Advances in Research

Volume 25, Issue 6, Page 297-308, 2024; Article no.AIR.127829
ISSN: 2348-0394, NLM ID: 101666096

Exploring Potential of Organo-mineral Fertilizers in Augmenting Crop Yield and Quality – A Review

Varalakshmi, V [a++*], Bhagyalakshmi T [a] and Shivakumar Mirji [a]

[a] *Department of Soil Science and Agricultural Chemistry, CoA, V.C. Farm, Mandya-571405, India.*

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/air/2024/v25i61203

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/127829

Review Article

Received: 02/10/2024
Accepted: 04/12/2024
Published: 07/12/2024

ABSTRACT

Inorganic fertilizers are essential for improving crop yield and quality through enhanced crop efficiency. However, their continuous use often causes nutrient imbalances, leading to poor yield and quality. Organic manures, while effective in improving soil fertility and crop productivity, face challenges such as limited availability, variable quality, transportation issues, heavy metal contamination and slow nutrient release. The exclusive dependence of either organic or inorganic fertilizers has not adequately fulfilled the increasing demands for enhanced agricultural output and quality. To address these challenges, organo-mineral fertilizers (OMFs) have emerged as an innovative solution. OMFs are derived from the combination of mineral and organic nutrient sources, integrating the benefits of both. This low input technology supplies nutrients in balanced quantities that are readily and steadily available throughout the growing season. OMFs improve soil

[++] *Ph.D Scholar;*
**Corresponding author: E-mail: varalu713@gmail.com;*

Cite as: *V, Varalakshmi, Bhagyalakshmi T, and Shivakumar Mirji. 2024. "Exploring Potential of Organo-Mineral Fertilizers in Augmenting Crop Yield and Quality – A Review". Advances in Research 25 (6):297-308. https://doi.org/10.9734/air/2024/v25i61203.*

physical properties, enhance fertility and support sustainable crop production. They also promote plant resistance to biotic and abiotic stress, offering a holistic approach to agricultural challenges. The development of OMFs aligns with the recycling of urban, industrial and agricultural residues, reducing dependency on raw materials for chemical fertilizers and contributing to environmental sustainability. Advances in OMF preparation, using various mineral and organic matrices, have demonstrated their ability to address nutrient deficiencies, particularly in tropical soils, where poor fertility often limits productivity. OMFs enhance soil physico-chemical and biological properties, addressing soil degradation while improving crop yield and quality. They ensure an optimal supply of nutrients, support long-term soil health and align with modern fertilizer management strategies aimed at sustainable agricultural productivity. In conclusion, OMFs are a promising solution for boosting crop quality and yield while maintaining soil fertility. By incorporating the advantages of organic and inorganic inputs, they provide a balanced, sustainable, and efficient strategy to address growing demands for food production.

Keywords: Fertilizers; nutrient; organo-mineral; quality; yield.

1. INTRODUCTION

An immense quantity of waste emanates from a multitude of sectors, including agriculture, industrial complexes, urban developments and mining sites. This waste is characterized by a rich nutritive composition and a highly recyclable disposition, presenting a significant opportunity to counteract the inherent shortcomings associated with the singular application of either organic or inorganic nutrient sources (Smith, 2015). A viable and sophisticated approach to ameliorating these dual challenges is the adoption of organo-mineral fertilizers (OMFs) (Johnson and Brown, 2018).

OMFs represent a class of agronomic solutions meticulously derived from the integration of mineral and organic nutrient sources. This intricate combination engenders a bifunctional mechanism of nutrient release: the organic components facilitate a controlled, gradual nutrient dispensation, whereas the inorganic elements afford an expedited, readily available nutrient supply (Davis *et al*., 2020).

The formulation of organo-mineral fertilizers necessitates the strategic deployment of diverse organic and inorganic substrates. Organic substrates encompass compost, peat, manure, wood ash, vermicompost, bonemeal, sapropel, rice bran, biochar, coffee husk, sawdust, wood shavings and sewage sludge (Anderson & Clark, 2017). Conversely, the inorganic spectrum encompasses mineral-based resources, such as rock phosphate, gypsum, lime, mica waste, feldspar and basalt, in addition to synthetic derivatives like monoammonium phosphate, diammonium phosphate, potassium nitrate, urea, single super phosphate, triple super phosphate and potassium chloride (Miller, 2016).

2. STANDARDIZED ENDORSEMENT, ENHANCEMENT AND UPCYCLING PATHWAYS FOR THE CONVERSION AND OPTIMIZATION OF ORGANIC AND MINERAL WASTE INTO HIGH VALUE ORGANO-MINERAL FERTILIZERS

The increasing need for sustainable agricultural practices and the efficient management of waste has led to the growing interest in organo-mineral fertilizers (OMFs). These fertilizers are the product of combining organic waste (such as compost, manure, and plant residues) with mineral nutrients (like rock phosphate, gypsum and synthetic fertilizers) (Smith, 2020). The process of converting organic and mineral waste into OMFs involves several pathways, which can be categorized as endorsement, enhancement and upcycling (Johnson and Lee, 2018).

2.1 Endorsement of Waste for Fertilizer Production

The first stage in the process of creating organo-mineral fertilizers is the endorsement of waste materials, which involves the identification and validation of both organic and mineral waste streams as suitable inputs for fertilizer production (Anderson, 2017). This stage ensures that the waste is rich in the nutrients necessary for plant growth, such as nitrogen, phosphorus, potassium, calcium and trace minerals (Brown *et al*., 2015). Mineral wastes, especially those from the phosphate industry, are particularly suitable for this process because they are abundant and contain significant amounts of essential fertilizing compounds. Organic waste is typically sourced from agricultural residues, urban green waste and industrial by-products (Wilson and Taylor, 2016).

2.2 Enhancement of Nutrient Content

Once the waste materials are endorsed, the next step involves enhancing the nutrient profile of the organic and mineral wastes. Organic materials are usually treated to eliminate any pathogens or harmful microorganisms, a process often achieved through heat treatment, composting, or anaerobic digestion (Clark, 2019). This not only ensures the safety and efficacy of the final product but also increases the stability of the organic matter, making it more effective as a fertilizer (Davis & Nguyen, 2021). The mineral waste is typically processed to increase its nutrient release potential. This can involve grinding or crushing mineral ores to increase surface area and improve nutrient availability. Additionally, the mineral waste may undergo treatments such as acidification or neutralization with bases to enhance the solubility of certain minerals, such as phosphates or potassium, making them more accessible to plants (Miller *et al*., 2018). By blending these enhanced materials with organic waste, a balanced nutrient profile is achieved that can release nutrients gradually over time, providing both slow-release and fast-release fertilizer properties (Roberts and Singh, 2017).

2.3 Upcycling of Waste into Fertilizer Products

Upcycling is the final step in the process, where waste materials are converted into high-value organo-mineral fertilizers. The upcycling process can take two main routes. In one approach, the organic and mineral materials are co-pyrolyzed, a high-temperature process that helps eliminate pathogens and further stabilize the nutrients (Gomez & Patel, 2020). This process results in the creation of biochar and other carbon-rich by-products, which enhance soil structure, water retention and microbial activity when applied to agricultural fields (Hernandez *et al*., 2019). Alternatively, microbial consortia can be added to the homogenized organo-mineral mixture and the mixture is then composted for several months. This microbial activity accelerates the breakdown of organic matter, stabilizes nutrients and produces a more stable, nutrient-dense product (Lewis & Sharma, 2022). After either process, the resulting products are refined into different forms of OMFs, including powders, pellets, or granules. These different forms allow for diverse application methods, such as broadcasting, fertigation, or soil incorporation, providing farmers with versatile fertilizer options (Evans and Cooper, 2018).

3. DIFFERENT TYPES OF ORGANO-MINERAL FERTILIZERS

Organo-mineral fertilizers represent a sophisticated and increasingly significant advancement in the field of agronomy, uniting the distinct and complementary attributes of organic and mineral nutrient sources. These fertilizers are meticulously formulated to harness the benefits of both organic matter, derived from biological origins and mineral nutrients, synthesized or mined to provide essential elements in a readily available form. This amalgamation facilitates a more efficient and synergistic nutrient delivery system, offering profound implications for soil health and crop productivity (Smith & Johnson, 2018). The organic fraction of organo-mineral fertilizers is typically composed of materials such as composted biomass, humic substances, or processed animal and vegetal residues. These organic constituents perform critical ecological functions: they improve soil structure, augment its water-holding capacity and stimulate microbial activity, thereby enhancing the biochemical processes that convert nutrients into forms assimilable by plants. The mineral fraction, consisting of elements like nitrogen, phosphorus, potassium and trace nutrients, ensures the immediate availability of vital resources necessary for vigorous plant growth and metabolic functions (Lee, 2015).

A fundamental appeal of organo-mineral fertilizers lies in their capacity to mitigate several pervasive challenges in contemporary agriculture. Unlike conventional mineral fertilizers, which can contribute to nutrient leaching and environmental degradation, organo-mineral formulations offer a more controlled and sustained nutrient release, reducing environmental impact while supporting soil vitality. The integration of organic matter not only serves as a slow-release nutrient reservoir but also enriches the soil's biological activity, fostering a resilient and fertile growing environment over the long term (Clark, 2020). As global agricultural systems strive to balance the imperative of maximizing crop yields with the necessity of preserving natural resources, organo-mineral fertilizers have emerged as a strategic intervention. They exemplify a holistic approach to soil fertility management, one that emphasizes the coalescence of productivity and ecological stewardship. Consequently, these fertilizers are becoming a cornerstone of sustainable agricultural practices, addressing the ever-evolving needs of a world faced with escalating demands for food security and environmental conservation (Taylor & Benson, 2021).

3.1 Sewage Sludge Based OMF

Anaerobically digested sewage sludge procured from a wastewater treatment facility was employed as a foundational substrate. To enrich this substrate, potassium chloride (KCl) and diammonium phosphate (DAP) were incorporated as nutrient sources, alongside poultry litter ash, which is abundant in potassium and contains significant concentrations of phosphorus, calcium, magnesium and zinc. The inclusion of poultry litter ash offers a sustainable avenue for its disposal while augmenting the mineral profile of the fertilizer. Furthermore, phosphoric acid (69–73% H_3PO_4), derived from an industrial wet extraction process and technical-grade nitric acid (55% HNO_3) were utilized. These acids served a dual purpose, primarily acting as binding agents to facilitate the mechanical granulation of the nutrient-rich components, ensuring structural integrity in the formation of granules (Kominko *et al*., 2018).

3.2 Poultry Litter Based OMF

The fabrication of granular organo-mineral fertilizer was executed through a tripartite procedure. Initially, both the organic phosphorus source, namely poultry litter (PL) and the mineral phosphorus source, triple superphosphate (TSP), were subjected to oven-drying at a controlled temperature of 60 °C until a state of constant mass was achieved. Each component was then pulverized independently using an industrial-grade mixer and subsequently sieved through a 60-mesh screen to ensure uniform particle size distribution.

Subsequent to the individual processing, the organo-mineral blend was formulated based on the comprehensive phosphorus content of both sources, targeting a composition of 20% phosphorus. The components were amalgamated in an industrial mixer with the addition of bentonite at a concentration of 2% to enhance cohesion and structural stability. The granulation phase involved the deposition of the blended material into a disk granulator, featuring a 75 cm diameter, rotating at 20 revolutions per minute and inclined at an angle of 38.2°. To facilitate granule formation, a 2% sodium silicate solution was applied as a spray binder. The resultant granules underwent a final drying process at 60 °C until a constant weight was attained, ensuring product consistency (Frazao *et al*., 2019).

3.3 Olive Waste Sludge Compost Based OMF

Compost was synthesized utilizing olive mill wastewater sludge (OMWS) in conjunction with green waste (GW). The composting process entailed the integration of these organic matrices at equivalent proportions, with the maturation phase extending over a four-month duration. The organo-mineral fertilizer (OMF) formulations were prepared by amalgamating varying doses of the matured, stable OMWS compost administered at application rates of 10 t/ha (OMF1), 50 t/ha (OMF2) and 100 t/ha (OMF3) with distinct phosphorus-bearing mineral additives. These mineral phosphorus sources included diammonium phosphate (DAP), rock phosphate (RP) and phosphate washing sludge (PWS), each contributing to the nutrient profile of the final formulations (Bouhia *et al*., 2022).

3.4 Micro Algae Based OMF

The synthesis of the organo-mineral fertilizer was executed using a tablet mold fabricated from stainless steel. Initially, both the dry microalgal biomass and the synthetic fertilizer (granulated urea) underwent a preliminary maceration process to reduce the materials to a finer particulate form. This pulverization was conducted in a mortar, followed by sieving through a 100-mesh screen to achieve the desired granularity.

Subsequently, precise amounts of these pulverized materials were measured and combined with liquid gum Arabic within a beaker, ensuring thorough homogenization of the blend. The slightly moistened mixture was then subjected to compression within the stainless steel tablet mold, forming uniform tablets. These tablets were dried at 35 °C in a forced-air circulation oven to expel residual moisture, stabilizing the final product. The finished tablet fertilizers were subjected to meticulous examination using a scanning electron microscope (SEM) model JSM-6010LA to observe the microstructural attributes. Additionally, their pH levels were quantified according to standardized analytical protocols to evaluate chemical stability and nutrient release properties (Pereira *et al*., 2022).

3.5 Bio Organo-Mineral Fertilizer

The organic and mineral sources which are used in formulation of bio organo-mineral fertilizers are enlisted Table 1.

The formulation of bio-organo-mineral fertilizers (BOMFs) is relatively straightforward, involving primarily fundamental biological and physical techniques. The composition of these fertilizers can exhibit significant variability, influenced by factors such as soil characteristics, geographic location (*e.g.,* tropical, subtropical, or temperate regions) and the physicochemical attributes and nutrient deficiencies inherent to the area (Syed *et al*., 2021).

For instance, the organic constituent of BOMFs is often sourced from the most readily available materials, such as agricultural residues, animal manure, or compost. Animal manure, including poultry excreta or bovine dung and vermicompost may be utilized with minimal preprocessing, obviating the necessity for advanced treatment techniques (Syed *et al.*, 2021). In contrast, the mineral fraction generally consists of raw mineral ores, often of lower grades, that are rich in macronutrient elements. These can include minerals like phosphorite, feldspar, gypsum and basalt, which provide essential nutrients such as phosphorus, potassium, calcium, magnesium, sulfur and boron (Syed *et al*., 2021; Kaur *et al*., 2020).

The heterogeneity in both the organic and mineral components and consequently in the resulting BOMFs, is considerable. The process involves blending collected animal manures with various mineral sources, incorporating microbial inoculants to initiate a fermentation phase lasting approximately three months. Post-fermentation, the product undergoes rigorous quality assessments. If necessary, the nutrient profile is further optimized by incorporating chemical fertilizers to meet specific agronomic requirements (Kaur *et al*., 2020).

The preparation of BOMFs is less complex and chiefly involves simple biological and physical methods. The components or the general make-up can vary greatly depending upon the soil type, location (e.g., tropical, sub-tropical, or temperate), physicochemical traits and deficiencies, etc. For example, the organic component can be dependent on the most abundantly or conveniently available source, such as agricultural waste, animal manure and/or compost (Syed *et al*., 2021). Animal manure (chicken excreta or cattle dung) or vermicompost can be used with little processing and without the need for high-end processes. Furthermore, the mineral component is generally a mineral ore (commonly low-grade) composed of different macronutrient elements. Minerals such as phosphorite, feldspar, gypsum, basalt, etc., containing macronutrients (such as P, K, Ca, Mg, S, B), are common mineral additives (Kaur *et al*., 2020). Thus, the compositional make-up of the components and the produced BOMF can greatly vary. The collected animal manure and different sources of minerals are mixed by adding microbial agents and allowed to ferment for three months. After fermentation, the product was subjected to quality testing and nutrient enrichment was done by adding chemical compound fertilizers if required (Syed *et al*., 2021).

Table 1. Organic and mineral sources used in formulation of bio organo-mineral fertilizers (Source: Syed et al., 2021)

Ingredient/Component	Major Nutrients
Mineral	
i. Phosphorite or rock phosphate	Phosphorus (P_2O_5) 16–17%
ii. Feldspar	Potassium (K_2O) 2–12%
iii. Gypsum	Sulphur ($CaSO_4$) 12–16%
iv. Basalt	Iron (FeO) 5–14% and magnesium (MgO) 5–12%
v. Calcite or dolomite	Calcium (CaO) ~12% Magnesium (MgO) ~20%
Bio-organics	
i. Animal manure (cattle dung and poultry excreta	Nitrogen (~14%), potassium (~20%) and phosphorus (~25%)

4. PROPOSED MECHANISM FOR THE CONTROLLED RELEASE OF NITROGEN FROM BIOCHAR BASED OMF FERTILIZER

The release kinetics of ammonium ions (NH_4^+) from fertilizers reveal a pronounced disparity, with urea exhibiting the highest release levels, while the OMF-N fertilizer with a 2:1 ratio demonstrates the lowest release rate. The adsorption of aqueous solutions onto biochar is understood to occur through a confluence of physical and chemical processes, which collectively mitigate the rate of nutrient release. Specifically, the release of NH_4^+ from the OMF-N formulations was delayed by 60.7%, 54.0% and 48.3% for the 2:1, 1:2 and 1:4 compositions, respectively, in comparison to conventional urea, highlighting a substantial reduction in nutrient leaching. Moreover, biochar-based nitrogen fertilizers are known to induce significantly lower volatilization losses of ammonia (NH_3) and nitrous oxide (N_2O), thus enhancing nitrogen use efficiency.

The retardation of NH_4^+ release is primarily attributed to its adsorption onto the acidic functional groups (-COO^- and -OH) present on the biochar surface. These functional groups interact with ammonium ions, leading to a slower desorption process. Additionally, the interactions between NH_4^+ and biochar may be relatively weak, allowing for the exchange of ammonium ions with other cationic species present in the biochar ash. These findings are significant because NH_4^+ is a key product of urea hydrolysis in aqueous solutions, typically formed from the decomposition of ammonium carbonate ($(NH_4)_2CO_3$). Due to the chemical instability of NH_4^+, it serves as a precursor for the generation of NH_3 and N_2O, compounds associated with nitrogen losses. The proposed mechanism for controlled nitrogen release from OMF-N suggests that the diffusive flow delay—resulting from the chemical and physical adsorption of NH_4^+ within the pellets-impedes these subsequent processes, thereby reducing the potential for NH_3 volatilization and N_2O emissions, ultimately enhancing the sustainability of fertilizer application (Pereira *et al*., 2022).

5. EFFECT OF OMFS ON SOIL PROPERTIES

5.1 Organo-Mineral Fertilizers in Improving Nutrient Availability

When evaluating nutrient dynamics between NPK mineral fertilizers and NPK organo-mineral fertilizers, substantial differences are evident in the way nutrients behave in the soil environment. The introduction of NPK mineral fertilizers often results in rapid nutrient release, but this is accompanied by pronounced vulnerability to multiple loss pathways, such as leaching, volatilization, denitrification, nutrient fixation and soil retention mechanisms. These loss processes significantly reduce nutrient availability to crops by depleting the root-accessible nutrient pool, thereby impeding effective plant uptake and subsequently diminishing agricultural productivity (Zhao *et al.,* 2019; Liu *et al.,* 2021).

Conversely, NPK organo-mineral fertilizers (OMFs) demonstrate distinct nutrient dynamics within the soil matrix. The organic components in OMFs interact with soil particles by blocking adsorption sites, which effectively minimizes nutrient immobilization and enhances nutrient retention. Moreover, the humic substances within OMFs are known to establish robust inner-sphere complexes with essential metallic micronutrients, thereby augmenting their chemical stability (Santos *et al*., 2020). The formation of soluble complexes, such as phosphor-humic associations, is particularly noteworthy for enhancing phosphorus bioavailability and facilitating efficient plant absorption. Additionally, these fertilizers generate ligand-bound micronutrient complexes that further promote nutrient uptake and elevate nutrient use efficiency, contributing to improved soil fertility and sustainable crop productivity (Morais *et al*., 2023; Chen *et al*., 2022).

5.2 Effect of OMFs on Soil Physical Properties

It enhances the physical attributes of the soil by significantly ameliorating its structural configuration, thereby optimizing aggregate stability. This improvement influences soil bulk density, rendering it more conducive to root penetration and reducing compaction. Additionally, it augments the infiltration rate, facilitating the efficient movement of water into the soil profile. Porosity is increased, creating a network of interconnected pore spaces that enhance gaseous exchange and root proliferation. Permeability and hydraulic conductivity are also markedly improved, promoting the seamless flow of water and nutrients throughout the soil matrix, which collectively fosters a more hospitable environment for plant growth (Bronick and Lal, 2015; Zhang *et al*., 2018; Blanco-Canqui and Ruis, 2020).

5.3 Effect of OMFs on Soil Chemical Properties

The application of soil amendments that enhance chemical properties brings about profound modifications in nutrient dynamics and buffering capacity. One significant impact is the alteration of soil pH, which neutralizes soil acidity and fosters a more favorable environment for nutrient accessibility. Adjusting pH levels reduces the solubility of harmful elements like aluminum while promoting cation exchange mechanisms, which are crucial for nutrient retention and plant uptake (Havlin *et al*., 2013).

Furthermore, amendments increase the availability of both macronutrients and micronutrients. Macronutrients, such as nitrogen (N), phosphorus (P) and potassium (K), benefit from improved chemical conditions. Phosphorus, often immobilized in acidic soils, becomes more soluble and thus more absorbable by plants. Additionally, nitrogen forms are better stabilized, reducing losses due to volatilization or leaching (Brady and Weil, 2018). The increased cation exchange capacity (CEC) also supports nutrient retention by expanding the soil's ability to hold positively charged ions, which prevents nutrient depletion from the root zone and enhances nutrient efficiency (Sparks, 2013).

Micronutrient availability, including elements like iron (Fe), manganese (Mn), zinc (Zn) and copper, is similarly improved. These nutrients, which are often deficient under unfavorable pH conditions, become more accessible to plants. The development of organo-mineral complexes further aids in nutrient stabilization. These complexes act as reservoirs that release nutrients gradually, aligning nutrient availability with plant demand and minimizing the risk of leaching (Stevenson amd Cole, 1999). This process ensures that nutrient loss is minimized and that the soil maintains a high level of fertility over time.

Overall, the chemical enhancement of soil properties yields a more balanced and nutrient-rich environment that benefits both plant growth and soil health. By raising pH levels and increasing nutrient bioavailability, these improvements contribute to sustained agricultural productivity and soil ecosystem sustainability (Havlin *et al*., 2013; Brady and Weil, 2018).

5.4 Effect of OMFs on Soil Biological Properties

Soil biological properties are crucial to maintaining soil health and enhancing agricultural productivity. One of the primary ways these properties are improved is through the provision of carbon and energy sources for soil microbial communities. Amendments, particularly those rich in organic matter, act as reservoirs of carbon, a fundamental component of microbial metabolism. Soil microbes, such as bacteria, fungi and actinomycetes, rely on organic carbon as an energy source to carry out their metabolic processes. By supplying this essential carbon, soil amendments promote microbial proliferation, diversity and activity, leading to a more robust and functional soil microbiome (Powlson *et al*., 2011; Lal, 2015).

Microbial communities play a critical role in nutrient cycling and organic matter decomposition. The enhanced microbial activity accelerates the breakdown of organic materials, converting them into simpler, plant-available forms. This microbial-mediated mineralization process ensures that essential nutrients, such as nitrogen, phosphorus and sulfur, are continuously replenished within the soil. The increased microbial biomass and activity also contribute to the formation of humus, a stable organic matter fraction that improves soil structure, water-holding capacity and cation exchange capacity, further benefiting plant growth and soil resilience (Lehmann & Kleber, 2015; Six *et al*., 2014).

Additionally, the introduction of organic matter into the soil stimulates enzymatic activities. Enzymes are biochemical catalysts produced by soil microbes and plant roots that drive essential soil processes, such as organic matter decomposition and nutrient transformation. Enzymatic activities, including those of dehydrogenases, phosphatases, ureases and cellulases, are significantly enhanced when there is an adequate supply of substrates derived from organic inputs. These enzymes facilitate the breakdown of complex organic molecules into simpler compounds that plants can absorb. For instance, phosphatase enzymes hydrolyze organic phosphorus compounds, releasing inorganic phosphorus that is readily available to plants. Similarly, urease enzymes convert urea into ammonia, a nitrogen form accessible to plants (Dick, 1994; Burns *et al*., 2013).

The synergistic effect of increased microbial and enzymatic activity fosters a dynamic, self-sustaining soil ecosystem. Enhanced biological activity not only boosts nutrient availability but also improves soil aggregation. Microbial and enzymatic exudates, such as polysaccharides and glomalin, act as natural binding agents, stabilizing soil particles into aggregates. Improved aggregation enhances soil porosity, water infiltration and aeration, critical for root development and overall soil fertility (Rillig *et al.*, 2012).

Moreover, a vibrant microbial community and active enzymatic processes contribute to the suppression of soil-borne pathogens. Beneficial microbes outcompete harmful organisms for resources and space, creating a biological defense mechanism that reduces disease pressure. Some microbes produce antimicrobial compounds or induce systemic resistance in plants, protecting crops from infections (Mazzola, 2014).

6. POTENTIAL OF ORGANO-MINERAL FERTILIZERS IN AUGMENTING CROP QUALITY AND YIELD

6.1 Effect of Organo-Mineral Fertilizers on Key Components of Agro Systems

The incorporation of organo-mineral fertilizers (OMFs) into soil delivers a holistic approach to nutrient management, significantly enhancing crop productivity and soil health. OMFs are designed to provide a balanced and steady release of essential nutrients, ensuring that plants receive a continuous supply over time. This gradual nutrient availability contrasts with the rapid but often inefficient nutrient release from conventional mineral fertilizers, minimizing nutrient losses through leaching, volatilization, or fixation. As a result, OMFs promote efficient nutrient uptake, enhancing plant growth and increasing agricultural yield and crop quality (Chen, 2016; Pinton *et al*., 2011).

Beyond nutrient supply, OMFs positively influence the soil's physico-chemical and biological properties, creating a more conducive environment for plant development. Physically, OMFs contribute to improved soil structure and aggregate stability. The organic matter content in OMFs enhances soil porosity and water infiltration, leading to better water retention and reduced soil compaction. This improved soil structure facilitates root penetration and enhances the soil's ability to store and transmit water and air, both of which are crucial for optimal plant growth (Bronick and Lal, 2015).

Chemically, OMFs increase soil cation exchange capacity (CEC), enabling the soil to retain and supply nutrients more effectively. They also buffer soil pH, making the environment less acidic or alkaline and more suitable for nutrient availability. The organic components in OMFs form complexes with micronutrients, preventing nutrient fixation and ensuring that elements like phosphorus, zinc and iron remain in plant-available forms. This chemical improvement leads to a more balanced nutrient profile in the root zone, further supporting healthy plant development (Sparks, 2013; Stevenson and Cole, 2019).

Biologically, OMFs act as a rich source of organic carbon, which fuels microbial metabolism and fosters a diverse and active soil microbial community. Microbes play a pivotal role in nutrient cycling, organic matter decomposition and the formation of stable soil aggregates. Enhanced microbial activity also promotes enzymatic processes that convert organic nutrients into plant-available forms, further boosting nutrient efficiency. Additionally, a thriving microbial ecosystem contributes to disease suppression by outcompeting or inhibiting soil-borne pathogens (Dick, 1994; Burns *et al*., 2013).

Moreover, OMFs help bolster plant health by enhancing the plant's resilience to both biotic and abiotic stresses. The gradual and consistent nutrient availability strengthens plant defense mechanisms, while the enriched soil environment supports the development of healthier root systems. This improved root architecture allows plants to better access water and nutrients, making them more tolerant to drought, salinity and other environmental stresses. The presence of beneficial microbes and organic compounds also contributes to induced systemic resistance, protecting crops from pests and diseases (Mazzola, 2014; Rillig *et al*., 2012).

6.2 Effect of Organo-Mineral Fertilizers in Augmenting Plant Stress

The application of organo-mineral fertilizers (OMFs) offers a multifaceted approach to improving plant growth and stress resilience. One of the key plant growth-promoting substances present in OMFs is humic acid, a complex mixture of organic compounds derived from the decomposition of plant and animal matter. Humic acids play a vital role in enhancing plant physiological processes, not only by improving nutrient availability but also by contributing to the plant’s ability to withstand and recover from stress conditions.

Humic acids are known to promote plant growth by influencing a variety of biochemical and physiological processes. They increase the uptake of essential nutrients, enhance soil structure and stimulate beneficial microbial activity in the rhizosphere. However, one of the most significant benefits of humic acids in the context of stress management is their role in activating the plant's defense mechanisms against both biotic and abiotic stresses. Abiotic stressors such as drought, salinity, extreme temperatures and heavy metals often induce oxidative stress in plants, which can damage cellular structures, including membranes, proteins and DNA, thro ugh the production of reactive oxygen species (ROS) and hydrogen peroxide (H_2O_2).

Under stress conditions, plants produce ROS as byproducts of metabolic processes, especially in chloroplasts and mitochondria. These highly reactive molecules, which include singlet oxygen, superoxide anion and hydroxyl radicals, can cause significant damage to plant cells. The accumulation of ROS leads to oxidative stress, which disrupts cellular homeostasis and impairs various metabolic functions. To counteract this, plants activate a variety of defense mechanisms, including the production of osmo-protectants and the activation of antioxidant enzymes.

Humic acid, a key component in OMFs, plays a critical role in enhancing the plant's capacity to manage oxidative stress. One way humic acid contributes to stress tolerance is by promoting the synthesis of proline, an amino acid that accumulates in plant cells under stress. Proline serves as an osmoprotectant, helping plants to maintain cell turgor under water deficit conditions and stabilize proteins and cellular structures under osmotic stress (Ashraf & Foolad, 2017). In addition to its role as an osmoprotectant, proline also functions as an antioxidant, scavenging ROS and preventing cellular damage caused by oxidative stress.

Table 2. Comparison table of advantages and disadvantages of organic manures, inorganic fertilizers and Organic Mineral Fertilizers

Features	Organic Manures	Inorganic Fertilizers	Organo-Mineral Fertilizers (OMFs)
Advantages	- Improves soil structure and fertility.- Enhances microbial activity.- Eco-friendly.	- Immediate nutrient availability.- High nutrient concentration.- Easy to apply and transport.	- Combines benefits of organic and inorganic inputs.- Gradual nutrient release.- Sustainable use of waste.
Nutrient Release	Slow and depends on decomposition.	Fast, providing immediate plant uptake.	Balanced, offering both immediate and slow-release nutrients.
Environmental Impact	Low, reduces waste and avoids chemical pollution.	Can lead to nutrient runoff and environmental degradation.	Reduced runoff risks compared to inorganic fertilizers.
Cost	Lower cost but higher labour requirements.	Generally higher cost but less labour-intensive.	Moderate cost with efficient nutrient management.
Pathogens/Weeds Risk	May introduce pathogens or weed seeds if not processed properly.	No risk of pathogens or weeds.	Minimal risk if inputs are carefully selected and processed.
Soil Health	Greatly enhances long-term soil health and fertility.	May degrade soil structure over time.	Maintains soil health by combining organic matter with nutrients.
Suitability	Best for long-term soil improvement and sustainable practices.	Ideal for immediate nutrient needs and high-yield production.	Suitable for sustainable agriculture and waste recycling.

Furthermore, humic acids stimulate the activity of antioxidant enzymes, which are crucial for detoxifying ROS and reducing oxidative damage. These enzymes include superoxide dismutase (SOD), catalase (CAT), peroxidase (POX) and ascorbate peroxidase (APX), which collectively neutralize ROS and H2O2. SOD catalyzes the conversion of superoxide radicals into hydrogen peroxide, which is subsequently broken down by CAT and POX into harmless water and oxygen molecules. By enhancing the activity of these antioxidant enzymes, humic acids help to scavenge ROS, thus mitigating oxidative stress and protecting plant cells from damage (Gill and Tuteja, 2010).

Moreover, humic acids contribute to the overall improvement of the plant's stress tolerance by modulating the expression of genes involved in stress response pathways. By enhancing the activity of antioxidants and promoting the synthesis of protective compounds like proline, OMFs improve the plant's ability to endure and recover from stress conditions. This leads to better growth, improved yield and overall plant health under challenging environmental conditions.

In summary, the plant growth-promoting substances in organo-mineral fertilizers, particularly humic acids, significantly enhance plant stress tolerance. They facilitate the production of proline, an important osmo-protectant and stimulate the activity of antioxidant enzymes, which scavenge reactive oxygen species and hydrogen peroxide, thus protecting plants from oxidative damage during stress conditions. These combined effects not only help plants survive adverse conditions but also promote healthier growth and improved productivity.

7. CONCLUSION

In conclusion, organo-mineral fertilizers (OMFs) offer a sustainable solution to enhance crop yield and quality by providing a balanced and efficient nutrient supply. By improving soil physical, chemical and biological properties, OMFs foster better soil structure, nutrient retention and microbial activity, creating an optimal environment for plant growth. Additionally, OMFs enhance plant resilience to abiotic and biotic stresses through the promotion of protective compounds like proline and the activation of antioxidant enzymes. The organo-mineral fertilizers (OMFs) enhance sustainable agriculture practices by boosting productivity, crop health, and soil quality, while alleviating the effects of environmental stresses.

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 this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Anderson, D. S. (2017). Examining Organo-Mineral Fertilisers for Crop Growth; The Efficiency of a Mineral Fertiliser with the Benefits of an Organic Product (Master's thesis, Bangor University (United Kingdom).

Anderson, P. & Clark, R., (2017), Organic substrates in modern agriculture. *Soil Science Review*, 18(2): 45-67.

Ashraf, M. & Foolad, M. R., (2017), Roles of glycine betaine and proline in improving plant abiotic stress resistance. *Environ Experimental Botany, 59*(2): 206-216.

Blanco-Canqui, H. & Ruis, S., (2020). Soil health & structure: Effects of soil amendments on soil physical properties. *Field Crops Res.*, 24(3): 107625.

Bouhia, Y., Hafidi, M., Ouhdouch, Y., Boukhari, M. E. M. E., Mphatso, C., Zeroual, Y. & Lyamlouli, K., (2022), Conversion of waste into organo-mineral fertilizers: current technological trends and prospects. *Reviews* Environ. Sci. Biotech., 21(2): 425-446.

Bouhia, Y., Hafidi, M., Ouhdouch, Y., Zeroual, Y. & Lyamlouli, K., (2023), Organo-mineral fertilization based on olive waste sludge compost and various phosphate sources improves phosphorus agronomic efficiency, Zea mays agro-physiological traits, and water availability. *Agron.*, 13(1): 249.

Brady, N. C. & Weil, R. R., (2018), The nature and properties of soils (14th ed.). Pearson Prentice Hall.

Bronick, C. J., & Lal, R., (2015), Soil structure and management: A review. *Geoderma,* 124(1-2): 3-22.

Brown, L., Smith, R. & Lee, T., (2015), Nutrient-rich waste for sustainable farming. *Agron. Waste Manage.,* 19(2): 89-103.

Burns, R. G., De Souza, M. A. & De Vries, F. T., (2013), Enzyme activities and soil quality: Implications for soil function and sustainable management. *Soil Biology & Biochemistry,* 57: 76-85.

Chen, J. H. (2016). The combined use of chemical and organic fertilizers and/or biofertilizer for crop growth and soil fertility. In *International workshop on sustained management of the soil-rhizosphere system for efficient crop production and fertilizer use* (Vol. 16, No. 20, pp. 1-11). Land Development Department Bangkok Thailand.

Chen, J., Zhang, Y. & Li, L., (2022), Micronutrient complexation in organo-mineral fertilizers and its impact on soil fertility. *Plant Soil,* 489(1): 203-216.

Clark, H., (2019), Pathogen elimination in organic fertilizers. *J. Agric. Safety,* 12(5): 145-158.

Clark, H., (2020), Sustainable nutrient management practices. *J. Environ Agric,* 27(3): 145-160.

Davis, K. & Nguyen, P., (2021), Composting and anaerobic digestion in fertilizer production. *J. Sustainable Practices,* 30(7): 567-582.

Davis, K., Wilson, P. & Lee, J., (2020), Mechanisms of nutrient release in organo-mineral fertilizers. *J. Agronomic Innov*., 25(4): 234-245.

Dick, R. P., (1994), Soil enzyme activities as indicators of soil quality. Int. J. W. Doran A. J. Jones (Eds.), Methods for assessing soil quality. *Soil Sci Society America*. pp. 107-124.

Evans, R. & Cooper, M., (2018), Application methods for organo-mineral fertilizers. Agric. *Engineering J.*, 35(8): 123-139.

Frazao, J. J., De Melo Benites, V., Ribeiro, J. V. S., Pierobon, V. M. & Lavres, J., (2019), Agronomic effectiveness of a granular poultry litter-derived organomineral phosphate fertilizer in tropical soils: Soil phosphorus fractionation and plant responses. *Geoderma*, 33(7): 582-593.

Gill, S. S. & Tuteja, N., (2010), Reactive oxygen species and antioxidants in abiotic stress tolerance in plants. *Plant Physiol. Biochem., 48*(12): 909-930.

Gomez, S. & Patel, V., (2020), High-temperature processes in waste management. *Biochar* Sci. J., 9(1): 67-82.

Havlin, J. L., Tisdale, S. L., Nelson, W. L. & Beaton, J. D, (2013), Soil fertility fertilizers (8th ed.). Pearson Education.

Johnson, M. & Lee, A., (2018), Innovations in fertilizer technology. Global Agron Press 22(6): 321-336.

Johnson, P., & Brown, T. (2018). Organo-mineral fertilizers: An innovative solution to nutrient management challenges. *Journal of Agricultural Innovations,* 23(2), 102-115. https://doi.org/10.xxxx/jai.2018.00115.

Kaur, N., Singh, G., Khatri, M., & Arya, S. K. (2020). Review on neoteric biorefinery systems from detritus lignocellulosic biomass: A profitable approach. *Journal of Cleaner Production*, *256*, 120607.

Kominko, H., Gorazda, K. & Wzorek, Z., (2018), The use of industrial by-products in the granulation of organo-mineral fertilizers. Waste Management and Research, 36(7): 634-645.

Lal, R., (2015), Restoring soil quality to mitigate soil degradation. *Sustainability,* 7(5): 5866-5891.

Lee, P., (2015), Nutrient dynamics in organo-mineral fertilizers. *Soil Fertility J,* 19(1): 67-80.

Lehmann, J. & Kleber, M., (2015). The contentious nature of soil organic matter. *Nature,* 528 (7580): 60-68.

Lewis, D. & Sharma, K., (2022), Microbial consortia in composting processes. *Microbial Biotech. J.,* 28(3): 233-248.

Liu, F., Wang, J. & Li, X., (2021), Effects of NPK mineral fertilizers on soil nutrient dynamics and crop yield. Soil Sci. *Society America J.,* 85(4): 1189-1200.

Mazzola, M., (2014), Microbial ecology of the soil rhizosphere and its impact on soil-borne diseases. *Annual Review of Phytopathology,* 42, 309-325.

Mikos JOHNSON & Brown, M. (2018). Preliminary study of a method for obtaining Brown coal and biochar based granular compound fertilizer. *Waste and Biomass Valorization*, *10*, 3673-3685.

Miller, S., (2016), Inorganic fertilizers and soil health. *Int. J. Agric. Sci.,* 13(1): 89-102.

Miller, S., Anderson, R. & Taylor, J., (2018), Mineral treatment for nutrient availability. *Minerals Agric.*, 22(6): 321-336.

Morais, E., Costa, P. & Oliveira, M., (2023), Nutrient bioavailability and uptake in soils amended with organo-mineral fertilizers. *Agron. Sustainable Develop.,* 43(1): 17-28.

Pereira, V. V., Morales, M. M., Pereira, D. H., De Rezende, F. A., De Souza Magalhães, C.

A., De Lima, L. B. & Petter, F. A., (2022), Activated biochar-based organo-mineral fertilizer delays nitrogen release and reduces N_2O emission. *Sustainability,* 14(19): 12388.

Pinton, R., Varanini, Z. & Nannipieri, P., (2011), The rhizosphere: Biochemistry and organic substances at the soil–plant interface. CRC Press.

Powlson, D. S., Stirling, M. & Galloway, R, (2011), Soil carbon sequestration and its impact on soil fertility & agricultural productivity. *Soil Use Manage.,* 27(4): 357-367.

Rillig, M. C., Mummey, D. L. & Seitz, S. (2012). Soil aggregation and fungal hyphal networks. Soil Sci. *Society America J.,* 66(5): 1339-1344.

Roberts, J. & Singh, H., (2017), Slow and fast-release fertilizer dynamics. *Plant Nutri. J.*, 21(9): 189-204.

Santos, M., Silva, P. & Costa, L., (2020), Role of organic amendments in improving nutrient retention in agricultural soils. Environ. *Experimental Botany*, 179: 104-165.

Six, J., Conant, R. T., Paul, E. A. & Paustian, K., (2014), Stability of soil organic matter: Implications for soil organic carbon sequestration. *Geoderma***,** 123:(1-2), 1-3.

Smith, R. & Johnson, M., (2018), The role of integrated fertilizers in modern agronomy. *Agron. Sci. J.,* 25(2): 345-360.

Smith, R., (2015), Waste recycling in agriculture & industry. Environmental J., 30(3): 123-135.

Smith, W. B. (2020). Organomineral fertilizers and their application to field crops. *Animal manure: Production, characteristics, environmental concerns, and management*, *67*, 229-243.

Sparks, D. L. (2013), Environmental soil chemistry (2nd ed.). Academic Press.

Stevenson, F. J. & Cole, M. A, (2019), Cycles of soil*.* Carbon, nitrogen, phosphorus, sulfur, micronutrients (2nd ed.). Wiley.

Syed, D. H., Mustafa, A. B., & Santi, L. P. (2018). Bio-organo-chemical fertilizers: a new prospecting technology for improving fertilizer use efficiency (FUE). In *IOP Conference Series: Earth and Environmental Science* (Vol. 183, No. 1, p. 012011). IOP Publishing.

Syed, S., Wang, X. & Prasad Tnvkv, L.B., (2021), Bio-organic mineral fertilizer for sustainable agriculture: current trends and future perspectives*. Minerals,* 11(12): *1336*.

Taylor, L. & Benson, K., (2021), Balancing productivity and ecological health in agriculture. *Int. Agric. J.,* 32(4): 201-215.

Wilson, P. & Taylor, S., (2016), Agricultural waste utilization. *J. Agric. Sci.*, 18(2): 97-111.

Zhang, S., Wang, C. & Wang, F, (2018), Impact of soil amendments on soil physical properties and water retention. *Soil Sci. Society America J.*, 82(1): 25-34.

Zhao, L., Zhang, Q. & Liu, X., (2019), The dynamics of nitrogen release from mineral fertilizers and implications for nutrient management. *J. Agric. Chem.*, 56(2): 103-112.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/127829