



## REVIEW ARTICLE

### Driving sustainability in tea farming: Insights on organo-mineral fertilizers

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#### ABSTRACT

Tea (*Camellia sinensis* L. O Kuntze) is an important cash crop grown globally, identified for its economic importance and health benefits. However, there are challenges such as nutrient deficiencies, especially in nitrogen (N), phosphorus (P), and potassium (K), together with adverse soil conditions, limiting optimal tea production. This review explains the role of organo-mineral fertilizers (OMFs) as a sustainable way to enhance tea production practices. OMFs, which combine organic matter with essential mineral nutrients, can simultaneously improve soil health, increase crop yields, and reduce the environmental impact associated with chemical fertilizers. Through a comprehensive examination of OMF production techniques, nutrient release patterns, and their positive effects on soil properties and greenhouse gas emissions, this article underscores the potential of OMFs in revitalizing tea farming systems. Despite their benefits, the adoption of OMFs remains low, particularly in regions like Africa. Hence, advocating for the integration of OMFs into fertilization practices, training programs for farmers, and supportive public policies is important to promote awareness of sustainable tea agriculture.

**Keywords:** organo-mineral fertilizers; tea farming; soil health; Sustainability management

#### INTRODUCTION

Tea (*Camellia sinensis* L. O Kuntze.) is an important cash crop, grown in 48 countries in the world covering over 4.2 million hectares, with an annual production of 6.34 million tons (Hoang et al., 2021). Tea plant produces leaves that are used to manufacture beverages, the most popular non-alcoholic, caffeine-containing beverage

(Natumanya Marriet and Mukadasi Buyinza, 2022); It is renowned for its health benefits associated with secondary metabolites like polyphenols, caffeine, theanine, and various vitamins and minerals (Liu et al., 2024, Manzoor et al 2024). Tea beverages are categorized as green (unfermented), white (lightly fermented), oolong (semi-fermented), or black (fermented) according to their production process (Vastrad et al., 2022). Black tea accounts for the largest share of global production at approximately 76–78%, followed by green tea at 20–22%, and oolong tea at 2% (Vastrad et al., 2022).

After water, tea is the second most important drink that is used all over the world to the extent that drinking tea is a daily habit for half of the world's population (Zhen 2002, Ho et al. 2009; FAOSTAT, 2020; Ahmed et al., 2020; FAO, 2022). Global tea production exceeds US\$ 17 billion yearly, with USD 9.5 billion in trade, providing significant export revenues for low-income nations and growing economies, particularly in Asia (Hajiboland, 2017; FAO, 2022a; Bermúdez et al., 2024).

Global tea production is expected to expand at a compound annual growth rate (CAGR) of 5.7% starting in 2021, according to research (Bermúdez et al., 2024). 60% of the world's tea production in 2022 came from smallholder farmers in developing nations, accounting for 9 million of the 13 million people working in the global tea business (Bermúdez et al., 2024). China, India, Japan, Sri Lanka, and Kenya are the top producers of tea in the world Producing over 160 thousand metric tonnes. In Africa Kenya is the main producer, producing over 570 thousand metric tonnes, almost 70% of the continent's total production followed by Malawi, Tanzania, and Uganda (Saifaddin, 2022).

Tea plants require a high level of nutrients due to the continuous harvesting of their leaves, which depletes essential elements from the soil. Among these nutrients, nitrogen (N) is the most critical, followed by potassium (K), calcium (Ca), phosphorus (P), sulfur (S), magnesium (Mg), and zinc (Zn). Nitrogen is particularly important as it serves as a fundamental component of plant tissues and is deeply involved in various physiological processes essential for the growth and productivity of tea plants. The nitrogen content in harvested tea leaves typically ranges from 3.5% to 5% on a dry matter basis, highlighting its significance in tea cultivation (Sedagathoor et al., 2009).

In addition to nitrogen, phosphorus (P) and potassium (K) play vital roles in both the growth and quality of tea leaves. A deficiency in these macronutrients has been shown to negatively impact tea yield and quality, leading to reduced biomass production and inferior leaf characteristics. Studies have demonstrated that inadequate N, P, and K levels result in lower chlorophyll content, diminished photosynthetic efficiency, and poor resistance to environmental stressors, all of which contribute to a decline in overall tea production (Wei et al., 2022). To mitigate these negative effects, the application of phosphate fertilizers has been found to significantly improve yield and quality parameters in tea plants. Phosphorus is particularly essential for root development, energy transfer, and cell division, making its availability crucial for sustaining healthy growth. Proper fertilization strategies incorporating phosphate fertilizers not only enhance nutrient uptake but also contribute to long-term soil fertility, ensuring the sustainability of tea cultivation (Hoang et al., 2021).

Among the chemicals that give teas their distinctive flavor and color are methylxanthines, polyphenols, carbohydrates, and amino acids, all of which significantly impact the final tea's quality. Dried tea comprises 3-5% caffeine, 2-5% amino acids, and 25 - 35% polyphenolic (Han et al., 2018). Catechins are also in charge of giving tea a bitter and astringent flavor, as well as a bitter aftertaste followed by a sweet one (Han et al., 2018). The amino acids in tea brew are sweet and sour, but caffeine is bitter. Because of this, tea is produced to be both mellow and brisk. Theanine, the primary free amino acid in tea, makes up approximately 1% to 2% (dry weight) of tea's total free amino acids. Additionally, the fragrance qualities of tea are influenced by about six hundred volatile chemicals. However, picking two leaves and a bud is one factor to ensure the quality of made tea, others factors include soil reactivity, elevation above sea level, and the surroundings in which tea is grown, which affect the tea's quality (Wei et al., 2022).

The tea plant requires a well-distributed annual rainfall of at least 1200 mm. In tea-growing regions, high rainfall leads to the leaching of cations such as  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , and  $\text{Na}^{+}$ , increasing the soil's  $\text{H}^{+}$  concentration, which lowers pH and promotes phosphorus (P) fixation (Alom et al., 2020). Consequently, high fertilizer application is necessary to provide sufficient phosphorus in a form that plants can absorb (Han et al., 2018). Due to the typically low pH of these soils, phosphorus tends to form compounds with iron ( $\text{Fe}^{3+}$ ), manganese ( $\text{Mn}^{2+}$ ), and aluminum ( $\text{Al}^{3+}$ ) (Heuer et al., 2017). As a result of excessive phosphorus fixation in acidic soils, tea plants are expected to absorb only 20% or less of the applied phosphorus fertilizers (Salehi & Hajiboland, 2008).

Tea growers commonly use both inorganic and organic fertilizers to replenish soil nutrients lost due to continuous cultivation. However, the high cost of these fertilizers significantly increases production expenses, making it difficult for smallholder farmers to afford them. As a result, many farmers struggle to maintain adequate nutrient levels in their soil, leading to reduced yields and lower profitability. The reliance on expensive fertilizers also poses economic challenges, particularly in regions where tea farming is the primary source of livelihood (Erenoğlu et al., 2023).

To address these challenges, organo-mineral fertilizers present a promising alternative, as they combine the benefits of both organic and inorganic fertilizers. These fertilizers supply essential macro and micronutrients while also enriching the soil with organic matter (O.M.), which help in maintaining soil structure, microbial activity, and nutrient retention. Organic matter enhances soil water-holding capacity, improves aeration, and promotes the formation of stable soil aggregates, all of which contribute to improved plant health and productivity. Additionally, increased organic matter supports beneficial microbial communities that facilitate nutrient cycling and disease suppression, leading to healthier tea plants with improved resistance to environmental stressors.

While the initial adoption of organo-mineral fertilizers may involve higher investment costs, they often lead to long-term profitability by improving soil fertility and ensuring more consistent and higher yields (Ye et al., 2022). Sustainable tea cultivation practices that incorporate organic matter result in reduced dependency on synthetic fertilizers, lower production costs over time, and enhanced resilience to climate variability. As a result, integrating organo-mineral fertilizers into tea farming systems can provide a viable pathway toward sustainable agriculture, ensuring both environmental and economic benefits for growers in the long run.

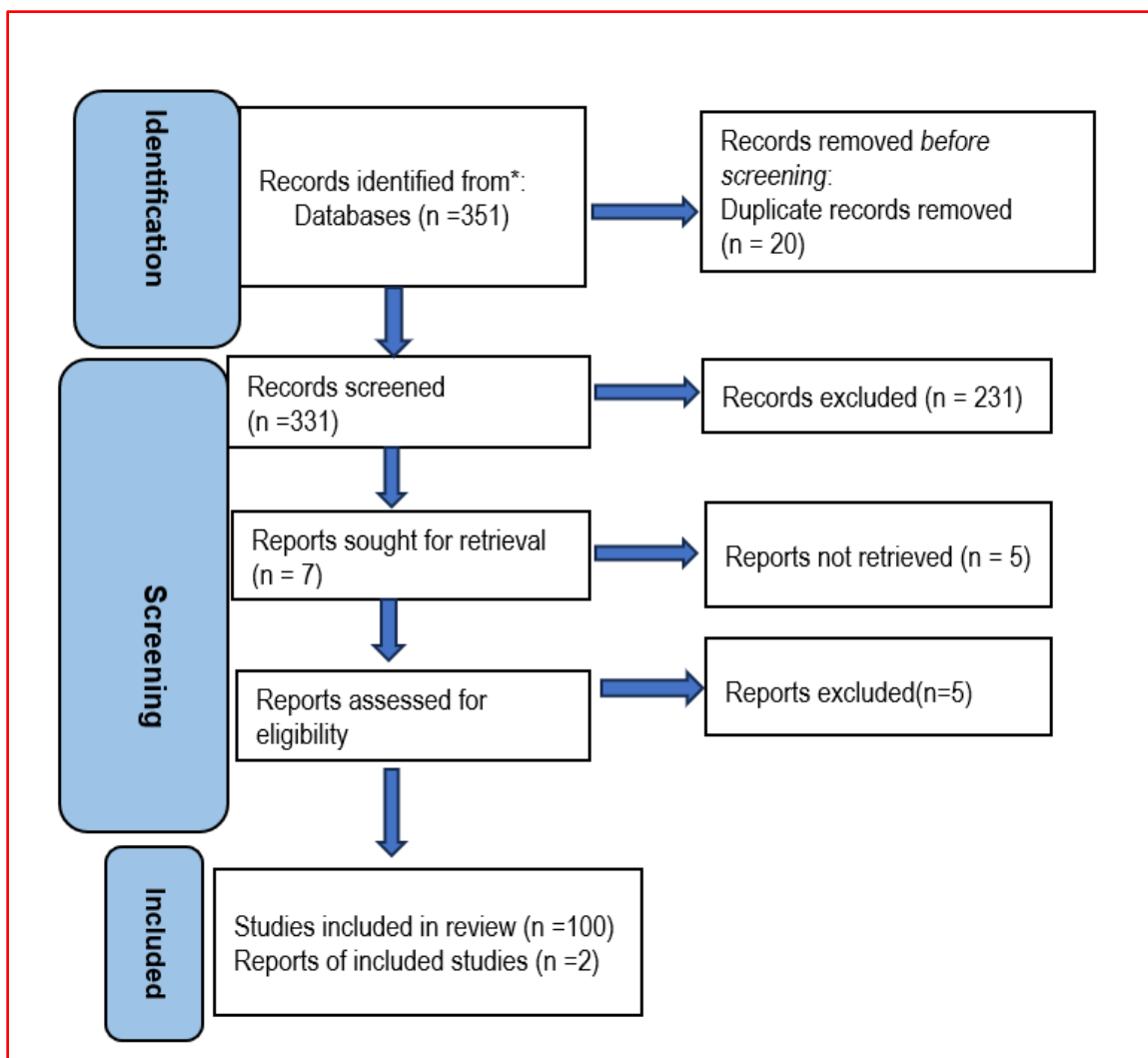
## **METHODOLOGY**

The study's methodology followed a systematic approach comprising three stages, by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, as illustrated in Figure 1: identification, screening, eligibility assessment, and inclusion. Search engines such as Elsevier, MDPI, Frontiers, and other major research databases were utilized to collect academic articles. Key search terms, including "tea farming," "organo-mineral fertilizers," "sustainability," and "soil health management strategies," were employed to ensure comprehensive coverage and minimize the risk of missing relevant information.

These searches initially identified 351 journal papers and seven reports. Of the 351 articles, 20 duplicates were removed. The remaining 331 papers underwent further screening, which rejected 231 articles due to their titles, abstracts, or content not aligning with the study's objectives. Additional screening excluded five of the seven reports, as they lacked directly relevant information. Ultimately, the final selection of articles and reports was formalized based on relevance and quality.

## **COMMON FERTILIZATION PRACTICES**

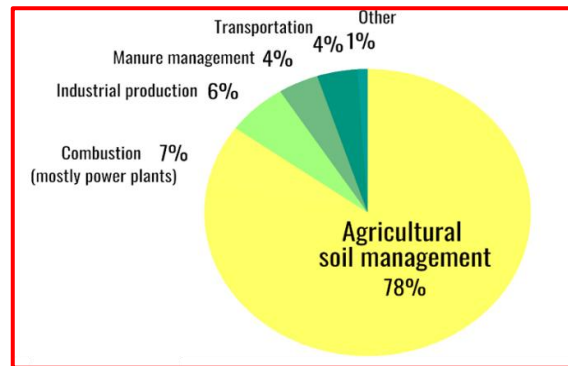
Generally, the tea plant needs 16 nutrient elements for optimal growth and productivity; however, nitrogen (N), phosphorus (P), and potassium (K) are required in larger quantities to sustain production (Le et al., 2021). The primary source of these nutrients is synthetic fertilizers, especially those high in nitrogen. According to the Institute of Himalayan Bioresource Technology in India, the cultivation of 1000 kg of dry weight tea leaves extracts between 40-50 kg of N, 4-8.5 kg of P, and 16-19 kg of K, while stems and old leaves contain approximately 50 kg of N, 12 kg of P, and 32 kg of K. However, the excessive application of synthetic fertilizers in conventional tea practices causes soil degradation, reduce microbial diversity and organic matter and cause Soil acidification in tea plantation which seriously reduce the yield and quality of tea (Ye et al., 2022). Table 1 illustrates the environmental impacts associated with the frequent use of chemical fertilizers, particularly nitrogen-rich fertilizers, in tea plantations. However synthetic fertilizers are widely used for cultivating various crops and play a crucial role in plant growth. Their significance lies in providing a consistent supply of precise nutrients to the soil. Unlike organic fertilizers, which require decomposition before plants can absorb them, synthetic fertilizers act immediately (Sabry et al., 2015). This rapid effectiveness is particularly advantageous for plants that are severely nutrient-deficient or struggling to survive.



**Figure 1.** Flow chart system on assessing the eligibility of the review papers

**Table 1.** The environmental impacts of synthetic fertilizer use in tea cultivation

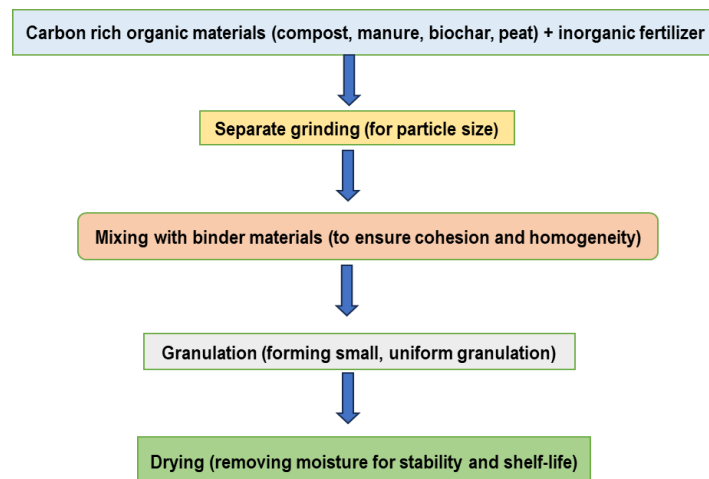
Findings	Reference
Prolonged use of nitrogen-based chemical fertilizers leads to soil acidification, nutrient inaccessibility, and reliance on additional applications, contributing to environmental degradation.	Yang et al. (2024)
Synthetic fertilizers increase nitrous oxide (N <sub>2</sub> O), a greenhouse gas with a global warming potential 265-298 times larger than CO <sub>2</sub> over 100 years.	IPCC (2013)
Synthetic fertilizers contribute significantly to nitrous oxide (N <sub>2</sub> O) emissions, with 10-15% of total nitrogen applied from agricultural soils treated with synthetic fertilizers being released as N <sub>2</sub> O	(Signor and Cerri ,2013)
In tea cultivation, 4.8-6.4% of nitrogen applied as synthetic fertilizers is converted into nitrous oxide (N <sub>2</sub> O), further increasing greenhouse gas emissions	Deng et al. (2017)
Agriculture is the leading contributor to nitrous oxide (N <sub>2</sub> O) emissions (Figure 2), mainly due to practices related to soil management and fertilizer application, as reported by the Environmental protection Agency (EPA, 2018).	



**Figure 2.** Sources of Nitrous Oxide

### ORGANO-MINERAL FERTILIZERS AND DEVELOPMENT OF TECHNIQUES FOR PRODUCING ORGANO-MINERAL FERTILIZERS

These fertilizers mix inorganic nutrients with organic materials. They offer a means to balance environmental health and productivity because they provide simultaneous long-term soil enrichment and quick nutrient availability (Ventura et al., 2020). The physicochemical characteristics of the personnel utilized and the existence of the adverse impact materials in the organic substrate determine the development methods for creating organo-mineral fertilizers (OMF) (Bouhia et al., 2022). Several factors influence the selection of suitable materials for the production of organic mineral fertilizers (OMF). Important considerations include affordability, local accessibility, high organic carbon content, enhanced cation exchange capacity, porous structure, biodegradability, and low-risk environmental materials. Organic materials are carefully cleaned before being added to OMF to allay worries about heavy metals and microbial diseases (Fachini et al., 2021; Kominko et al., 2018). Aerobic and anaerobic digestion processes primarily eliminate microbial infections. According to Uddin et al. (2024), heavy metal removal is more challenging and typically involves four steps: (a) modifying pH and oxidation potential to encourage heavy metal solubilization; (b) separating the liquid phase that contains the mobilized metals; (c) using chemical treatments to precipitate the metals; and (d) removing the precipitate. In the process of organo-mineral fertilizer production, carbon-rich organic materials such as compost, manure, biochar, or peat are combined with inorganic fertilizers (Figure 3). These components may be used directly depending on the required formulation. To ensure efficient processing, organic and inorganic materials are ground separately to achieve a uniform particle size. The ground materials are well mixed with binder materials to ensure proper cohesion and homogeneity. The resulting mixture then undergoes granulation, forming small, uniform granules that are easier to handle, transport, and apply to soil. These granules are subsequently dried using specialized equipment to remove moisture, enhancing their stability and shelf-life (Uddin et al., 2024).



**Figure 3.** Flow chart of Organo-mineral fertilizer preparation

## ORGANO-MINERAL FERTILIZERS AND THEIR INFLUENCE ON SOIL HEALTH AND REACTION

Chemical fertilizers that boost crop yields harm soil health, the environment, and its components (Syed et al., 2021; Srinivasrao, 2024). Long-term usage of chemical fertilizers harms soil health and the environment, and prices have risen over decades, reducing soil health (Srinivasrao et al., 2024). Combining chemical fertilizers with animal wastes to make organo-mineral fertilizers (OMF) can sustain agricultural productivity (Bouhia et al., 2022; Srinivasrao, 2024; Sakrabani, 2024). OMF manufacturing is a new method that uses organic feedstock like biosolids, livestock manure, crop residues, and food waste to create a balanced fertilizer product that adds plant nutrients and finely ground livestock manure or crop residues (Srinivasrao et al., 2024; Sakrabani, 2024).

OMF production uses organic feedstock's gradual nutrient release and mineral fertilizer's quick release patterns to reduce reliance. Although this concept is new, some have pioneered the use of OMF as biosolids as feedstock (Pawlett et al., 2015; Antille, 2017; Deeks, 2013). Burak and Sakrabani (2023) found that carbon capture technology was used to formulate OMF with crop yields comparable to mineral fertilizers. Recycled organic waste fosters a circular economy. It provides sustained crop nutrients and helps increase organic matter in agricultural soils (Sakrabani et al., 2023; Srinivasrao, 2024). A major benefit of OMF goods production is organic waste valorization, which correlates with organic farming (Bouhia et al., 2022). OMF manufacture uses chemical processes and a variety of feedstock-specific methods, such as thermal conversion, anaerobic digestion, and solid-state fermentation (Bouhia et al., 2022).

Co-processing mineral and organic resources instead of single applications increases the value of the final products due to chemical interactions that improve nutrient bioavailability, chemical reactivity, and slow-release properties (Kominko et al. 2019), which reduces the labor of applying fast releasers in splits. OMF also improve soil physicochemical and biological properties and functionalities and plant physiological features in agro-ecosystems (Pawlett et al., 2015).

OMF and its ingredients' persistence and evolution after crop cycles and cultural rotation, as well as their effects on plants' agro-physiological traits and soil properties (aggregation, pH, enzymes, microbial diversity, population, and activities), need long-term and short-term trials (Bouhia et al., 2022; Barto et al., 2010; Christensen, 1996). Research on OMF's biostimulant characteristics is required. The effect of OMF on root architecture and development and plant physiological features should be studied to explain how such products affect plant tolerance to biotic and abiotic stresses. OMFs improve soil biology, biochemistry, and nutrient cycling, making plants drought- and salinity-resistant (Bouhia et al., 2022). New organo-mineral products on the market must have research proof of their efficacy in increasing agricultural yields and soil parameters.

### INFLUENCE OF OMF ON SOIL PROPERTIES

Soil physical characteristics are essential for ensuring soil productivity and serve as fundamental indicators for assessing soil quality (Bhatt et al., 2019). Organomineral fertilizers (OMFs) contribute organic matter and humified substances, which significantly enhance soil structure. The addition of organic matter strengthens soil aggregate stability and reduces bulk density (Haynes & Naidu, 1998), improving aeration, permeability, water retention, hydraulic conductivity, and infiltration rates (Celik et al., 2004; Dexter et al., 2008; Murphy, 2015).

Research by Saha et al. (2017) demonstrated that OMFs produced through the granulation of urea and biochar increased the soil's capacity to hold water. Field experiments conducted by Akanni et al. (2011) also showed that applying OMFs improved physical soil properties, such as reducing bulk density and enhancing moisture retention—effects that were absent with chemical fertilizers. Likewise, Atere (2012) reported that applying OMFs at a rate of 30 g/kg soil decreased bulk density in greenhouse experiments. This improvement is linked to the presence of organic colloidal particles, which alter soil pore distribution and enhance water availability. Moreover, higher OMF application rates (30 g/kg soil) achieved the greatest field capacity (FC) and available water content (AWC), measuring 43.9% and 59.2%, respectively, compared to untreated soils (Atere, 2012). However, the efficacy of specific organic components, such as biochar, is highly influenced by soil properties.

Organomineral fertilizers increase nutrient content, especially N, P, and K this is because of the slow release of nutrients from organic fractions combined with the available inorganic components (Hakimi et al., 2024). Tea thrives in acidic soils, and by application of organo-mineral fertilizers buffers the soil acidity improving nutrient uptake (Ipinmoroti et al., 2007). Also, studies show that long-term application of OMF increases

organic carbon, fostering microbial communities that help nutrient cycling (Yang et al., 2022). The integrated use of organic and chemical fertilizers balances soil nutrient management. It combines the benefits of organic matter with the immediate availability of nutrients provided by chemical fertilizers. This strategy has proven effective in reducing dependency on chemical fertilizers while maintaining crop yield, particularly in tea production, and simultaneously improving soil health (Miao et al., 2024).

For many years tropical farming was discouraged using organic fertilizers because it causes bulkiness, high cost of transportation, and slow release of nutrients and delays their effects on production (Oshunsanya et al., 2023). Organo-mineral fertilizers significantly influence the soil's physical properties in terms of soil structure, water retention, compaction reduction, and enhanced soil aeration. The addition of organic matter in OMFs enhances the binding of soil particles into aggregates, improving soil texture and structure stability (David, Ionela & Marghitas, Marilena. (2014). Gurmu (2020). OMFs increase porosity by promoting the formation of both macro- and micropores within soil aggregates. This improves water infiltration and root aeration, fostering plant growth (Naliukhin et al., 2024). Therefore, stable aggregates protect soil from erosion and help maintain a balance between macro- and micropores essential for aeration and water movement. Organomineral fertilizers (OMFs) enhance soil water retention and infiltration by improving soil organic carbon (SOC) content, increasing cation exchange capacity (CEC), and optimizing soil structure. These effects are essential for maintaining soil moisture balance and supporting plant growth (Ventura et al., 2020).

### **IMPACT OF ORGANO-MINERAL FERTILIZERS ON NUTRIENT RETENTION**

Numerous organic materials and culture techniques have been demonstrated to help reduce nutrient leaching losses and maximise nutrient retention. According to Saha et al. (2023), leaching losses of total nitrogen (N) were remarkably reduced by 59% when brown coal and urea were used in field settings. Additionally, in a glasshouse investigation, Saha et al. (2018) reported that, in comparison to urea treatments, mineral nitrogen leaching losses for ferrosol, tenosol, and vertosol soils dropped significantly by 56%, 65%, and 42%, respectively. According to Ibrahim et al. (2023a), sepiolite, magnesium oxide (MgO), and biochar in a leaching column configuration, and they discovered a 21.1% decrease in nitrate (NO<sub>3</sub><sup>-</sup>) leaching. Using biochar and urea in soil column leaching studies, Pereira et al. (2022) observed that organic-mineral fertilizers (OMF) maintained 48–60% more ammonium (NH<sub>4</sub><sup>+</sup>) than urea. In addition, compared to urea treatments, the overall nitrogen emission was decreased by 27–60%. Additionally, Shi et al. (2020) found that using biochar and urea together reduced ammonium (NH<sub>4</sub><sup>+</sup>) leaching by 70% as compared to using commercial urea in a leaching column system. Research indicates that biochar can be combined with nitrogen-rich fertilizers such as urea. reduces the rate of nitrogen emission by 60% (Puga et al., 2019). In the meantime, adding biochar to triple superphosphate (TSP) dramatically decreased the rate of phosphorus release (Pogorzelski et al., 2020). Additionally, Wu et al. (2019) used magnesium chloride (MgCl<sub>2</sub>), biochar, and MgO in plastic bottles, showing that the material was beneficial in nutrient management by increasing phosphorus adsorption and decreasing phosphorus release.

### **GREENHOUSE GAS EMISSIONS AND OMF'S EFFECT**

In agricultural systems, innovative organic materials and synthetic fertilizers have demonstrated importance in reducing greenhouse gas emissions. For example, nitrous oxide (N<sub>2</sub>O) emissions were reduced by 64%, and ammonia (NH<sub>3</sub>) emissions were reduced by 73% when brown coal and urea were integrated into the field (Saha et al., 2023). However, it has also been shown that combining urea with biochar reduces overall N<sub>2</sub>O emissions by 23–28% (Shi et al., 2022). Additionally, a study by Saha et al. (2021) found that sweet corn and faba bean pastures treated with urea and brown coal had significant decreases in N<sub>2</sub>O (59%) and NH<sub>3</sub> (29%) emissions. According to Saha et al. (2018), field tests using urea and brown coal showed reductions in total N<sub>2</sub>O emissions of 31%, 42%, and 35% in Ferrosol, Tenosol, and Vertosol soils, respectively. Using the same materials, Rose et al. (2016) reduced N<sub>2</sub>O emissions in wheat grown in glasshouse conditions by 35%. This reveals that organo-mineral fertilizers could be the solution for dealing with greenhouse gas emissions.

### **CONCLUSION**

Adopting the use of organo-mineral fertilizers (OMFs) in tea farming is an important step toward maintaining tea farming stability. Combining organic matter with essential minerals will improve soil health, crop yields, and environmental impacts. These fertilizers improve soil structure and moisture retention, add nutrient availability, and simultaneously support the development of beneficial soil microbial communities. Their

application tackles critical nutrient deficiencies—especially in nitrogen, phosphorus, and potassium, which are largely needed by tea plants—and also contributes significantly to the mitigation of greenhouse gas emissions, making them an eco-friendly alternative to traditional chemical fertilizers. Due to the global significance of tea as a cash crop, there is a need for sustainable farming practices. Integrating OMFs into tea cultivation gives an effective strategy for long-term productivity and environmental insurance. By optimizing nutrient use, enhancing soil properties, and reducing emissions, OMFs sustain tea production and contribute to a healthier ecosystem. However, the use of OMFs in tea practices is still very low, especially in Africa, where tea crops are grown, including Tanzania. Therefore, strategies like encouraging the integration of OMFs into fertilization practices to improve soil fertility and crop productivity, training programs for tea farmers on the benefits and application methods of OMFs, and research and development efforts to create OMF formulations optimized for tea cultivation. Promote the recycling of organic waste for OMF production, align agricultural practices with waste management strategies, increase consumer awareness, and encourage farmers to adopt environmentally friendly practices.

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### AUTHORSHIP CONTRIBUTION STATEMENT

Braison Ernest Mjanja: conceptualization, investigation, data extraction and synthesis writing- original draft, writing–review and editing, and validation. Mawazo J Shitindi: conceptualization, formal analysis, supervision, writing–review and editing; Bonface J.H Massawe: conceptualization, formal analysis, investigation, writing–review and editing; glory R. Mulashani: Investigation, writing review and validation. Finias F Mwesige: Investigation, writing review and editing.

### CONFLICT OF INTEREST

The authors declare no conflict of interest.

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### ETHICAL APPROVAL

Not applicable.

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