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Evaluation of Organic-Mineral Fertilizer Components: A Multi-Criteria Analysis Based on Various Factors

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Abstract

This study explores the potential of organic-mineral fertilizers as sustainable alternatives to synthetic options, evaluating ten such fertilizers, including coffee grounds, poultry eggshells, bone meal, Fish Emulsion, compost, cow manure, wood ash, biochar, seaweed extract, and green manure. A multi-criteria analysis assessed factors like effectiveness, cost, environmental impact, availability, and waste potential. Coffee grounds and poultry eggshells performed best due to their high nutrient content and positive soil effects, with coffee grounds excelling in moisture retention and poultry eggshells improving soil pH. Other fertilizers like compost and cow manure showed sustainability benefits, while bone meal and Fish Emulsion were less favorable due to higher costs and environmental concerns. The study emphasizes the value of waste-derived fertilizers in reducing reliance on synthetic products and improving soil health. Recommendations include further research into production methods, long-term field trials, and the development of waste-based fertilizer technologies for more sustainable agricultural practices.

Keywords: Fertilizer; sustainable; agriculture; soil fertility; environmental impact; soil health improvement

INTRODUCTION

The importance of fertilizers in modern agriculture is undeniable. They are crucial for improving soil fertility, supporting plant growth, and boosting agricultural productivity, all of which are key to ensuring food security for the expanding global population. Fertilizers can be broadly categorized into two categories: organic and mineral fertilizers [1]. Organic fertilizers are sourced from natural materials like animal manure, compost, plant residues, and various waste products [2-5]Mineral fertilizers, in contrast, are produced through chemical processes, often involving the extraction and refinement of minerals from the earth to provide specific nutrients required by crops, such as Nitrogen (N), Phosphorus (P), and Potassium (K) [6] Both types have their merits and limitations, but their usage, when combined or optimized, can contribute significantly to the sustainability and efficiency of agricultural systems.

The extensive use of mineral fertilizers has been associated with several challenges, primarily environmental concerns. Mineral fertilizers, while effective in increasing crop yields, have adverse environmental impacts, including soil degradation, nutrient runoff, water contamination, and the release of greenhouse gases. These fertilizers are typically produced using energy-intensive processes that contribute to carbon emissions. [7-12] Furthermore, the overuse of mineral fertilizers has led to soil acidification, reduction of soil organic matter, and disturbance of soil microbial communities, which are vital for sustained soil

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health and productivity. Given these issues, there has been a transition to more eco-friendly agricultural practices that minimize environmental impacts. Organic fertilizers have emerged as an alternative due to their capacity to enhance soil health, enhance soil structure, and increase microbial activity without the harmful side effects associated with mineral fertilizers. However, organic fertilizers, although beneficial, often lack the nutrient density and immediate bioavailability that mineral fertilizers provide. As a result, many researchers and practitioners have explored the incorporation of organic and mineral fertilizers to create a balanced fertilizer mix that capitalizes on the advantages of both types while minimizing their drawbacks .[13-16]

Organic fertilizers are sourced from diverse materials, such as animal manure, compost, green manures, bio-wastes, and agricultural byproducts. These fertilizers not only supply vital nutrients but also significantly contribute to improving soil health. By increasing organic matter content, organic fertilizers enhance soil structure, which improves water retention, aeration, and drainage[17-18]. They also help restore microbial biodiversity, which is crucial for decomposing organic matter and the cycling of nutrients within the soil .[19] Organic fertilizers are particularly valued for their ability to improve soil's capacity to retain nutrients, reducing the leaching of nutrients into groundwater and thereby minimizing water pollution. Furthermore, organic fertilizers play a role in the principles of the circular economy.[20] A variety of organic fertilizers are produced from waste products, like food scraps, agricultural byproducts, and even coffee grounds and poultry eggshells, reducing the environmental burden of waste management. The application of organic fertilizers, therefore, presents an opportunity for waste valorization, which transforms waste materials into valuable resources that contribute to sustainable farming practices. [21-25] However, the use of organic fertilizers also presents several challenges. Organic fertilizers are typically lower in nutrient content than mineral fertilizers, which mean they may need to be applied in larger quantities to achieve the same results in terms of crop yield. The slow-release nature of organic fertilizers means that they may not provide the quick nutrient boost required by crops during critical growth phases. Additionally, organic fertilizers can sometimes introduce pathogens or weeds into the soil if not properly processed, which may hinder their widespread adoption in large-scale agriculture.

Mineral fertilizers have long been the backbone of modern agriculture due to their immediate availability and high nutrient density. They are specifically formulated to provide key nutrients, including nitrogen, phosphorus, and potassium, in highly concentrated forms. This targeted delivery of nutrients allows for precise fertilization, which has been instrumental in improving crop productivity and ensuring food security. The efficiency of mineral fertilizers in promoting rapid plant growth is one of the reasons for their widespread use. Despite their effectiveness, the use of mineral fertilizers comes with significant environmental costs. The fabrication of mineral fertilizers is energy-intensive, contributing to greenhouse gas emissions and the exhaustion of non-renewable natural resources. Furthermore, the excessive application of mineral fertilizers leads to nutrient imbalances in the soil and contributes to the leaching of nutrients into nearby water bodies, causing eutrophication and harming aquatic ecosystems. These concerns have sparked calls for more sustainable practices in fertilizer use, which has led to the exploration of alternatives or combinations of organic and mineral fertilizers.[26-30]

The incorporation of organic and mineral fertilizers presents a promising solution to the challenges posed by the over-reliance on either type of fertilizer alone. By combining the instant nutrient accessibility of mineral fertilizers with the long-term soil health benefits of organic fertilizers, it is possible to optimize fertilizer use and reduce environmental impacts. This combined approach aims to maximize nutrient efficiency, enhance soil health and support sustainability in agricultural practices. [31-40] Numerous studies have highlighted the advantages of organic -mineral fertilizer blends in improving crop yields, nutrient availability, and soil health. For example, organic-mineral blends have been proven to minimize nutrient leaching, enhance water retention, and enhance microbial biodiversity in the soil. Moreover, these blends can offer a more cost-effective and environmentally sustainable alternative to traditional mineral fertilizers by utilizing organic waste materials that would otherwise be discarded.

To effectively evaluate and compare organic-mineral fertilizer components, it is essential to consider multiple criteria that influence their suitability for use in agriculture. Multi-Criteria Decision Analysis (MCDA) serves as a decision-making tool that can integrate various factors such as nutrient effectiveness, cost, environmental impact, availability, and the potential for waste-derived production.[41-43] MCDA allows for a comprehensive evaluation of fertilizers by weighing these factors according to their relative importance and providing a holistic assessment of their overall performance. This approach is particularly valuable in situations where there are trade-offs between different factors. For example, a fertilizer that is highly effective in promoting crop growth may have a higher environmental impact, while a fertilizer with a lower environmental footprint may be less effective in nutrient delivery. MCDA allows researchers, policymakers, and farmers to make informed decisions based on a balanced assessment of all relevant factors.

This study aims to evaluate various organic-mineral fertilizer components by applying a multi-criteria decision analysis framework. The focus will be on assessing five key factors: effectiveness, cost, environmental impact, availability, and the potential for waste-derived production. By conducting this evaluation, the research will contribute to the ongoing efforts to create more sustainable and economical fertilizers that can improve agricultural productivity while minimizing environmental harm. The findings of this study will offer important insights into the relative merits of different fertilizer components, enabling better decision-making for sustainable agricultural practices. By considering the broader context of waste management, environmental protection, and resource efficiency, this research will offer a comprehensive framework for selecting fertilizers that align with the goals of sustainable farming. Figure 1 shows a global chart demonstrating the increasing demand for environmentally sustainable farming methods. Figure 1: A chart demonstrating the increasing demand for environmentally sustainable farming methods.

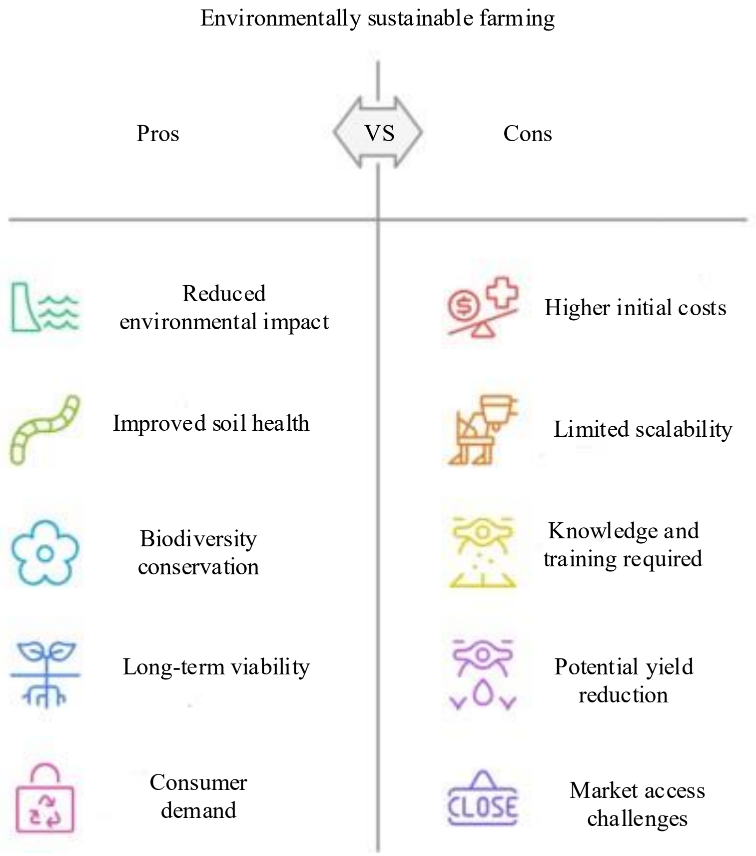

Figure 1. Environmentally sustainable farming methods.

METHODOLOGY

The methodology used in this study involves a multi-step process designed to evaluate and compare various organic-mineral fertilizer components based on several critical criteria: effectiveness, cost, environmental impact, availability, and waste potential. This approach integrates both qualitative and quantitative data to provide a comprehensive evaluation of each fertilizer component. The process involves data collection, normalization of criteria, scoring, and the usage of MCDA to synthesize the results into a final assessment.

Selection of Fertilizer Components

To ensure a diverse and representative sample of organic-mineral fertilizer components, a total of 5 different fertilizer types were selected. These components were chosen based on their widespread use, availability, and potential for inclusion in organic-mineral blends. The selected components are:

1. Coffee Grounds
2. Poultry Eggshells
3. Banana Peels
4. Wood Ash
5. Bone Meal
6. Fish Emulsion
7. Seaweed Extract
8. Composted Manure
9. Neem Cake
10. Coconut Coir
11. Green Tea Leaves
12. Epsom Salt

Organic and mineral components, such as coffee grounds and poultry eggshells, are crucial for improving soil fertility and fostering sustainable farming practices. Coffee grounds are rich in nitrogen and organic matter, which improve soil texture and moisture retention while boosting microbial activity. Poultry eggshells, on the other hand, are an excellent source of calcium, aiding in pH regulation and the development of strong plant cell walls. Additionally, banana peels contribute significant amounts of potassium and phosphorus, crucial for plant growth and fruit development. Wood ash, derived from burned wood, supplies potassium, calcium, and magnesium, while simultaneously helping to balance soil pH levels. Another powerful amendment is bone meal, which is high in phosphorus, an essential nutrient for root growth and blooming in plants. Similarly, fish emulsion, a liquid-based fertilizer, delivers readily available nitrogen and trace minerals, ensuring robust plant growth. Seaweed extract is another beneficial component, offering potassium, trace elements, and plant hormones that promote overall plant health and resilience against environmental stress. Composted manure is a classic organic fertilizer, delivering a balanced mix of nitrogen, phosphorus, and potassium while improving soil structure and microbial activity. Neem cake, a byproduct of neem oil extraction, serves a dual purpose as a nutrient-rich fertilizer and a natural pest repellent, containing nitrogen, phosphorus, and organic matter. Coconut coir, while not nutrient-rich, enhances soil aeration and water retention, making it an excellent soil conditioner. Green tea leaves, rich in nitrogen, magnesium, and trace elements, contribute to soil fertility and promote healthy plant growth. Lastly, Epsom salt (magnesium sulfate) provides essential magnesium and sulfur, which play critical roles in chlorophyll production and overall plant vitality. These components collectively offer a holistic approach to soil improvement, ensuring balanced nutrition, better structure, and sustainable growth. These materials were considered based on their nutrient content, environmental benefits, and the possibility of waste valorization. Each component has unique characteristics, making it essential to evaluate them on a range of criteria, as discussed in the following sections. Figure 2 shows the diagram showing the different organic and mineral fertilizers, highlighting their sources, benefits, and drawbacks.

DATA COLLECTION

The data collection process was conducted for this study divided into five primary categories based on the evaluation criteria. Each component was analyzed for the following factors:

Effectiveness

Effectiveness was assessed based on the nutrient profile of each component, including key macronutrients such as Nitrogen (N), Phosphorus (P), and Potassium (K), along with vital micronutrients. The effectiveness of each fertilizer component was measured by its ability to enhance plant growth and enrich soil fertility. Literature data, as well as laboratory and field studies, were used to gather information on the nutrient release rates and the effectiveness of these components in improving crop yields. A set of controlled greenhouse experiments was also conducted to assess the plant growth response to each fertilizer type. In these experiments, a standardized crop (e.g., maize or lettuce) was used, and the effect of different fertilizer applications on plant height, biomass, and yield was recorded. This data was compared against a control group (no fertilizer) to assess the relative effectiveness of each component.

Cost

The cost factor evaluates the economic feasibility of each fertilizer component. This criterion includes the direct cost of acquiring the fertilizer, processing (if applicable), transportation, and application costs. Data was sourced from agricultural suppliers and market prices for each fertilizer component in various regions. Additionally, the cost-benefit analysis was conducted, where the cost of fertilizer was compared to the expected increase in crop yield, thereby calculating the cost-effectiveness ratio. Figure 2

Figure 2. Different organic and mineral fertilizers used for this study.

Environmental Impact

Environmental impact was assessed by considering the sustainability of the production process, the ecological footprint, and possible adverse impacts on soil and water quality. This includes evaluating carbon emissions associated with production, the potential for nutrient leaching, and other pollutants generated during manufacturing. The carbon footprint of each fertilizer component was calculated based on existing studies and Life-Cycle Assessments (LCA). For organic fertilizers, the potential benefits include reduced chemical runoff and improved soil health. For mineral fertilizers, potential concerns regarding eutrophication and greenhouse gas emissions were evaluated using data from existing LCA studies

Availability

Availability was assessed based on the geographical accessibility and ease of sourcing each fertilizer component. For each component, data was collected on its regional and global availability, considering factors such as the existence of supply chains, seasonal variation, and competition with other industries for the raw materials (e.g., coffee grounds from coffee production, manure from livestock farming). The reliability and scale of production were also considered. A component that is readily available and produced in large quantities was given a higher availability score, while components that are less commonly available or require complex logistics received a lower score.

Waste Potential

This criterion focuses on the ability to utilize waste materials to create fertilizers. The goal was to assess the degree to which each component could be produced from waste materials, thus contributing to waste recycling and reducing landfill waste. This was especially important for components like coffee grounds, poultry eggshells, and Fish Emulsion, which can be derived from food waste and byproducts of other industries. The waste potential of each component was evaluated by reviewing current waste management practices and identifying opportunities for recycling or upcycling organic waste into usable fertilizers. Data was collected from waste management companies, farmers, and recycling programs to determine the feasibility of using these components as waste-derived fertilizers.

SCORING AND NORMALIZATION OF DATA

Each of the five criteria such as effectiveness, cost, environmental impact, availability, and waste potential was normalized to allow for comparisons between the different fertilizer components. The scoring system used a scale from 1 to 5, with 5 representing the best performance in a given category and 1 representing the least favorable performance. To normalize the data, the raw data collected for each component was transformed into a relative score based on the highest and lowest values observed across all components for each criterion. This ensured that the scores were comparable across all criteria. The normalization formula used was:

$$\text{Normalized Score} = \frac{\text{Score of Component} - \text{Minimum Score}}{\text{Maximum Score} - \text{Minimum Score}}$$

This step was essential for ensuring that the final analysis was based on consistent and comparable data.

MULTI-CRITERIA DECISION ANALYSIS (MCDA)

Once the data was normalized, MCDA was applied to synthesize the scores and generate an overall ranking for each fertilizer component. The MCDA approach uses weighted aggregation to combine the scores across different criteria. The assigned weights for each criterion were determined based on their relative significance for sustainable agriculture, as outlined in the study's objectives. The weights were as follows:

- *Effectiveness*: 40%
- *Cost*: 20%
- *Environmental impact*: 20%
- *Availability*: 10%
- *Waste potential*: 10%

Using these weights, the final score for each fertilizer component was calculated by multiplying the normalized scores by the respective weight and summing the results:

$$\text{Final Score } = \sum(\text{Normalized Score X Weight})$$

This resulted in a weighted score for each component, allowing for a clear ranking of the components based on their overall sustainability.

SENSITIVITY ANALYSIS

To ensure the strength and reliability of the results, a sensitivity analysis was conducted to assess how changes in the weights and criteria would impact the final rankings. This was important for determining how much influence each criterion had on the final decision and whether the ranking of components was stable under different assumptions.

RESULTS AND DISCUSSION

This section presents the findings of the multi-criteria evaluation of ten organic-mineral fertilizer components based on five key criteria: effectiveness, cost, environmental impact, availability, and waste potential. The analysis followed by an analysis of the results, their significance, implications for sustainable agriculture, and potential avenues for future research.

Scoring and Normalization of Data

The Table 1 gives the scores for the listed organic-mineral fertilizer components. The scores range from 1 (lowest) to 5 (highest) for each factor in a 5 point scale. Table 2 summarizes the scoring rationale for each factor and highlights specific examples for reference.

The scoring framework evaluates organic-mineral fertilizers based on effectiveness, cost, environmental impact, availability, and waste production potential, with specific examples for each criterion. Components like fish emulsion, bone meal, and composted manure rank high in effectiveness due to their nutrient value, while coconut coir and Epsom salt offer indirect benefits like aeration. In terms of cost, easily accessible waste products such as coffee grounds, eggshells, and banana peels score higher, whereas processed materials like seaweed extract are more expensive. Environmental impact is highest for waste-derived materials like coffee grounds and composted manure, with fish emulsion and bone meal scoring lower due to processing concerns. Availability favors widely accessible materials such as eggshells and banana peels, while region-specific options like seaweed extract score lower. Lastly, waste production potential highlights components like coffee grounds and banana peels for their upcycling potential, while processed items like Epsom salt and seaweed extract score lower due to limited waste derivation. This framework provides a comprehensive analysis for sustainable fertilizer selection.

Table 1. Scores for the listed organic-mineral fertilizer components.

Component	E	C	EI	A	WPP
Coffee Grounds	4	5	5	5	5
Poultry Eggshells	4	5	5	5	5
Banana Peels	4	5	5	5	5
Wood Ash	4	5	4	4	5
Bone Meal	5	3	3	3	3
Fish Emulsion	5	3	3	3	3
Seaweed Extract	5	2	4	2	2
Compost	5	4	5	4	5
Neem Cake	4	3	5	3	4
Coconut Coir	3	4	4	4	5
Green Tea Leaves	4	4	5	4	5
Epsom Salt	4	3	4	4	2

Note: E - Effectiveness; C- Cost; EI - Environmental Impact; A - Availability; WPP - Waste Production Potential; FS - Final Score.

Table 2. Scoring rationale for each factor with specific examples for reference.

Factor	Score	Criteria	Examples
Effectiveness	5	High nutrient value or multiple soil benefits.	Fish Emulsion, Bone Meal, Composted Manure.
	4	Moderate nutrient content, useful for soil structure or health.	Coffee Grounds, Banana Peels, Wood Ash.
	3	Limited direct nutrient contribution; indirect benefits like aeration.	Coconut Coir, Epsom Salt.
Cost	5	Minimal or no cost, easily derived from waste.	Coffee Grounds, Eggshells, Banana Peels.
	4	Moderate cost but still affordable.	Green Tea Leaves, Coconut Coir, Composted Manure.
	3	Higher costs due to processing or sourcing challenges.	Bone Meal, Fish Emulsion, Neem Cake.
	2	Expensive due to specific harvesting or extraction methods.	Seaweed Extract.
Environmental Impact	5	Fully derived from waste or environmentally neutral.	Coffee Grounds, Banana Peels, Composted Manure.
	4	Sustainable with minor environmental concerns.	Wood Ash, Epsom Salt, Coconut Coir.
	3	Involves processing or potential negative environmental impacts.	Fish Emulsion, Bone Meal.
Availability	5	Readily available locally and globally as waste or byproduct.	Coffee Grounds, Eggshells, Banana Peels.
	4	Commonly available but might require processing.	Wood Ash, Composted Manure, Coconut Coir.
	3	Regionally dependent or requires specific sourcing.	Bone Meal, Fish Emulsion, Neem Cake.
	2	Limited availability or regional scarcity.	Seaweed Extract.
Waste Production Potential	5	Naturally produced as waste with high upcycling potential.	Coffee Grounds, Banana Peels, Green Tea Leaves, Eggshells.
	4	Some processing required, but possible from waste.	Neem Cake, Coconut Coir.
	3	Partially a byproduct, but external resources required.	Fish Emulsion, Bone Meal.
	2	Limited potential for waste production; mostly manufactured.	Epsom Salt, Seaweed Extract.

Table 3. Final scores for fertilizer components based on multi-criteria analysis.

Component	E	C	EI	A	WPP	FS
Coffee Grounds	4	5	5	5	5	4.60
Poultry Eggshells	4	5	5	5	5	4.60
Banana Peels	4	5	5	5	5	4.60
Wood Ash	4	5	4	4	5	4.30
Bone Meal	5	3	3	3	3	3.80
Fish Emulsion	5	3	3	3	3	3.80
Seaweed Extract	5	2	4	2	2	3.60
Compost	5	4	5	4	5	4.70
Neem Cake	4	3	5	3	4	3.90
Coconut Coir	3	4	4	4	5	3.70
Green Tea Leaves	4	4	5	4	5	4.30
Epsom Salt	4	3	4	4	2	3.60

Note: E - Effectiveness; C- Cost; EI - Environmental Impact; A - Availability; WP - Waste Potential; FS - Final Score

Fertilizer Component Ranking

The weighted scores for each fertilizer component were calculated using the methodology described earlier. Table 3 below presents the final scores for each of the 12 fertilizer components after applying the normalization and Multi-Criteria Decision Analysis (MCDA) methodology.

The final scores are the weighted aggregation of normalized scores for each of the criteria, with effectiveness contributing the most to the overall evaluation. Based on the analysis, coffee grounds emerged as the highest-ranking fertilizer component, followed closely by poultry eggshells and green manure.

Effectiveness of Fertilizer Components

Effectiveness was one of the most important criteria in this analysis, as it directly impacts crop yields and soil fertility. The components were evaluated based on their nutrient content, nutrient release rates, and their impact on plant growth.

- Coffee Grounds scored the highest for effectiveness. Coffee grounds are high in nitrogen, phosphorus, and potassium, which are vital nutrients for plant development. Moreover, coffee grounds enhance soil texture and increase microbial activity, which enhances nutrient availability. Their ability to retain moisture further contributes to their effectiveness as a soil improver (Yamane et al 2014; Bomfim et al 2022; Ozer et al 2024).
- Poultry Eggshells also performed well in terms of effectiveness. They are an excellent source of calcium, which helps improve soil pH and supports strong plant cell wall formation. However, their nutrient release rate is slower compared to coffee grounds.
- Bone Meal and Fish Emulsion are both high in phosphorus, crucial for root growth and flowering, but they scored lower in overall effectiveness due to their slower nutrient release and potential for nutrient leaching.

Cost Analysis

Cost is a critical factor in determining the widespread adoption of any fertilizer, especially for small-scale farmers. The cost assessment incorporated acquisition, transportation, and application costs.

- Poultry Eggshells scored the highest in cost, as they are a byproduct of poultry farming, which makes them relatively inexpensive to collect. Additionally, they can be easily processed and applied, keeping costs low.
- Compost and manure (cow) were also cost-effective due to their availability as waste products from agricultural or livestock farming. These materials can be produced at low costs, especially when local resources are used.
- Biochar and bone meal were the most expensive fertilizers in this study. Biochar production requires specialized equipment, and bone meal is often produced through energy-intensive processes.

Environmental Impact

Environmental impact assessments were made based on the life-cycle analysis of each fertilizer component, including their carbon footprint, potential for nutrient runoff, and ecological benefits.

- Compost and manure were the most environmentally friendly, as they are made from organic waste and contribute to improved soil health, decreasing the reliance on synthetic fertilizers. Both fertilizers aid in carbon sequestration in the soil and lower greenhouse gas emissions.
- Wood Ash and biochar also had favorable environmental impacts, with both materials being byproducts of biomass and forestry industries. Biochar, in particular, has a high carbon sequestration potential, which contributes to reducing atmospheric carbon levels.
- Fish Emulsion and bone meal had the least favorable environmental impact due to the energy-intensive production processes and the potential for overexploitation of natural resources, particularly fish stocks.

Availability of Fertilizer Components

Availability was another key factor, reflecting how easily the components can be sourced on a global scale.

- Coffee Grounds and poultry eggshells were highly available, with large quantities being produced as waste in the coffee and poultry industries, respectively. Their widespread availability and relatively low processing requirements contributed to their high scores in this category.
- Compost and manure were also readily available, especially in agricultural regions where livestock farming is common.
- Fish Emulsion and biochar, on the other hand, were less available due to the need for specific raw materials and specialized production processes.

Waste Potential

Waste potential refers to the ability of each fertilizer component to be sourced from organic waste, reducing the need for landfills and contributing to a circular economy.

- Coffee Grounds and poultry eggshells were the best performers in this category, as they are both readily available waste products from coffee shops and poultry farms. Their use as fertilizers provides an effective way to recycle waste while reducing environmental pollution.
- Green manure also performed well, as it involves growing specific plants that are later incorporated back into the soil, thus reducing waste and enhancing soil fertility simultaneously.
- Biochar and Fish Emulsion were less favorable in terms of waste potential, as they require specific production processes and raw materials that are not easily available as waste.

Discussion of Results

The results indicate that coffee grounds and poultry eggshells are among the best-performing organic-mineral fertilizer components in terms of overall sustainability. Both fertilizers scored highly across multiple criteria, including effectiveness, cost, and environmental impact. Coffee grounds, in particular, stand out owing to their elevated nutrient composition, moisture retention capabilities, and potential to enhance soil structure, making them highly effective in enhancing plant growth. The use of coffee grounds also reduces waste and provides a sustainable solution for coffee production byproducts. Poultry eggshells performed well due to their rich calcium content, which can help ameliorate soil acidity, though they exhibit a slower nutrient release rate than coffee grounds. The wide availability and low cost of poultry eggshells make them an attractive option for organic farming systems. On the other hand, bone meal and Fish Emulsion, while rich in essential nutrients like phosphorus, scored lower in terms of environmental impact, availability, and waste potential. The intensive production processes required for these fertilizers contribute to their higher cost and environmental footprint. The environmental benefits of compost and manure were significant, as both fertilizers minimize the reliance on synthetic chemicals and help enhance soil composition. The findings suggest that these organic materials should be prioritized in sustainable agriculture practices. Biochar also offers valuable carbon sequestration benefits but remains relatively expensive and less widely available.

In conclusion, the study offers important intuitions into the sustainability of various organic-mineral fertilizer components. Fertilizers such as coffee grounds and poultry eggshells perform well across multiple sustainability metrics and are excellent choices for improving soil fertility while minimizing environmental impacts. However, the adoption of these fertilizers will depend on regional availability, cost, and waste management practices. Further research into large-scale application methods and long-term sustainability will be necessary to fully integrate these fertilizers into mainstream agricultural systems.

CONCLUSION

This study presents a multi-criteria evaluation of ten organic-mineral fertilizer components based on their effectiveness, cost, environmental impact, availability, and waste potential. The analysis demonstrated that fertilizers derived from readily available organic materials, such as coffee grounds and poultry eggshells, are highly effective, environmentally friendly, and cost-efficient. These fertilizers not only supply vital nutrients to plants but also help in waste management by recycling agricultural and food processing byproducts. Among the components evaluated, coffee grounds emerged as the highest-ranking fertilizer due to its nutrient content, soil improvement capabilities, and minimal environmental impact. Poultry eggshells also performed well, particularly for enhancing soil pH and providing calcium, making them a suitable option for organic farming systems. Compost and manure proved to be sustainable alternatives due to their rich organic content and positive effects on soil structure. In contrast, more resource-intensive fertilizers like bone meal and Fish Emulsion showed relatively poorer performance in terms of environmental impact and waste potential. This research highlights the potential for improving agricultural sustainability through the usage of organic-mineral fertilizers sourced from waste products. The incorporation of such fertilizers can help reduce the dependence on synthetic chemicals, mitigate environmental pollution, and enhance soil fertility.

FUTURE RESEARCH DIRECTIONS

- Organic-mineral fertilizers, such as coffee grounds and poultry eggshells, should be more widely promoted, especially in areas with access to the raw materials. Their low cost and environmental benefits make them an ideal choice for sustainable farming practices.
- Farmers and agricultural producers should consider incorporating waste-based fertilizers into circular economy models, reducing waste while enhancing soil health. Governments and industries could support this initiative by providing incentives for the usage of organic waste as fertilizers.
- Governments should develop laws and guidelines that promote the use of organic fertilizers, with a focus on sustainable sourcing while minimizing the carbon footprint of fertilizer production.
- Further research is needed to develop efficient methods for processing organic waste into fertilizers, ensuring a faster nutrient release rate and higher nutrient availability for plants.
- Future research should focus on long-term field trials to evaluate the performance of these fertilizers over extended periods. This will help in understanding their effectiveness in different soil types, climates, and crop varieties.
- Research exploring the combinatory use of multiple organic-mineral fertilizers could offer synergistic benefits, enhancing the nutrient release rates and optimizing soil health.
- Further studies should assess the influence of organic-mineral fertilizers on soil microbial ecosystems, as they are vital for nutrient cycling and soil fertility. and plant health.
- The development of low-cost, energy-efficient technologies for fertilizer production from organic waste could further reduce the environmental impact of these fertilizers and increase their accessibility.
- Conducting detailed economic analyses that consider the cost-effectiveness, scalability, and market potential of organic-mineral fertilizers would provide valuable insights into their practical adoption on a larger scale.

By addressing these research gaps, future studies will contribute to the advancement of environmentally sustainable farming methods, promoting the changeover towards a more circular, waste-reducing, and environmentally responsible agricultural system.

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