosion (Lal, 2017). Regrettably, poor land management techniques make erosion worse and cause the soil to lose important organic matter. The implementation of knowledge-based erosion protection systems requires immediate attention (Telles et al., 2011). Although some farmers believe that soil erosion is an unstoppable force, there is hope for reducing its effects and protecting our essential soil resources when a planned approach is combined with technical improvements.

Degradation of the soil is further exacerbated by improper land use practises. Overgrazing and monoculture are examples of unsustainable farming practises that deplete vital nutrients. CO2 initiated in plant biomass that climate change may impact soil erosion (Mullan, 2013). The issue is made worse by accelerated processes such erosion, flooding, drought, and salinization (Hossain et al., 2020). Excessive irrigation can cause salinization, which makes the land unusable by leaving behind salt deposits. Drought parches topsoil, affecting crop output and the general health of the soil (Potopová et al., 2020). Flooding erodes this soil. We must strike a balance between environmental care and productivity to ensure a sustainable future, keeping in mind that robust soils are essential to both food security and ecological resilience.

c. Canals for large-scale irrigation and deforestation

Erosion, salinization, and waterlogging can result from improper canal design and upkeep. Natural habitats are disrupted by deforestation together with such indirect effects as drought which is fuelled by industrial expansion and urbanisation. When trees are taken down, the soil's structure becomes unstable, making it more susceptible to erosion and nutrient loss.

d. Greenhouse gas emissions and global warming

Changes in soil properties cause nitrous oxide and carbon dioxide to be released into the atmosphere. These pollutants feed a vicious cycle by making global warming worse (Noyes et al., 2009). A feedback loop is created when soil health continues to decline as temperatures rise.

e. Decreased farm productivity and uncertainty in the soil

The productivity of agriculture decreases with nutrient depletion, loss of soil structure, and decreased water-holding ability (Bhattacharya, 2021).

Protentional Soil Health Improvement Factors

To counteract soil degradation and enhance the organic matter of the soil, it is crucial to understand the role of microorganisms and nutrients in maintaining soil health and fertility (Pankhurst and Lynch, 1995). Microorganisms including bacteria, fungi, and protozoa play a vital role in the decomposition of organic matter and the recycling of nutrients in the soil (Sahu et al., 2019), and also contribute to improve soil structure by producing glues and binding agents (Huang, 2004).

a. Traditional approaches for sustainable practice

Research studies show that fields cultivated using traditional agricultural methods (TAM) represents a time-tested approach to farming deeply rooted in ecological principles. Unlike modern intensive agriculture, which relies heavily on external inputs, TAM emphasizes harmony with nature. It minimizes energy use by employing animals (such as bulls) for tasks like ploughing. Soil fertility is enhanced through organic manure and biofertilizers, minimizing chemical fertilizers. TAM embodies a climate-smart, sustainable approach to food production, safeguarding the environment for future generations. TAM may yield less compared to those treated with fertilizers or modified compost (Diop, 1999), however systematically practiced TAM, can significantly enhance crop production. TAM fosters a balanced ecosystem where productivity thrives while minimizing environmental impact. Implementing agricultural tactics such as intercropping, residual mulching, and minimal tilling is recommended as a profitable and environmentally sustainable farming practice in TAM (Tabriz et al., 2021). These tactics can facilitate the advancement of sustainable agriculture and guarantee the welfare of both individuals and the environment.

b. Conservation agriculture as sustainable practice

In the last half century, there has been a substantial overhaul of the global agriculture industry. This type of agriculture necessitates a greater amount of fossil fuel energy, water, synthetic pesticides, and fertilizers, resulting in detrimental effects on the air, soil, water, and biodiversity (Hiranandani, 2010). Conservation agriculture has gained significant attention in the past decade as a way of "sustainable intensification." The objective of this approach is to encourage the use of economically feasible and environmentally conscious farming methods. Nevertheless, the efficacy of conservation agriculture in enhancing intensive smallholder farming remains unsubstantiated (Jat et al., 2020). Promoting economically feasible and environmentally responsible, sustainable farming practices is crucial. Through the implementation of conservation agriculture and other sustainable agricultural techniques, can guarantee the security of global food supplies while simultaneously safeguarding the environment and public health.

c. Policy approach for sustainable practice

The perceived importance of sustainable agricultural practices is positively correlated with socio-economic position, increased extension support services, higher level of education, and property ownership (Füsun Tatlidil et al., 2009). Nevertheless, this requires considerably larger number of farming households, substantial legislative, institutional, and professional changes (Pretty, 1999).

d. Regulatory measures

Investment subsidies enhance eco-efficiency by efficiently allocating resources, ensuring a balance between economic and environmental considerations. They promote the adoption of environmentally sustainable practices by enterprises, which include minimizing the consumption of fossil fuels and water. Additionally, they actively foster the advancement of sustainable technologies, advocating for sustainable agriculture and striving for a more sustainable future for forthcoming generations. (Czyżewski et al., 2021). Successful implementation requires the crucial elements of stakeholder awareness and involvement (Badsar et al., 2023). It requires incentives to encourage firms to embrace environmentally sustainable practices, thereby decreasing their reliance on fossil fuels and synthetic pesticides. Advocating for the use of sustainable farming methods fosters environmentally conscious habits and ensures a sustainable future for both present and future generations.

Rekindling Enthusiasm for the Promotion of Nutritious Soils

Organic fertilizers enhance eco-efficiency by efficiently allocating resources and achieving a balance between economic and environmental factors. They enhance soil fertility and productivity while minimizing reliance on artificial fertilizers, promoting abundant crop yield. Organic fertilizers have a vital role in promoting sustainable agriculture and protecting the environment (Strauss et al., 2023). Soil pH, organic matter content, nutrient concentrations, and salt levels all have a significant impact on the growth and development of plants. These factors influence the accessibility of nutrients, water, and oxygen to roots, hence impacting plant health and productivity. Ensuring the ideal levels is crucial for the well-being and efficiency of plants (Adderley et al., 2023).

i. Manure

The utilization of cow dung is an asset for achieving eco-efficiency by facilitating optimal allocation of resources and maintaining a balance between economic and environmental considerations. It functions as an inoculant for microorganisms, stimulating soil health and enhancing plant growth.

ii. Bacteria

Plant growth promoting rhizobacteria (PGPR), a common term for beneficial soil bacteria (Hayat et al., 2010), play a major role in both soil health and plant growth. These microbes live in symbiotic relationships with plant roots, carrying out several vital tasks (Harman and Uphoff, 2019). They produce plant hormones, fight infections, improve nutrient availability, stabilise soil structure, and store organic materials (Hamid et al., 2021). Unfortunately, these helpful microorganisms are unintentionally impacted by the extensive use of synthetic chemicals, such as herbicides. We must find a balance between meeting crop protection demands and maintaining the microbial ecosystem to achieve sustainable agriculture. Robust ecosystems, improve soil fertility, and promote healthy plant development by utilising the potential of PGPR (Hakim et al., 2021).

iii. Carbon

Soil organic carbon has a crucial role in maintaining soil health, promoting plant growth, and mitigating erosion. Sustainable farming practices are both economically feasible and environmentally conscientious efforts to enhance soil carbon, to guarantee food safety and safeguarding public (Ayub Bagwan et al., 2023b).

iv. Biochar

Biochar is environmentally and economically efficient soil amendment that helps maintain soil fertility. It can efficiently decrease the presence of metal in soil by improving soil characteristics and promoting the growth of microbial communities

Nanotechnology for Sustainable Soil Management and Crop Yield

Nanotechnology is a potent instrument that can enhance eco-efficiency by facilitating the optimal allocation of resources. This technology has the potential to harmonize economic and environmental factors, thereby contributing to a more sustainable future. It enhances soil fertility, diminish the need for synthetic fertilizers, and sustain crop productivity, rendering them a potent instrument (Arora et al., 2024).

Nanotechnology has garnered significant acclaim as the forthcoming scientific revolution because of its purported properties that include expedited computing systems, and resolutions to energy challenges, among others. Nevertheless, the benefits and drawbacks of nanotechnology are context-dependent. At the atomic and molecular levels, nanotechnology manipulates and controls materials, leading to the creation of innovative materials and devices with exceptional qualities and functionalities (Yadav et al., 2023). In addition to improving physiological parameters like enhanced photosynthetic activity and nitrogen metabolism in many crop plants, the positive morphological effects of nanomaterials include enhanced germination percentage and rate, length of root and shoot and their ratio, and vegetative biomass of seedlings (S. Kumar, Samiksha, et al., 2020).

Conclusion

Excessive use of synthetic chemicals has significantly degraded soil fertility. Long-term reliance on chemical fertilizers is not a viable solution for future agricultural growth and soil sustainability (Syers, 1997). Economic incentives have driven farmers to adopt these practices, but urgent attention is required to develop alternative measures that mitigate impending destruction. Soil erosion, whether natural or human-induced, contributes significantly to nutrient depletion. As a vital livelihood for all living beings, agriculture relies solely on soil. Neglecting soil health not only impacts human well-being but also disrupts ecological balance. Urgent regulatory policies are imperative to sustain soil quality and ensure effective management.

Conflict of Interest

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