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Organic Waste Valorization through Composting as Part of a Circular Economy

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Abstract: Organic solid waste management is a significant challenge given environmental and sustainability concerns. Organic waste, including food residues, plant materials, agricultural waste, and other biological components, makes up a large portion of human-generated waste. Effective management of this waste is a priority for governments and businesses to reduce its ecological footprint and exploit its potential. Composting organic waste is an essential practice with numerous benefits for agriculture and the environment, turning waste into nutrient-rich compost that improves soil structure and health, reduces waste, decreases greenhouse gas emissions, and promotes sustainable agriculture.Olive pomace, the residue from olive oil extraction, is rich in fibers, residual oil, and polyphenols. When composted with other organic materials, it produces compost that enhances soil structure, water retention, and provides essential nutrients to plants. Household organic waste, such as food scraps and fruit and vegetable peelings, decomposes into compost rich in organic matter and nutrients, improving soil quality and structure. Poultry manure, high in nitrogen, phosphorus, and potassium, stabilizes nutrients and reduces pathogens when composted, producing balanced, nutrient-rich compost that enhances soil fertility and promotes healthy crop growth. Green waste, such as leaves and grass clippings, also benefits from composting, producing compost rich in organic matter that improves soil structure, increases water retention, and supplies essential nutrients to plants.Composting organic waste reduces waste, enriches soils, and supports sustainable agriculture by transforming olive pomace, household waste, poultry manure, and green waste into valuable compost. This practice reduces dependence on chemical fertilizers, contributing to sustainable farming and reducing water pollution caused by nutrient runoff. Organic waste valorization through composting is crucial in the circular economy, turning waste into valuable resources, reducing raw material needs, lowering waste management costs, and promoting sustainability. Studies have demonstrated the effectiveness of composts as soil amendments, reducing waste volume and management costs.

Keywords: Composting, Organic waste valorization, Circular economy, Environmental management, Sustainable agriculture.

Introduction

Organic waste valorization is essential in waste management, converting organic components into useful resources with significant environmental and socio-economic benefits. It reduces pollution, greenhouse gas emissions, and promotes responsible management of organic materials. Besides environmental advantages, it

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presents economic potential for public entities and businesses, fostering a sustainable and environmentally friendly future (Doughmi et al., 2022).

Managing organic solid waste, such as food residues, plant materials, and agricultural waste, has become a priority for governments and businesses to reduce ecological footprints while exploiting their potential. Transforming organic waste into useful resources decreases the volume of waste destined for landfills, essential for more sustainable waste management (Ministry of Energy Transition and Sustainable Development. Department of Sustainable Development, 2012). This exploration examines common valorization methods, like composting, and their benefits, including reducing greenhouse gas emissions, improving soil fertility, and creating bio-based raw materials. However, it also highlights challenges such as environmental concerns related to incineration, the need for adequate infrastructure, and public awareness (Doughmi et al., 2022; Doughmi et al., 2024).

Composting transforms organic matter into nutrient-rich soil amendments, improving soil quality and reducing the need for synthetic fertilizers. Compost contains essential nutrients for plants and helps to rebalance soil pH, promoting plant growth. It stimulates soil microbial activity, releasing nutrients and suppressing pathogens, thus improving crop health (Hay et al., 1996). Composting reduces the amount of organic waste in landfills and methane emissions. It decreases dependence on chemical fertilizers, contributing to more sustainable agriculture and reducing water pollution. Enriching soils with organic matter and nutrients, composting supports sustainable agriculture, increased productivity, and environmental preservation, promoting healthier soils and more sustainable land use (Zhang et al., 2013).

Moreover, the application of compost in agronomy contributes to soil conservation by diminishing the reliance on synthetic fertilizers. Organic substrates are increasingly utilized in agriculture not only as fertilizers but also as soil ameliorants. Organic matter constitutes a vital component of soil, influencing its physical, chemical, and biological characteristics (Hassink et al., 1997; Herold et al., 2014). Numerous studies have demonstrated the beneficial impacts of organic amendments, particularly when combined with mineral fertilizers, on cultivated soils (Alvarez et al., 1998; Goyal et al., 1999; Blair et al., 2006; Gong et al., 2009; Butler & Hooper, 2010; Evans et al., 2012; Zhou et al., 2013; Cannavo et al., 2014).

In this context, this research emphasizes the valorization of olive by-products. Compost derived from olive pomace could serve as an effective soil amendment, facilitating an environmentally sustainable recycling of waste materials. This approach may enhance the yield of organic emmer production, maintain soil fertility, and mitigate pollution risks associated with landfill disposal (Diacono & Montemurro, 2019). For this, we made six mixtures of different composition based on olive pomace associated with different percentages of organic household waste. Physicochemical and bacteriological characterization of the different mixtures at the initial state at the beginning of the composting process and once the compost is mature at the end of the composting process.

Method

Sampling

Organic wastes including olive pomace, household organic waste, poultry manure, and green waste were collected and prepared for composting. Olive pomace was sourced from a three phase's extraction system olive oil production facility in Tiflet city, household waste from the wholesale market in the city of Salé, poultry manure from a farm located in Tiflet city, and green waste from the higher school of technology in Salé gardening activities. These materials were mixed in appropriate ratios to balance nutrient composition and achieve an optimal C/N ratio. The mixture was placed in a 30 liters composting barrels and regularly turned for proper aeration (Doughmi et al., 2022; Doughmi et al., 2024).

Table 1. Composts mixtures

Mixtures	**Signification**
Gr	Olive pomace
D	Organic household waste
F	Poultry manure
V	Green waste

Physicochemical and Biological Characterization

Moisture levels were maintained between 40-60% to activate the microbial activity and it was determined by drying the samples at 105 °C until a constant mass is obtained then at 525 °C for 4 hours to determine the organic matter by ignition loss (Rodier et al., 2009). Temperatures were monitored to ensure they remained within the optimal range of 50-65°C. The compost matured over 4 months, during which the organic material stabilized and nutrient availability increased. Upon maturation, the compost was harvested, sieved, and analyzed for nutrient content, pH, moisture content, and microbial activity.

However, the other macro elements were obtained by calcination in the oven at 500 °C for 2 hours to 3 hours; the obtained ashes were dissolved to determine the other mineral elements (Pinta, 1979). Total nitrogen NTK and ammoniacal nitrogen $NH4^+$, total organic carbon and the macro elements (P_2O_5, K_2O, Na_2O, CaO, MgO and Cl^-) were determined by different methods in the Research Unit on Environment and Natural Resource Conservation at the National Institute of Agronomic Research Rabat laboratory (Doughmi et al., 2022). The concentrations of heavy metals (ETM) are measured by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) at the CNRST in Rabat (Doughmi et al., 2024). Concerning microbiological analyses (fecal pollution indicators: thermotolerant coliforms and *E. coli*) were determined within the microbiology laboratory at the Higher School of Technology of Salé, and were counted by the 3 tube NPP method (Rodier et al., 2009) (Doughmi et al., 2022).

Phytotoxicity Test

This phytotoxicity test involves germinating fenugreek seeds under specific conditions of temperature (25°C), humidity (70%), and light (0% for germination and 1000% for growth). Fifteen fenugreek seeds were placed on filter paper in petri dishes. The dishes were irrigated every 48 hours with 3 mL of compost solutions (Doughmi et al., 2023).

Measured Parameters

- *Germination Rate* = (number of germinated seeds * 100) / number of tested seeds.
- *Germination Index* = (number of germinated seeds in the sample / number of germinated seeds in the control) x (root lengths of germinated seeds in the sample / root lengths of germinated seeds in the control) x 100.
- *Vigor Index* = (Root length + Shoot length) * Germination rate %.

Statistical Analysis

All the parameters analyzed in this study were processed using SPSS software (Statistical Package for the Social Sciences, version 20). The results are presented as mean ± standard deviation and were analyzed using analysis of variance (ANOVA).

Results and Discussion

Physicochemical and Bacteriological Characterization

The composts generated in this study were deemed suitable for agricultural use, featuring a neutral pH across all blends, an ideal C/N ratio around 20, and an electrical conductivity not surpassing the acceptance threshold for use as a soil amendment (3 mS cm^{-1}). Furthermore, the mixtures exhibited a reduction in pollution indicators. These composts are enriched with nutrients, allowing them to act as fertilizers and soil enhancers for mineral-poor soils. Upon completion of the composting process, an optimal C/N ratio was found in the GD2 blend (18.56), with a maximum Na^+ ion concentration of 0.70% and an ammonium nitrogen content below the limit value (400 mg kg^{-1}) (Doughmi et al., 2022) (Table 3). Additionally, the mixtures demonstrated a reduction in pollution indicators. By the conclusion of the composting process, the GF2 blend recorded the lowest C/N ratio (15.85), along with the highest levels of P_2O_5 (0.2606%) and ammoniacal nitrogen (360.74 mg kg^{-1}) below the limit value (400 mg kg^{-1}) too (Doughmi et al., 2024) (Table 3).

The pH of the compost's aqueous solution began to rise from the thermophilic phase onward. This phase's alkalinization results from ammonia, a base, generated through bacterial hydrolysis of proteins and organic nitrogen. During the maturation phase, the pH stays basic but gradually drops over time, eventually reaching neutrality. This pH stability is due to the slow maturation reactions and the buffering capacity of humus (Fauci et al., 1999).

Initially, the electrical conductivity is high, but it decreases over the composting period, ultimately dropping below the threshold of 3 mS cm^{-1} (Soumaré et al., 2002). Throughout the composting process, the level of extractable ammoniacal nitrogen declines as the compost ages, while the nitrate content increases. This transformation from ammonia nitrogen to nitrate nitrogen happens through the mineralization of complex nitrogen compounds into ammonia and amino acids (Table 3).

Ammonium can either be directly utilized in microbial metabolism or oxidized into nitrates and nitrites by nitrogen-fixing organisms (Aylaj & Lhadi, 2008). The changes in the C/N ratio are directly tied to the biodegradation of organic matter, which leads to both the release of carbon as CO_2 and the apparent concentration of mineral elements (N, P, K, etc.). Furthermore, nitrogen is lost as ammonia during the thermophilic phase, which tends to moderate the reduction in the C/N ratio. Similar results have been documented by other researchers (Hafidi, 1996 and Bousselhaj et al., 1996). The C/N ratio serves as another indicator of compost maturity (Lhadi et al., 2004, 2006; Aylaj, 2002; Tazi, 2001; Ozores-Hampton et al., 1998; Mathur et al., 1993).

The properties of the studied mixtures reveal a high concentration of fecal coliforms at the onset of the composting process, which significantly decreased by the end of the treatment. In particular, the GD3 mixture showed a dramatic reduction from 4.19 10^7 TC g^{-1} to 63.3 TC g^{-1}. A notable decrease rate of 76.34% was observed for the thermotolerant coliforms in the GD3 mixture (Doughmi et al., 2022) (Table 3).

The analysis of heavy metals in these compost samples shows that they meet regulatory standards (NF. U 44-051, 2006). They can be safely utilized as organic soil amendments to enhance agricultural soils and support plant growth without the danger of excessive metal contamination. These findings highlight the effectiveness of the composting process employed to create these organic amendments and their appropriateness for environmentally sustainable agricultural use. Nonetheless, it is advisable to maintain regular monitoring of compost quality to ensure its environmental safety and effectiveness in soil enhancement (Doughmi et al., 2022).

In this research, the findings indicate that trace metal concentrations in the compost samples remain below the recommended thresholds for safe agricultural use. The highest levels of heavy metals were observed in poultry manure compost, with post-composting concentrations of Iron (652.62 mg kg^{-1}), Copper (45.34 mg kg^{-1}), Manganese (509.73 mg kg^{-1}), Zinc (364.46 mg kg^{-1}), and Nickel (3.33 mg kg^{-1}) (Doughmi et al., 2024) (Table 2). Conversely, regarding heavy metals, the peak levels after composting were recorded in green waste compost for Chromium (10.40 mg kg^{-1}) and Lead (2.36 mg kg^{-1}), and in poultry manure compost for Cadmium (0.27 mg kg^{-1}) (Doughmi et al., 2024) (Table 2).

Table 2. ETM limit values

ETM	V (mg kg^{-1})	D (mg kg^{-1})	F (mg kg^{-1})	Gr (mg kg^{-1})	ETM limit values (mg kg^{-1}) (NF. U 44-051, 2006)
Cd	0,025 ±0,06	0,19 ±0,16	0,27 ±0,42	0,08 ±0,03	3
Hg	-	-	-	-	2
Pb	2,35 ±0,50	0,75 ±0,84	1,74 ±1,52	0,1125 ±0,19	180
Fe	561,68 ±453,20	287,57 ±44,58	652,62 ±151,77	545,18 ±261,28	-
As	-	-	-	-	18
Mn	91,45 ±27,78	58,62 ±16,66	509,73 ±72,57	28,85 ±7,39	6
Cu	8,46 ±2,50	8,54 ±1,22	45,34 ±8,43	8,30 ±1,93	300
Cr	10,40 ±5,96	6,51 ±2,51	2,75 ±1,19	2,22 ± 2,42	120
Ni	2,68 ±1,14	2,80 ±2,82	3,33 ±1,80	1 ±1,17	60
Se	-	-	-	-	12
Zn	58,57 ±6,47	25,30 ±7,08	364,46 ±41,22	10,88 ±3,92	600

The presence of harmful microorganisms in composted waste can pose a possible risk of infecting crops where compost has been used. Thus, employing composts in agriculture necessitates not only verification of their agronomic effectiveness but also, and more crucially, confirmation of their environmental and health safety (Houot et al., 2009). The presence of pathogenic microorganisms in composted waste poses a potential risk of contaminating crops grown with compost. Thus, the use of composts in agriculture requires not only validation of their agronomic benefits but also assurance of their environmental and health safety (Houot et al., 2009). Composting is essentially a microbiological process that heavily relies on temperature changes within the windrows. The temperature inside the compost mass dictates the rate of many biological processes and influences the evolution and succession of the microbial community (Mustin, 1987).

Table 3. Physicochemical and bacteriological characterization

	Before composting			After composting		
Composts	Gr	D	F	Gr	D	F
pH	5.05 ± 0.53	6.18 ± 0.33	7.52 ± 0.07	7.90 ± 0.29	7.70 ± 0.33	8.00 ± 0.08
EC mS cm^{-1}	1.77 ± 0.10	0.72 ± 0.04	3.33 ± 0.19	1.74 ± 0.08	1.33 ± 0.13	2.66 ± 0.13
Humidité %	26.52 ± 3.46	91.10 ± 3.16	15.73 ± 0.38	15.22 ± 1.47	26.41 ± 2.70	32.86 ± 1.74
OM %	92.35 ± 2.46	89.87 ± 2.38	94.53 ± 1.06	52.62 ± 2.71	44.18 ± 2.70	56.64 ± 5.01
Ash %	7.65 ± 2.46	10.13 ± 2.38	5.47 ± 1.06	47.38 ± 2.71	55.82 ± 2.70	43.36 ± 5.01
TOC %	53.57 ± 1.43	52.13 ± 1.38	54.83 ± 0.62	30.52 ± 1.57	25.62 ± 1.57	32.85 ± 2.90
NTK %	1.27 ± 0.04	1.57 ± 0.02	2.85 ± 0.18	1.06 ± 0.03	1.31 ± 0.09	2.85 ± 0.02
C/N ratio	42.23 ± 1.40	33.28 ± 0.46	19.30 ± 1.20	28.90 ± 0.81	19.68 ± 1.28	11.57 ± 0.72
PO_4^{3-} %	0.0187 ± 0.0013	0.0655 ± 0.0044	0.3259 ± 0.0099	0.0260	0.0875	0.4518
P_2O_5 %	0.007 ± 0.001	0.014 ± 0.002	0.187 ± 0.009	0.0088	0.0194	0.2725
CaO %	0.22 ± 0.007	0.12 ± 0.005	0.63 ± 0.050	0.38	0.22	0.63
MgO %	0.08 ± 0.005	0.14 ± 0.005	0.23 ± 0.030	0.04	0.08	0.43
K_2O %	0.46 ± 0.001	1.52 ± 0.002	1.45 ± 0.087	0.40	0.95	1.92
Na_2O %	0.05 ± 0.001	0.27 ± 0.002	0.24 ± 0.034	0.19	0.51	1.02
Cl^- %	0.0185 ± 0.001	0.0235 ± 0.001	0.0236 ± 0.0004	0.0242	0.0301	0.0291
SO_4^{2-} %	0.0035 ± 0.0006	0.0042 ± 0.0007	0.0120 ± 0.0085	0.0036	0.0035	0.0085
NO_3^- mg kg^{-1}	57.55 ± 10.37	127.32 ± 27.29	379.01 ± 76.92	151.11 ± 14.44	189.29 ± 15.46	779.57 ± 84.48
NH_4^+ mg kg^{-1}	526.01 ± 41.78	728.29 ± 22.31	1116.29 ± 77.37	259.25 ± 19.84	287.93 ± 41.32	586.32 ± 72.00
Thermotolerant coliforms (Log_{10} g^{-1})	8	8	9.2	5.0	5	6.6
E.coli (Log_{10} g^{-1})	7.2	**8**	8.2	2	2	5

Phytotoxicity Test

The first graph shows the germination rate of fenugreek seeds for each type and mixture of compost (Figure 1). Composts made from green waste (V) at 25% (86.67%), 50% (86.67), and 75% (70%) show the highest germination rates, even surpassing the control (63.33%). Composts from poultry manure (F) (73.33% at 25% dilution) and olive pomace (Gr) (80% at 75% dilution) show relatively high germination rates, although slightly lower than green waste. Organic household waste (D) shows the lowest germination rates, particularly at concentrations of 75% and 100% (Figure 1).

The second graph presents the germination index, which takes into account both the germination rate and root growth (Figure 2). The results show that the mixtures of green waste compost (V) have the highest germination indices (at 25% with 305.63%, 50% with 312.62%, and 75% with 210.23%), suggesting not only successful germination but also vigorous root growth. Composts from olive pomace (Gr) and poultry manure (F) follow with moderately high indices. Compost from organic household waste (D) once again shows inferior performance, indicating possible phytotoxicity or nutrient deficiency for germination and growth (Figure 2).

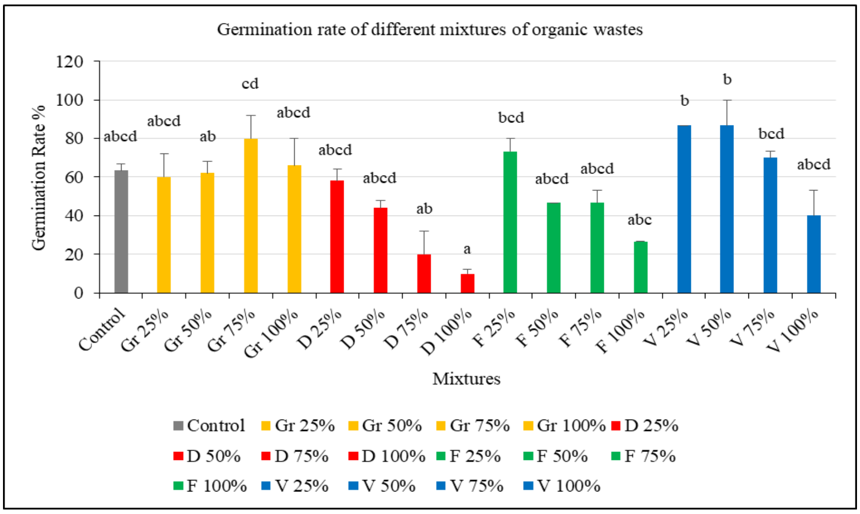

Figure 1. Germination rate of different mixtures of organic wastes

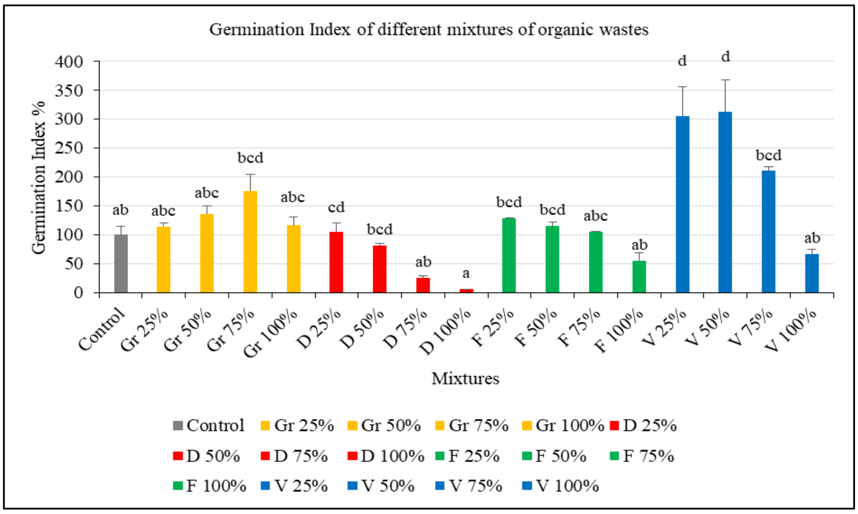

Figure 2. Germination index of different mixtures of organic wastes

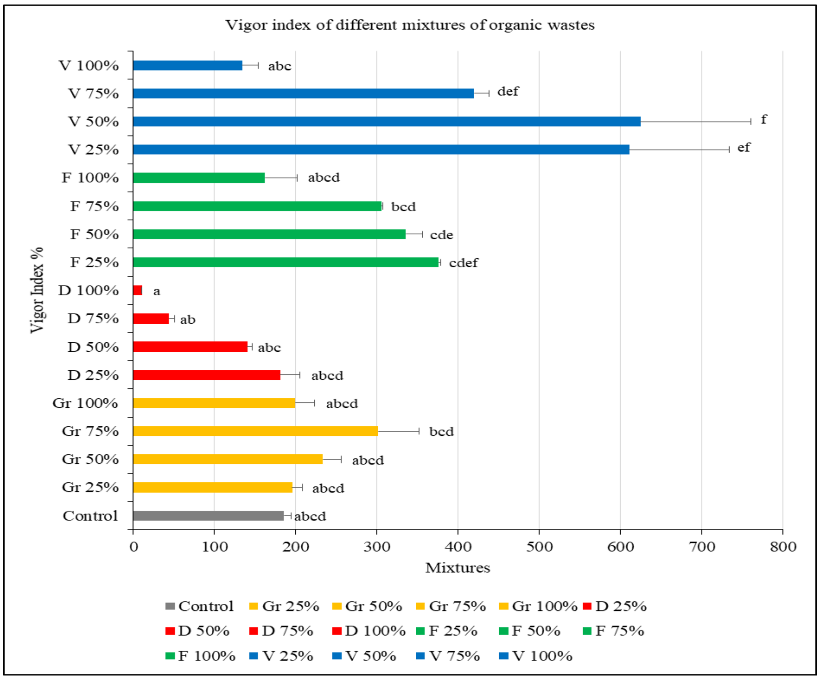

Figure 3. Vigor index of different mixtures of organic wastes

The third graph illustrates the vigor index, a measure that integrates root and stem length as well as the germination rate (Figure 3). Green waste composts (V) dominate once again, particularly at concentrations of 25% (610.58%), and 50% (624.54%), demonstrating robust growth. Composts from poultry manure (F) and olive pomace (Gr) show acceptable vigor indices, but lower than those of green waste. Organic household waste (D) has lower vigor indices, which supports previous results regarding its potential phytotoxicity (Figure 3).

Green waste composts appear to be the most favorable for the germination and growth of fenugreek seeds, indicating their high potential for use as a non-phytotoxic organic amendment. Olive pomace and poultry manure are also effective, although less so than green waste. In contrast, organic household waste composts show signs of phytotoxicity, possibly requiring additional treatment or dilution before application to avoid negative effects on germination and plant growth.

Conclusion

This research focused on the agronomic utilization of various types and sources of organic waste, including olive solid residues (olive pomace from a three-phase continuous extraction system at a milling unit in Tiflet city, Khemisset province, Rabat-Salé-Kénitra region). The olive pomace was mixed in different ratios with other wastes such as organic household refuse, poultry litter, and green waste. These wastes constitute the majority of organic waste in Morocco. The goal of this study was to agronomically utilize these various types of waste through composting. Composting is a biological and ecological breakdown process that reduces waste volume, lowers landfill costs, and converts waste into nutrient-rich bio fertilizers that benefit impoverished soils within a green and circular economy framework.

The composts produced in this investigation were assessed as suitable for agronomic applications, exhibiting a neutral pH across all formulations, an optimal carbon-to-nitrogen (C/N) ratio of approximately 20, and an electrical conductivity that did not exceed the permissible limit for soil amendment usage (3 mS cm^{-1}). Additionally, the mixtures indicated a reduction in pollution metrics. These composts are nutrient-dense, facilitating their role as fertilizers and soil conditioners for mineral-deficient substrates. Upon completion of the composting process, the ammonium nitrogen concentration remained below the threshold value (400 mg kg^{-1}). Furthermore, the mixtures demonstrated a reduction in pollution metrics. In addition, green waste composts are the most effective for germinating and growing fenugreek seeds, making them a valuable non-phytotoxic organic amendment. In contrast, organic household waste composts exhibit phytotoxicity and may require treatment or dilution to avoid negative effects on plant growth.

Recommendations

To valorize organic waste through composting within a circular economy, it is essential to raise awareness among citizens about source separation and establish collection and composting infrastructure. Local authorities should support community and home composting initiatives through grants and training. Promoting the use of compost in agriculture and urban green spaces is crucial, as is the adoption of incentive policies to encourage companies to invest in innovative composting technologies. These measures will transform organic waste into valuable resources, reducing environmental impact and promoting economic and social sustainability.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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