Mini Review

Plant nutrition in organic agriculture

Abstract

Organic agriculture aims to sustain ecosystems, including soil microorganisms, fauna, and humans, by producing high-quality, nutritious food and avoiding the use of synthetic agrochemicals. It prioritizes long-term soil health and ecological balance over short-term, direct feeding by fostering a vibrant soil ecosystem. It is a resilient and self-sustaining system that provides for plant needs while enhancing the environment through the use of organic fertilizers and microorganisms. Plant nutrition in organic agriculture is a holistic, systems-based approach. Organic farming relies on natural inputs to provide nutrients for plants, derived from living organisms, including compost, manure, biochar, cover crops, and green manures. It supplies essential nutrients for plant growth and serves as a slow-release fertilizers, returning some of the nutrients absorbed from the soil. Organic fertilizers improve soil health by promoting better root development, nutrient uptake, and overall plant health. Soil microorganisms are fundamental to nutrient availability in organic agriculture because they mediate decomposition, nutrient cycling, and transformation processes. Beneficial microorganisms affect soil structure and enhance soil aggregation, which involves the distribution of water, air, and nutrients. It includes plant growth-promoting bacteria (PGRB), nitrogen-fixing bacteria, phosphate-solubilizing microorganisms, and mycorrhizal fungi (AMF), which play important roles in maintaining soil fertility and facilitating plant nutrient uptake. Microbial communities convert soil organic matter and minerals, releasing the nutrients they contain and making them available to plants. Organic farming requires more complex management and planning than conventional agriculture and leads to more efficient and environmentally benign nutrient use.

Keywords: biochar, compost, ecosystems, manure, cover crops

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Introduction

Organic farming has gained momentum as a sustainable alternative to conventional agriculture, driven by global demand for organic products and environmental concerns. The adoption of organic farming practices is increasing each year as producers, consumers, and the government recognize the benefits of sustainable agriculture. Organic farming focuses on producing safe food in an environmentally friendly manner, avoiding synthetic pesticides and fertilizers, and promoting biodiversity.

Organic farming requires more complex management and planning than conventional agriculture, but the theory leads to more efficient and environmentally benign nutrient use.[1]

The main macronutrients in plant nutrition are nitrogen (N), phosphorus (P), and potassium (K), supplied mainly through mineral or organic fertilizers.[2] Each nutrient element performs specific functions in plant growth and metabolism, and deficiencies or excesses can lead to plant health issues.[3]

Plant nutrition is a bottleneck in organic agriculture, with ongoing efforts to find alternatives to mineral fertilizers, which are expensive and environmentally damaging (e.g., soil salinization).[4] In arid and semi-arid regions, soil organic matter is typically very low, making conservation and improvement of soil fertility crucial for sustainable farming.[5]

Plant nutrition in organic agriculture is fundamentally different from that in conventional agriculture. It shifts the focus from feeding the plant directly with soluble, synthetic fertilizers to feeding the soil ecosystem, which in turn supports and feeds the plant.[6] Nutrition in organic systems works on nourishing the soil before the plants and avoiding synthetic fertilizers, in accordance with the well-known maxim, "Feed the soil, not the plant."

Integrated plant nutrition management in organic systems considers three major sources: organic (soil organic matter, manures, and cover crops), natural materials (rocks), and biological (microorganisms, N-fixation).[7] Conservation and organic agriculture promote the integration of legumes in cropping systems to enhance soil fertility and plant nutrition, but technology transfer to resource-poor farmers remains a challenge.[8]

Organic agriculture relies on a holistic approach to plant nutrition, emphasizing soil health, organic inputs, biological processes, and sustainable management, but faces challenges in nutrient adequacy, soil fertility, and dissemination of technology.[9]

Why has organic agriculture not yet been widely adopted?

The slow adoption of organic agriculture is not due to a single factor but a complex interplay of economic, structural, social, and perceptual barriers. It requires a deep understanding of soil ecology, crop rotations, and biological pest control—skills that are different from conventional, input-driven farming. Access to reliable extension services and advisors is limited in many regions.[10]

The infrastructure (for processing, storage, and distribution) and supply chains are still geared toward large-scale conventional agriculture. It often struggles to access organic seeds, nutrients, and specialized equipment.

Organic farming methods are easier to implement on large-scale farms, while small farmers are often hesitant to invest in long-term soil health. Furthermore, agricultural subsidies in many countries (such as EU's CAP or the US farm bills) encourage farmers to switch to organic farming, which is not available in developing countries.

Providing plant nutrients is a crucial factor in implementing organic farming, particularly NPK. The nutritional philosophy of organic systems relies on integrating locally available resources such as compost, manure, and biochar, as well as the use of cover crops, especially legumes, to fix atmospheric nitrogen. In addition, it is complemented by plant stimulants such as humic acids, protein hydrolysates, and seaweed extracts, as well as inoculant microorganisms including mycorrhizae fungi, nitrogen-fixing bacteria, and earthworms.

This work discusses how to meet plant nutrient requirements at various growth stages through the different sources permitted in organic farming, thus overcoming potential nutrient deficiencies in this type of agriculture.

Principles and goals of plant nutrition in organic agriculture

Organic agriculture aims to sustain the ecosystems, including soil microorganisms, fauna, and humans, by producing high-quality, nutritious food and avoiding the use of synthetic fertilizers and pesticides.[11] Organic farming systems aim to improve sustainability by reducing inputs, promoting crop rotation, using cover crops such as legumes, and applying manure.

Organic farming relies on natural inputs to provide nutrients for plants, such as compost and manure, which return some of the nutrients absorbed from the soil. It also contributes to environmental protection and maintaining high yields for different crops by safely disposing of plant and animal waste and providing habitat for many microorganisms.[12]

Organic matter is a key component of soil fertility, improving its structure, stability, and water retention capacity. It is derived from plant residues, animal manure, and microorganism secretions, and it provides numerous nutrients that directly impact plant productivity and quality. Soil organic matter is particularly crucial for storing and supplying nitrogen and phosphorus.

Organic fertilizers support the accumulation of organic matter, maintain soil health, and promote diverse microbial communities. Furthermore, organic fertilization alters the composition and function of soil microbial communities, thereby enhancing nutrient transformation and availability.[13]

Organic fertilizers are nutrient sources derived from living organisms, including compost, manure, biochar, and green manures. They are characterized by their slow release of plant nutrients and are processed from biomass, animal and plant waste, and plant residues. These fertilizers are rich in organic matter and contain essential macronutrients (nitrogen, phosphorus, potassium) and micronutrients (iron, zinc, manganese).[14]

The plant nutrition paradigm is shifting from viewing organic nutrition as a simple substitution of synthetic NPK for "organic" sources to understanding it as management of the rhizosphere microbiome for plant-mediated nutrition.[10] Plants don't just absorb nutrients from organic sources. They exude specific compounds to recruit and feed microbial consortia (bacteria and mycorrhizal fungi) that perform critical functions: unlocking nutrients from soil minerals (e.g., phosphorus solubilization), fixing atmospheric nitrogen (beyond just legumes), and suppressing pathogens. The plant is considered the "conductor," and soil health is the "orchestra" in organic systems.

Organic nutrition management, optimizing nutrient balance, can enhance the plant's production of secondary metabolites (antioxidants, polyphenols, alkaloids). Organic systems contribute to a circular economy by transforming agricultural waste (crop residues, food processing byproducts, compost, manure, and wood chips) into sustainable plant fertilizers through anaerobic digestion (to produce energy and organic fertilizer), and advanced composting techniques (such as worm composting, biochar, and soluble fertilizers).[15]

Nutrient supply and plant growth

Organic fertilizer supplies essential nutrients for plant growth and serve as slow-release fertilizers, delivering nutrients over an extended period, thereby enhancing plant growth and yield and improving the quality of various plants.[16] Organic fertilizers mitigate environmental risks such as eutrophication, groundwater contamination, and over-fertilization by releasing nutrients slowly and having lower solubility than synthetic ones. They contribute to climate change mitigation and the preservation of scarce natural resources by recycling organic waste and fixing carbon in the soil.[17]

The use of organic fertilizers has been shown to increase nutrient uptake, such as nitrogen, phosphorus, and potassium, by crops and improve soil fertility, thereby supporting plant nutrition and productivity.[18] Organic fertilizers improve soil health by contributing to better root system development, nutrient uptake, and overall plant health as follows:

- Improving soil structure and organic matter content
- Increasing soil porosity and aeration
- Enhancing water infiltration and retention
- Decreasing soil acidity
- Promoting the diversity and quantity of beneficial organisms.

Main organic sources of Nutrients

Compost: Compost is one of the main sources of nutrients in the organic system, especially for nitrogen (N). Compost is commonly applied before planting or during the growing season, but nutrient availability depends on plant species, environmental conditions, and timing/method of application.

Compost plays a multifaceted role in plant nutrition by supplying essential nutrients, improving soil health and structure, enhancing microbial activity, and providing environmental benefits. However, their limitations in nutrient content and release rate often necessitate their use in combination with other organic fertilizers, particularly biofertilizers for optimal crop production.[19]

Biochar: Biochar is a substance rich in carbon and has remarkable resistance to decomposition. It is mainly generated via the pyrolysis (thermal degradation) of biomass, particularly agricultural residues, in a closed furnace with a limited oxygen supply. Biochar improves soil water retention due to its fine particle size and high porosity. Applied biochar enhances drought-stressed soil by reducing ionic and osmotic toxicity and increasing water availability, thereby mitigating the impact of abiotic stresses and improving plant growth.

The addition of biochar has been shown to mitigate the impact of abiotic stresses (by reducing ionic and osmotic toxicity and increasing water availability) and improve yield. The presence of biochar significantly impacted antioxidant enzyme activity.[20] Biochar soil application has a positive impact on soil, as it supports nitrogen fixation, minimizes soil-borne diseases spread and nitrate leaching, and reduces nitrous oxide emissions.

Manures: Recycling of nutrients through crop residues and animal manures is essential. Manure cannot fully replace nutrients removed from the farm in produce, leading to evidence of declining soil phosphorus (P) and potassium (K) in some organic systems.[21]

Green manure and animal manure are rich source of nutrients, particularly nitrogen. Crucially, raw manure must be composted or applied well before harvest to avoid the risk of pathogen contamination.[22]

Mineral-based amendments: These are natural rocks and minerals that are approved for use in organic farming. They are typically slow-release and used to provide specific nutrients. Microorganisms are regularly used for decomposition and nutrient release.[23]

Main rocks use in organic farming include:

- For Phosphorus (P): Soft rock phosphate.
- For Potassium (K): Langbeinite and greensand.
- For Calcium (Ca): Agricultural gypsum and limestone (which also raise pH).
- For Micronutrients: Derivatives from natural sources can be used in chelated form as a source of boron, zinc, manganese, and other minerals.

Biological and microbial contributions

Beneficial microorganisms, including plant growth-promoting bacteria (PGRB), nitrogen-fixing bacteria, phosphate-solubilizing microorganisms, and mycorrhizal fungi (AMF), play important roles in maintaining soil fertility and facilitating plant nutrient uptake.[9] Microbial communities convert soil organic matter and minerals, releasing the nutrients they contain and making them available to plants.[24]

Soil microorganisms are central to nutrient availability in organic agriculture through their roles in decomposition, nutrient cycling, symbiosis, and response to management practices, ultimately supporting soil fertility and crop productivity.[25]

These microorganisms act in the decomposition of plant residues and release nutrients into the rhizosphere, making them available to plants. Applying organic residues to soil, manure, and crop rotation enhances nutrient availability, improving the efficient nutrient cycle and stimulating root growth through a complex network of microorganisms (Table 1).

Table 1 Role of microbial communities in plant nutrition

Microbial function	Mechanism/process	Impact on nutrient availability	References
Decomposition & Mineralization	Breakdown of organic matter	Release of N, P, S for plant uptake	Naqvi et al.[25]
Symbiosis (AMF, PGPR)	Nitrogen fixation, P solubilization	Enhanced nutrient absorption	Abobatta[26]
Organic Amendments	Stimulate microbial activity	Improved soil fertility & structure	Baruah & Deb[27]
Soil Aggregation	Microbial influence on structure	Better water, air, nutrient distribution	Wei et al.[28]
Rhizosphere Interactions	Rhizodeposition, competition	Efficient nutrient cycling	Hada et al.[29]

Microbial Interactions: Bacteria, fungi, and protists interact within soil aggregates, influencing nutrient mineralization and cycling. Fertilization practices and environmental conditions shape the structure and biodiversity of these communities.[30]

AMF, in particular, improves mineral uptake, which may explain differences in mineral composition of plant food between conventional and organic systems.[31]

Bioorganic fertilizers, such as nitrogen-fixing bacteria, phosphate-solubilizing bacteria, and mycorrhizal fungi, promote soil microbial activity, thereby enhancing nutrient cycling and plant health, suppressing soil pathogens, and reducing plant disease incidence.[20]

Microbial inoculants and biofertilizers introduce or enhance beneficial soil microbes (Table 2), numerous organisms are used, including

- Mycorrhizal Fungi: Form a symbiotic relationship with plant roots, extending their reach for water and phosphorus.
- Rhizobia Bacteria: Inoculated onto legume seeds to form nitrogen-fixing nodules on their roots.
- Other Beneficial Microbes: Bacteria (like Bacillus spp.) and fungi (like Trichoderma spp.) that aid in nutrient solubilization and disease suppression.

Table 2 Key aspects of plant nutrition in organic agriculture

Aspect	Organic agriculture approach	Challenges/limitations	References
Nutrient Sources	Compost, manure, crop residues, legumes, beneficial microorganisms	Inadequate N, declining P & K, low organic matter	Landa-Acuña et al.[9]
Nutrient Cycling	Feed the soil, not the crop; rely on microbial mineralization and crop rotations	Requires complex management, planning	Merfield[32]
Soil Fertility	Enhance organic matter, microbial activity, and ecosystem health	Low fertility in arid/semi-arid and coarse soils	Bistgani et al.[5]
Environmental Impact	Avoid synthetic fertilizers/pesticides; focus on sustainability	Technology transfer, nutrient recovery	Khan et al.[8]
Plant Health and Yield	Maintain through balanced nutrition, disease resistance, and stress tolerance	Deficiencies/excesses affect health and yield	Mészáros et al.[3]

Microbial diversity is enhanced by the provision of organic amendments, thereby improving nutrient cycling and crop yields.[26] Organic agriculture relies on soil microorganisms for sustainable nutrient management and preserves soil health.

Role of soil microorganisms in nutrient availability

Soil microorganisms are fundamental to nutrient availability in organic agriculture because they mediate decomposition, nutrient cycling, and transformation processes. They decompose organic matter and release essential nutrients through mechanisms such as oxidation, reduction, solubilization, and chelation, directly affecting nutrient availability for plants. Microorganisms store carbon and nutrients in their biomass and act as labile reservoirs with rapid turnover, which influences soil productivity and nutrient cycling.[28]

Impact of organic amendments and fertilization practices

Organic amendments: The addition of organic materials such as manure, compost, and crop residue improves soil fertility, structure, and quality by stimulating microbial activity and diversity. Organic amendments enhance nutrient cycling and increase crop yields.[30]

Microbial communities: Beneficial microorganisms affect soil Structure and enhance soil aggregation, which involves the distribution of water, air, and nutrients. Soil aggregates provide habitats for essential microbes and facilitate nutrient cycling.[32] The diversity and efficiency of microbial communities are crucial for nutrient competition and facilitation among plants. While plants contribute organic matter through rhizodeposition, driving the activity of heterotrophic microorganisms in the rhizosphere.

Challenges and limitations

In low-input systems, such as those in countries like Senegal, plant nutrition relies primarily on decomposition of soil organic matter, still limited by the low storage capacity of coarse-textured soils, necessitating strategies based on soil fauna.[33]

The abundance of macro- and microelements in soils is usually insufficient for full plant yield, and fertilization is needed to correct deficiencies. The need to recover nutrients and improve their use efficiency is vital for phosphorus and nitrogen due to limited reserves and environmental impacts of fertilizer production.[2]

Conclusion

Organic agriculture focuses on sustaining ecosystems, including soil microorganisms, animals, and humans, by producing nutritious food without synthetic chemicals. Organic farming uses organic fertilizers and microorganisms to enhance soil health and effectively manage plant and animal waste, contributing to environmental protection and maintaining high crop yields. Plant nutrition in organic farming is a holistic process that relies on natural inputs like compost, manure, biochar, cover crops, and green manures. These inputs provide essential nutrients and act as slow-release fertilizers, promoting better root development and overall plant health. Soil microorganisms play a key role in making nutrients available, as they facilitate decomposition and nutrient cycling, improving soil structure and aiding in nutrient uptake. Beneficial microorganisms, such as specific bacteria and fungi, are crucial for maintaining soil fertility. Organic farming requires more planning and management than conventional methods, leading to more efficient and eco-friendly nutrient use.

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None

Conflict of interest

The authors declare that they have no conflicts of interest.

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