The Influence of Soil Health on Food Security and Nutrition: A Review

Obiora, C. U.[1], Obiora, U. B.[2], Anene, N. M. [1] and Mmuoh, C. S. [1]*

1Department of Food Science and Technology, Faculty of Agriculture, Nnamdi Azikiwe University Awka, Anambra State, Nigeria.
2Centre for Environmental Management and Control, University of Nigeria Nsukka, Enugu State

KEYWORDS

Food security,
Soil health,
Soil nutrient dynamics,
Sustainable agriculture

ABSTRACT

This paper provided a review on the crucial role of soil in food production, nutritional quality, and sustainable agricultural practices. By analyzing soil composition and nutrient availability, soil management practices for sustainable agriculture, soil microorganisms and food safety, soil contamination and food quality, soil health and nutritional quality of crops, impact of climate change on soil fertility and food production, future perspectives and innovation, this article aimed to enhance our understanding of the interconnections between soil and food, ultimately contributing to the development of innovative agricultural practices and improved food security.

***CORRESPONDING AUTHOR**

uc.obiora@unizik.edu.ng,
+2348137749586

INTRODUCTION

Soil plays a vital role in facilitating plant growth by offering essential elements like nutrients, water, oxygen, and physical support. Additionally, it serves as a habitat for soil organisms that contribute to the fertility and stability of the soil (FAO, 2015). The health of soil directly influences the nutritional quality of crops. Soil health indicators, such as organic matter content, nutrient availability, and microbial activity, influence the nutrient composition of harvested crops. Conversely, nutrient deficiencies or imbalances in the soil can result in nutrient-deficient crops, affecting human health and nutrition (Silver *et al.,* 2021). Adequate nutrient availability in the soil is essential for optimal plant growth, crop yield, and nutritional quality. Efficient soil management practices are crucial for maximizing food production and ensuring sustainable agricultural systems. Farmers employ various techniques to maintain soil health and fertility, including the application of organic and inorganic fertilizers, crop rotation, and integrated pest management. These activities may impair soil quality and reduce its capacity to support food production. One of the major challenges for soil management is to balance the demand for food with the conservation of soil functions and services. To overcome these challenges, it is necessary to enhance the effectiveness and sustainability of nutrient utilization, minimize soil erosion, and rehabilitate degraded soils (FAO, 2015; Silver *et al.*, 2021). Soil provides the essential foundation for plant growth, nutrient availability, and overall crop productivity. By implementing effective soil management practices and promoting soil health, we can enhance food production, improve the nutritional quality of crops, and foster sustainable food systems. This article aims to provide a comprehensive understanding of the intricate relationship between soil and food,examining the crucial role of soil in food production, nutritional quality, and sustainable agricultural practices, ultimately contributing to the development of innovative agricultural practices and improved food security.

Soil Composition and Nutrient Availability

Soil composition plays a crucial role in determining the availability of nutrients for plant uptake, ultimately influencing crop growth and productivity. The physical and chemical properties of soil, along with its mineral composition and organic matter content, collectively contribute to nutrient availability (Marschner and Rengel, 2023).The physical properties of soil, such as texture, structure, and porosity, affect nutrient retention and movement. Soils with finer particles, such as clay, have a higher cation exchange capacity, allowing them to retain and supply nutrients to plants over an extended period. Chemical properties of soil, including pH, organic matter content and nutrient-holding capacity, also impact nutrient availability. Soil pH significantly influences nutrient solubility and availability. Acidic soils with low pH levels can limit the availability of essential nutrients like phosphorus, calcium, and magnesium, while alkaline soils can restrict the uptake of micronutrients like iron and zinc (Aziz *et al.*, 2010).Organic matter in the soil plays a vital role in nutrient cycling and availability. It acts as a reservoir of nutrients, releasing them gradually over time for plant uptake. Soil fertility is closely linked to nutrient availability, as fertile soils contain adequate levels of essential nutrients required for plant growth. In addition to yield and nutritional composition, nutrient availability affects the overall health and resilience of plants. Balanced nutrient uptake supports plant immune systems, helping to combat diseases and pest infestations. To ensure optimal nutrient availability for crops, soil testing and nutrient management practices are essential. Soil testing provides insights into the nutrient status of the soil, allowing for targeted fertilizer application based on specific crop requirements. Adopting precision nutrient management strategies can help prevent nutrient deficiencies or excesses, optimizing crop quality and minimizing environmental impacts (Silver *et al.,* 2021).

Soil Management Practices for Sustainable Agriculture

Sustainable soil management practices are essential for maintaining soil health, improving agricultural productivity, and preserving natural resources. These practices aim to optimize soil functions while minimizing negative environmental impacts (Powlson*et al.,* 2011).Crop rotation involves the systematic rotation of different crops on the same piece of land over time. This practice helps break disease and pest cycles, enhances soil structure, and improves nutrient availability. Diversification of crops also promotes biodiversity, reduces the reliance on chemical inputs, and enhances overall ecosystem resilience (Powlson*et al.,* 2011; Tugrul, 2019).Cover cropping involves planting specific crops during fallow periods or between main crops. They also contribute to weed suppression, pest control, and nutrient cycling (Lal*et al.*, 1997).Effective nutrient management is crucial for sustainable soil fertility and crop productivity. It involves optimizing the application of organic and inorganic fertilizers based on soil nutrient testing and crop nutrient requirements. Balancing nutrient inputs with crop uptake minimizes nutrient losses, reduces environmental pollution, and improves nutrient use efficiency (Earles and Williams, 2005). Integrated Pest Managementcombines various pest control strategies to minimize the use of chemical pesticides while effectively managing pests. This approach integrates cultural practices, biological control agents, and targeted pesticide application. By minimizing pesticide use, Integrated Pest Management helps protect beneficial soil organisms, pollinators, and overall ecosystem health (Reganold*et al*., 1990; Powlson*et al.*, 2014). Sustainable water management practices, such as precision irrigation, help optimize water use efficiency and conserve water resources.

Soil Microbiome and Food Safety

Soil microorganisms play a critical role in maintaining food safety throughout the agricultural production chain and have a significant impact on food safety. While beneficial soil microorganisms contribute to nutrient cycling and plant health, soil-borne pathogens pose risks to human health when transmitted to crops and consumed. Beneficial soil bacteria and fungi, such as *rhizobia* and *mycorrhizal fungi*form symbiotic relationships with plants, enhancing nutrient uptake and promoting plant health. These microorganisms contribute to sustainable agriculture practices by reducing the need for chemical fertilizers and pesticides (Altomare, and Tringovska, 2011).Soil can also harbor pathogenic microorganisms, including bacteria, viruses, and parasites, which can contaminate crops and pose risks to human health. Pathogens such as *Salmonella, Escherichia coli (E. coli), Listeria monocytogenes*, and various parasites can be present in soil and be transferred to food crops through contaminated irrigation water, contaminated manure or compost, or poor hygiene practices during harvesting and processing (Qian*et al.*, 2021). Soil contamination can occur due to various factors, including improper handling and application of manure or sewage sludge, runoff from animal production facilities, polluted irrigation water, and the use of contaminated agricultural inputs. These contaminated soils can introduce pathogenic microorganisms into the food production system, increasing the risk of foodborne illnesses(Sethi and Gupta, 2020).Implementing Good Agricultural Practices is essential for reducing the risk of soil microbial contamination in food production include measures such as proper composting techniques, appropriate use of manure and irrigation water, regular monitoring and testing of soil and water sources, and adequate hygiene practices during crop handling and processing.

Soil Contamination and Food Quality

Various contaminants, such as heavy metals, pesticide residues, and pollutants, can accumulate in soil and affect the quality and nutritional value of crops. Heavy metals, including lead, cadmium, mercury and arsenic, can accumulate in soil due to human activities such as industrial processes, mining, and the use of contaminated fertilizers or irrigation water. These heavy metals can be taken up by plants and accumulate in their tissues, affecting crop quality (Golia, 2023). High levels of heavy metal contamination in soil can lead to reduced crop yield, decreased nutrient uptake, altered nutrient composition, and compromised food safety (Lewin *et al.,* 2018).Chronic exposure to pesticide residues in food can have adverse effects, including neurotoxicity, endocrine disruption, and increased cancer risk. To mitigate these risks, proper pesticide application techniques, adherence to recommended safety intervals, and compliance with maximum residue limits are essential (Van Boxstael *et al.*, 2013).Soil pollution, resulting from the release of pollutants such as industrial chemicals, heavy metals, and persistent organic pollutants, can impact food nutritional value (Mishra *et al.*, 2016). Pollutants can affect the soil's fertility, nutrient cycling processes, and microbial activity, thereby influencing the availability and uptake of nutrients by plants (Oves *et al.*, 2012). Soil pollution can lead to nutrient imbalances, reduced crop quality, and compromised nutritional value of food, potentially affecting human health and well-being.

Soil Health and Nutritional Quality of Crops

Soil health indicators provide valuable insights into the overall condition and functionality of the soil ecosystem (Weil, 2004). These indicators include physical, chemical, and biological properties that influence nutrient availability and uptake by plants. For example, soil organic matter content is closely related to nutrient cycling and can enhance nutrient retention and release in the soil (El-Ramady*et al.,* 2014). Other indicators, such as pH, nutrient levels, microbial activity, and soil structure, also impact crop nutrition. Assessing these soil health indicators helps identify potential nutrient limitations or imbalances, guiding appropriate management strategies to optimize crop nutrition (Karlen*et al.,* 1999).Organic amendments, such as compost and manure, enrich the soil with nutrients and enhance soil microbial activity, ultimately benefiting crop nutrition. On the other hand, inappropriate use of fertilizers, excessive tillage, or improper irrigation practices can negatively impact soil health and subsequently affect crop nutrient content (Ghorbani *et al.,* 2008). Soil characteristics, including texture, pH, and mineral content, addition of fertilizer can affect nutrient availability and uptake by plants. For instance, acidic soils may limit the availability of certain nutrients, while alkaline soils can affect nutrient uptake due to ion imbalances (Lehmann *et al*., 2020). Additionally, soils with varying mineral compositions can influence the nutrient content of crops. Understanding these soil-crop interactions can help identify potential nutritional variations and guide targeted agricultural practices to address specific nutrient deficiencies or imbalances.

Future Perspectives and Innovations

In recent years, there has been growing interest in exploring emerging technologies and approaches to enhance soil and food systems (Caliman *et al*., 2011). Advancements in technology are revolutionizing the way we understand and interact with soil and food production. Several emerging technologies and approaches hold tremendous promise for improving soil health and food systems (Giller*et al.,* 2004). Nanoparticles, such as nano-fertilizers and nano-pesticides, offer targeted and controlled delivery of nutrients and pest management agents to plants. These nanomaterials can improve nutrient uptake efficiency, reduce chemical usage, and mitigate environmental impacts (Manjunatha *et al.,* 2016). This approach emphasizes the use of beneficial microorganisms and organic amendments to enhance soil fertility, suppress diseases, and promote plant growth. Harnessing the power of microbial communities can result in improved nutrient cycling, reduced reliance on synthetic inputs, and increased soil biodiversity (Giller*et al.,* 2004). As urbanization continues to increase, vertical farming presents a sustainable solution for cultivating food in limited spaces. By utilizing advanced lighting systems, hydroponics, and aeroponics, vertical farms can optimize resource utilization, minimize water usage, and reduce transportation costs(Al-Kodmany, 2018).Some notable innovations include remote sensing and satellite imagery (Yang *et al*., 2012), sensor-based soil monitoring

(Bogue, 2017). These data enable farmers to implement precise irrigation and nutrient management strategies, reducing resource wastage and optimizing crop productivity. Farmerscan detect early signs of stress or diseases and take prompt corrective actions(Robert, 2002). This holistic approach promotes adaptive management strategies, leading to improved productivity, profitability, and environmental stewardship (Glover *et al*., 2000).

CONCLUSION

The relationship between soil and food is crucial for sustainable agriculture and food security. This article explores emerging technologies and approaches in soil and food, precision agriculture, and soil monitoring techniques, emphasizing the integration of soil health assessments into food production systems. Adoption of innovative technologies can enhance sustainability by optimizing resource use, reducing chemical inputs, and improving soil health, leading to resilient and productive agricultural systems. Precision agriculture minimizes waste, conserves water, and boosts crop productivity while reducing environmental pollution. However, further research and collaboration are needed to understand the impact of changing climatic conditions on soil fertility and crop performance, and to explore regenerative agriculture practices for enhancing ecosystem services and biodiversity. Integrating soil health assessments into food production empowers farmers to implement targeted management practices for sustainable outcomes, paving the way for a more resilient and productive future in soil and food production.

REFERENCES

Al-Kodmany, K. (2018). The vertical farm: A review of developments and implications for the vertical city. *Buildings*, *8*(2), 24.

Altomare, C., and Tringovska, I. (2011). Beneficial Soil Microorganisms, an Ecological Alternative for Soil Fertility Management. *Genetics, biofuels and local farming systems*. pp. 161-214.

Aziz, T., S. Ullah, A. Sattar, M. Nasim, M. Farooq and Khan, M. M. (2010).Nutrient Availability and Maize (*Zea mays L*.) Growth in Soil amended with Organic Manures. *International Journal Agric. and Biology*, 12: 621–624

Bogue, R. (2017). Sensors key to advances in precision agriculture. *Sensor Review*, 37(1):1-6.

Caliman, F. A., Robu, B. M., Smaranda, C., Pavel, V. L., and Gavrilescu, M. (2011).Soil and groundwater cleanup: benefits and limits of emerging technologies. *Clean Technologies and Environmental Policy*, 13: 241-268.

El-Ramady, H. R., Alshaal, T. A., Amer, M., Domokos-Szabolcsy, É.,Elhawat, N., Prokisch, J., and Fári, M. (2014). Soil quality and plant nutrition. *Sustainable Agriculture Reviews 14: Agroecology and Global Change*, 345-447.

Food and Agriculture Organization of the United Nations (2015).*FAOSTAT Statistical Database*. [Rome].

Ghorbani, R., Wilcockson, S., Koocheki, A., and Leifert, C. (2008). Soil management for sustainable crop disease control: a review. *Environmental Chemistry Letters*, 6:149-162.

Giller, K.E., Chalk, P., Dobermann, A., Hammond, L., Heffer, P., Ladha, J.K., Nyamudeza, P., Maene, L., Ssali, H. and Freney, J., (2004).Emerging technologies to increase the efficiency of use of fertilizer nitrogen. *Agriculture and the nitrogen cycle: assessing the impacts of fertilizer use on food production and the environment*, 65:35-51.

Glover, J. D., Reganold, J. P., and Andrews, P. K. (2000).Systematic method for rating soil quality of conventional, organic, and integrated apple orchards in Washington State. *Agriculture, ecosystems and environment*, 80(1):29-45.

Golia, E. E. (2023). The impact of heavy metal contamination on soil quality and plant nutrition.Sustainable management of moderate contaminated agricultural and urban soils, using low cost materials and promoting circular economy. *Sustainable Chemistry and Pharmacy*, 33:101046.

Karlen, D. L., Eash, N. S., and Unger, P. W. (1992).Soil and crop management effects on soil quality indicators. *American Journal of Alternative Agriculture*, 7(2):48-55.

Lehmann, J., Bossio, D. A., Kögel-Knabner, I., and Rillig, M. C. (2020). The concept and future prospects of soil health. *Nature Reviews Earth and Environment*, 1(10):544-553.

Lewin, C. S., Seo, B. H., Kim, H. U., Owens, G., and Kim, K. R. (2018).Application of soil amendments to contaminated soils for heavy metal immobilization and improved soil quality—A critical review. *Soil science and plant nutrition*, 64(2):156-167.

Manjunatha, S. B., Biradar, D. P., and Aladakatti, Y. R. (2016). Nanotechnology and its applications in agriculture: A review. *Journal farm Sciences*, 29(1):1-13.

Marschner, P. and Rengel, Z. (2023). Nutrient availability in soils.*Marschner's Mineral Nutrition of Plants (Fourth Edition)*, pp. 499-522. https://doi.org/10.1016/B978-0-12-819773-8.00003-4

Mishra, R. K., Mohammad, N., and Roychoudhury, N. (2016). Soil pollution: Causes, effects and control. *Van Sangyan*, 3(1):1-14.

Oves, M., Khan, M. S., Zaidi, A., and Ahmad, E. (2012). Soil contamination, nutritive value, and human health risk assessment of heavy metals: an overview. *Springer Vienna*. pp. 1-27.

Powlson, D. S., Gregory, P. J., Whalley, W. R., Quinton, J. N., Hopkins, D. W., Whitmore, A. P., and Goulding, K. W. (2011). Soil management in relation to sustainable agriculture and ecosystem services. *Food Policy*, 36:S72-S87.

Qian, H., Zhang, Q., Lu, T., Peijnenburg, W. J., Penuelas, J., and Zhu, Y. G. (2021). Lessons learned from COVID-19 on potentially pathogenic soil microorganisms. *Soil Ecology Letters*, *3*(1):1.

Reganold, J. P., Papendick, R. I., and Parr, J. F. (1990).Sustainable agriculture. *Scientific American*, 262(6):112-121.

Sethi, S., and Gupta, P. (2020). Soil contamination: a menace to life. *Soil Contamination*. IntechOpen.

Tugrul, K. M. (2019). Soil management in sustainable agriculture. In *Sustainable crop production*. London, UK: IntechOpen.

Van Boxstael, S., Habib, I., Jacxsens, L., De Vocht, M., Baert, L., Van de Perre, E., Rajkovic, A., Lopez-Galvez, F., Sampers, I., Spanoghe, P. and De Meulenaer, B. (2013).Food safety issues in fresh produce: Bacterial pathogens, viruses and pesticide residues indicated as major concerns by stakeholders in the fresh produce chain. *Food Control*, 32(1):190-197.

Weil, R. R., and Magdoff, F. (2004).Significance of soil organic matter to soil quality and health. *Soil organic matter in sustainable agriculture*, 1-43.

Yang, C., Everitt, J. H., Du, Q., Luo, B., and Chanussot, J. (2012). Using high-resolution airborne and satellite imagery to assess crop growth and yield variability for precision agriculture. *Proceedings of the IEEE*, 101(3): 582-592.