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Comparative Analysis of Physicochemical Properties and Agronomic Performance of Different Vermicompost Feedstocks

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Abstract

Vermicomposting is an environmentally sustainable, economically viable, and agronomically valuable method for converting organic waste into nutrient-rich soil amendments, thereby supporting sustainable development. However, the fertilization efficiency of vermicompost can vary significantly depending on the physicochemical properties of the feedstock used. This study aims to compare different feedstocks on vermicompost and evaluate their performance on soil fertility and plant nutritional status. Organic matter (OM), pH, salinity (EC), total Kjeldahl nitrogen (TKN), total phosphorus (TP) and total potassium (TK) of various vermicompost samples were taken into consideration to evaluate their fertilization efficiency as performance determinants in terms of plant growth, plant nutritional status, yield, crop quality and cost with the aim of determining the weights of the specific parameters in the total performance using multi-criteria decision-making (MCDM) methods. The integrated ENTROPY-TOPSIS method was used. Twenty-one different vermicompost feedstock analyses were collected from the literature and compared in order to create an agronomic performance ranking based on the selected criteria. The ENTROPY method revealed that the TP was the most influential factor (21.6%), followed by the EC (20.7%) and the TK (18.5%), while the OM had the lowest impact (11.3%). Based on the TOPSIS ranking, vermicompost from brewer's spent grain achieved the highest performance, followed by cow manure plus rice straw and olive pruning waste, whereas paper waste ranked at the bottom. A comparative analysis with other objective MCDM weighting methods proved strong correlations, particularly with WENSLO, MPSI and LODECI methods, confirming the robustness of the ENTROPY method.

Keywords: sustainable economic development; plant nutritional status; soil fertility; multi-criteria decision-making (MCDM) methods; feedstock analysis; total P; total K; total Kjeldahl N; pH; electrical conductivity; organic matter

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1. Introduction

Vermicompost improves soil fertility by increasing the organic matter (OM), balancing the salinity (EC), stabilizing the pH, and enhancing the availability of essential nutrients, which together promote better plant growth and nutrient uptake compared to conventional fertilizers [1]. Vermicompost is rich in humic substances and microbial biomass, which can contribute to increase the soil OM with improvement of soil structure [2] and water retention, creating a favorable environment for root growth [3]. Moreover, the supply of vermicompost also enhances cation exchange capacity (CEC), allowing soils to retain and supply nutrients more effectively [3]; at the same time, vermicompost generally has a low EC compared to chemical fertilizers, reducing the risk of soil salinization. Furthermore, by buffering salt, vermicompost helps maintain osmotic balance, preventing stress on plant roots; thus, long-term use improves soil resilience against salinity-related degradation. Vermicompost also tends to neutralize soil pH [2], moving acidic or alkaline soils toward a more balanced range; this stabilization enhances nutrient solubility and microbial activity, making nutrients more available to plants. Vermicompost contains plant-available nitrogen (N) forms, such as ammonium (NH_4^+) and nitrate (NO_3^-), that are released gradually, thus reducing leaching losses and providing N gradually during the season [4,5]. Earthworm activity enhances the mineralization of organic phosphorus (P), increasing its availability; it also improves P solubility by lowering its fixation in alkaline soils [6,7]. Moreover, vermicompost supplies readily available potassium (K), which is crucial for plant water regulation and enzyme activation; OM interactions prevent K leaching, ensuring long-term fertility benefits [8,9]. In sum, vermicompost supplies essential macronutrients such as N, P, K, calcium (Ca), magnesium (Mg), and sulfur (S), as well as micronutrients including iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn), together with bioactive compounds such as humic substances and enzymes [2,10–20].

The effectiveness of vermicompost in improving soil and supporting plant growth depends on the materials fed to the worms. Following a typical input–output relationship, the nutritional quality of the feed directly influences the composition and value of the resulting vermicompost [21]. Vermicompost quality is strongly linked to its nutrient composition (N, P, K), pH balance, and OM content [22]. Together, these parameters determine its effectiveness as a soil amendment and its role in improving plant growth and soil health [10,16,19,20].

Vermicompost can be produced from a wide range of organic waste, often used in combination. Common feedstocks include animal manures (e.g., cow dung and other livestock excreta) [15]; municipal and household organic waste (such as kitchen scraps, food waste, paper, cardboard, and yard trimmings) [23,24]; agricultural residues (including crop residues, rice straw, plant debris, and garden waste) [25–27]; and pre-treated sewage or industrial sludges [25–28].

The substrate type is a primary determinant of nutrient variation in vermicompost, with numerous studies demonstrating that the choice of feedstock—such as crop residues, animal manures, agro-industrial byproducts, or plant materials—leads to significant differences in N, P, and K content, as well as other macro- and micronutrients. For example, combinations such as common bean straw, coffee husk, and cow dung yield vermicompost with superior NPK profiles compared to single substrates or less nutrient-rich materials [22–29]. Studies consistently report that vermicompost N, P, and K content varies significantly with the substrate type. For example, vermicompost derived from tea leaves showed the highest N and P contents, whereas mixtures of vegetable waste and cow dung evidenced the highest K levels [27]. Vermicompost from cattle manure generally contains higher N and P than that derived from sewage sludge, but it has a lower K content [30]. In addition, cow manure combined with maize and soybean residues has been found to be a suitable substrate for *Eisenia andrei*. This combination also yielded the highest concentrations of nutrients (N, P, K, and S), along with substantial carbon (C) loss (up to 77% of the initial C) and relatively low N loss [31].

Scientific studies commonly use the analysis of variance (ANOVA) to assess the effect of vermicompost on plant performances and soil fertility; this method primarily focuses on identifying the differences between the composted and non-composted treatments and estimating the agronomic impact of vermicompost. In contrast, multi-criteria decision-making (MCDM) methods—such as AHP, TOPSIS, VIKOR, and PROMETHEE—are increasingly applied to address more complex evaluations. These tools enable the ranking of alternatives based on multiple criteria and are particularly useful in environmental decision-making contexts, including comparisons of waste management strategies, composting versus alternative treatments, and the selection of appropriate technologies [32–34].

Several studies have applied MCDM methods to waste and biomass management; however, none of these specifically use these approaches to rank or evaluate different vermicompost substrates. The existing reviews highlight the widespread application of MCDM techniques (such as AHP, TOPSIS, VIKOR, and PROMETHEE) in complex decision-making contexts, mainly in the industrial and mining sectors, but not in vermicomposting specifically [35,36]. They concentrated on specific areas such as sustainability assessment, waste management and resource recovery, policy and institutional decision-making, technology and process optimization. MCDM is widely used to evaluate vermicompost as a part of sustainable waste management and soil amendment strategies [37,38]. The criteria often include the nutrient quality (NPK, organic matter), the environmental impact (C footprint, salinity reduction), and the economic feasibility [39,40]. Vermicomposting is assessed as a method for recycling organic waste (manure, food waste, agricultural residues) [41]. MCDM helps compare different waste treatment options (composting, anaerobic digestion, landfilling) based on cost, efficiency, and environmental impact [42,43]. Institutions and municipalities often rely on MCDM approaches to assess whether vermicomposting represents the most suitable waste management strategy [44,45]. Furthermore, MCDM tools are used to optimize process parameters, including the feedstock type, the moisture content, the temperature, and the selection of the appropriate earthworm species [1,46]. In agrifood waste biomass studies, MCDM is often combined with LCA to select the best uses of the residues (e.g., composting vs. anaerobic digestion vs. pyrolysis), typically using AHP and TOPSIS [47]. Agrifood waste biomass studies consider criteria such as the environmental impact, the cost, and the energy recovery; however, they do not compare different vermicompost feedstocks. In circular economy and waste-related decisions, MCDM is widely used to choose technologies and scenarios, again with TOPSIS and AHP being the most common, but not for substrate-level vermicompost optimization [48].

Comparative information on the properties and the agronomic performance of different types of vermicompost is still limited in the literature. Therefore, the main objective of this study was to evaluate and compare the fertilization efficiency of types of vermicompost derived from different feedstocks by identifying the relative importance of key physicochemical parameters through a multi-criteria decision-making approach. In particular, OM, pH, salinity, total Kjeldahl nitrogen (TKN), total phosphorus (TP), and total potassium (TK) were considered as the main indicators influencing plant growth, plant nutritional status, yield, crop quality, and economic performance.

2. Materials and Methods

2.1. Vermicompost Description and Selection

Physicochemical properties, which are frequently used in the literature as performance determinants of vermicompost, obtained from different organic waste sources, are called the criteria in this analysis. Table 1 contains the code of the performance criteria, the abbreviation name of the criteria and the key physicochemical parameters used to evaluate the agronomic performance of the vermicompost feedstocks. Each criterion reflects an essential aspect of soil fertility and nutrient availability, thereby serving as an indicator of the suitability of the feedstock materials for vermicomposting and their potential contribution to plant growth.

Table 1. Criteria for agronomic performance of vermicompost feedstocks.

Criterion	Physicochemical Parameters	Description	Relevance in Vermicomposting
C1	Organic Matter (OM)	Fraction of decomposed plant and animal residues, including humus and soil biota	Enhances biological activity, improves soil structure, water retention, microbial activity, nutrient cycling, and overall compost fertility
C2	pH	Measure of the acidity or alkalinity of the material	Regulates microbial processes and affects nutrient solubility and availability; near-neutral pH is generally preferred for earthworm and microbial activity
C3	Electrical Conductivity (EC)	Indicator of soluble salt and nutrient concentration in the feedstock	Reflects salinity and nutrient availability; excessive EC may cause salt stress in earthworms and negatively affect plant growth
C4	Total Kjeldahl Nitrogen (TKN)	Combined content of organic nitrogen and ammonium nitrogen	Indicates nitrogen-supplying potential; higher TKN may support plant vegetative growth
C5	Total Phosphorus (TP)	Includes both organic and inorganic phosphorus forms	Assesses phosphorus-supplying capacity; phosphorus is essential for root development, energy transfer, and plant metabolism
C6	Total Potassium (TK)	Includes exchangeable and structurally bound potassium forms	Contributes to nutrient-rich vermicompost; potassium supports enzyme activation, water regulation, and plant stress resistance

Twenty-one vermicompost types were selected from the literature for their positive effects on plants and soil and their physicochemical properties were used to rank their agricultural productivity performance (Table 2).

Table 2. Physicochemical properties of different vermicompost feedstocks.

Code	Vermicompost Feedstock	Main Chemical Parameters [1]	Benefits to Soil	Benefits to Plants	Literature
A1	Brewer's spent grain	OM: 0.40 pH: 4.44 EC: 1.12 TKN: 1.40 TP: 1.80 TK: 2.20	Low EC minimizes salt stress, contributes moderate OM and enhances microbial activity.	Balanced N, high P and high K support root development, vegetative growth, and crop quality.	[49–55]
A2	Cow manure	OM: 0.56 pH: 3.39 EC: 8.40 TKN: 2.14 TP: 0.77 TK: 3.05	Improves soil structure, water retention, and biological activity due to organic matter.	High N and K promote vegetative growth, yield, and stress tolerance.	[56–62]

Table 2. *Cont.*

Code	Vermicompost Feedstock	Main Chemical Parameters [1]	Benefits to Soil	Benefits to Plants	Literature
A3	Cow manure plus rice straw (50:50)	OM: 0.88 pH: 3.04 EC: 0.96 TKN: 2.16 TP: 1.27 TK: 1.01	High OM and low EC greatly improve soil structure, aeration, and water retention.	High N and adequate P support strong root and shoot development.	[25,56,63,64]
A4	Cow dung	OM: 0.34 pH: 5.75 EC: 2.81 TKN: 2.37 TP: 0.64 TK: 1.16	Enhances soil structure and microbial activity; relatively more suitable pH.	High N supports vegetative growth; moderate P and K provide balanced nutrition.	[63,65–74]
A5	Rice straw plus animal wastes (50:50)	OM: 0.32 pH: 2.90 EC: 4.59 TKN: 1.69 TP: 1.26 TK: 1.31	Enhances biological activity and P availability.	Moderate N, good P, and good K support early growth and root development.	[25,63,64,75]
A6	Cow dung plus food industry sludge (70:30)	OM: 0.53 pH: 3.96 EC: 1.80 TKN: 2.60 TP: 0.98 TK: 0.76	Adds organic matter with moderate EC, improving soil fertility with low salinity risk.	High N supports vegetative growth.	[67,76]
A7	Olive pruning waste	OM: 0.48 pH: 0.01 EC: 8.91 TKN: 1.86 TP: 2.23 TK: 1.74	Improves soil nutrient status, especially P content.	High P and adequate K enhance root growth, flowering, and crop quality.	[57,58,77,78]
A8	Olive pruning waste plus cow manure (50:50)	OM: 0.48 pH: 2.24 EC: 12.64 TKN: 1.62 TP: 0.44 TK: 1.77	Provides organic matter but may increase soil salinity due to very high EC.	Supplies K, contributing to crop quality and stress resistance.	[57,58,77,78]
A9	Nutshell	OM: 0.41 pH: 3.89 EC: 1.53 TKN: 0.41 TP: 0.01 TK: 0.14	Low EC makes it safe for soil; improves soil structure slightly.	Very low nutrient content; minimal direct fertilization effect.	[59]
A10	Nutshell plus cow manure (50:50)	OM: 0.37 pH: 3.40 EC: 8.35 TKN: 0.76 TP: 0.38 TK: 0.40	Improves soil C content and structure.	Limited nutrient contribution.	[59]
A11	Pumpkin plus cow manure (30:70)	OM: 0.44 pH: 1.56 EC: 9.75 TKN: 0.90 TP: 1.04 TK: 2.75	Contributes organic matter and potassium, improving soil fertility.	High K improves fruit quality, color, taste, and stress tolerance.	[79]

Table 2. *Cont.*

Code	Vermicompost Feedstock	Main Chemical Parameters [1]	Benefits to Soil	Benefits to Plants	Literature
A12	Cotton boll	OM: 0.76 pH: 2.60 EC: 16.53 TKN: 2.93 TP: 0.26 TK: 3.72	High OM significantly improves soil physical properties.	Very high N and K strongly enhance growth, yield, and quality.	[80–82]
A13	Cotton boll plus cow manure (50:50)	OM: 0.74 pH: 5.76 EC: 16.66 TKN: 4.30 TP: 0.77 TK: 3.10	Enriches soil with organic matter and nutrients.	Very high N and high K promote vigorous growth and high yield quality.	[80–82]
A14	Watermelon skin plus cow manure (40:60)	OM: 0.03 pH: 4.44 EC: 0.74 TKN: 3.26 TP: 0.61 TK: 1.90	Low EC allows safe application; minimal salinity risk.	High N and adequate K support plant growth efficiently.	[83]
A15	Paper waste	OM: 0.02 pH: 0.01 EC: 6.12 TKN: 0.24 TP: 0.02 TK: 0.14	Minimal contribution to soil structure and fertility.	Negligible nutrient supply.	[11,68,84]
A16	Rice straw	OM: 0.02 pH: 0.16 EC: 2.98 TKN: 0.07 TP: 0.01 TK: 0.01	Limited soil improvement effect based on low OM and nutrients.	Very low nutrient content; minimal plant benefit.	[25,64,68,84,85]
A17	Farmyard manure	OM: 0.52 pH: 0.61 EC: 2.38 TKN: 2.23 TP: 0.94 TK: 1.69	Improves soil structure, water retention, and microbial activity.	High N and good K provide balanced plant nutrition.	[78]
A18	Banana leaf waste plus cow dung (60:40)	OM: 0.34 pH: 5.76 EC: 1.87 TKN: 1.38 TP: 0.83 TK: 0.83	Low EC and suitable pH support safe soil application and microbial activity.	Moderate NPK provides balanced but mild nutrient supply.	[31,69]
A19	Banana leaf waste plus cow dung (40:60)	OM: 0.28 pH: 6.39 EC: 1.81 TKN: 1.77 TP: 0.93 TK: 0.94	Improves soil physical and biological properties with low salinity risk.	Balanced nutrients support overall plant growth.	[31,69]

Table 2. *Cont.*

Code	Vermicompost Feedstock	Main Chemical Parameters [1]	Benefits to Soil	Benefits to Plants	Literature
A20	Cow manure plus hazelnut husk (50:50)	OM:0.81 pH: 1.10 EC: 4.06 TKN: 0.75 TP: 0.08 TK: 0.41	High OM improves soil structure, aeration, and water retention.	Limited direct nutrient supply.	[62]
A21	Cow manure plus olive pomace (50:50)	OM: 0.86 pH: 2.90 EC: 2.96 TKN: 0.81 TP: 0.06 TK: 0.41	Enhances soil aggregation, aeration, and water-holding capacity.	Limited nutrient contribution; mainly improves soil quality.	[62,78]

[1] OM: organic matter, pH: potential of hydrogen, EC: electrical conductivity, TKN: total Kjeldahl nitrogen, TP: total phosphorus, TK: total potassium.

2.2. ENTROPY Method

The ENTROPY method is one of the most frequently used MCDM methods in the literature [86,87]. The concept of entropy was defined by Shannon as a measure of uncertainty in knowledge [88]. Previously, it was used to measure the amount of useful information that a dataset provides. Later, it started to be used to determine the importance of the criteria. In MCDM problems, it enables the objective determination of the criterion weights. The weight values of the criteria are determined in five steps [89–91].

Step 1—Creation of the matrix. The first application step of the ENTROPY method is to create the initial decision matrix in Equation (1) [86].

$$X_{ij} = \begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mn} \end{bmatrix} \tag{1}$$

In the equation, the term m represents the number of alternatives in the decision process, and the term n represents the number of performance criteria in the decision process. In the matrix, Xij expresses the performance value of alternative i according to criterion j.

Step 2—Normalizing the decision matrix. Each element in the matrix is normalized differently depending on whether it is benefit- or cost-oriented. A benefit-oriented criterion means "greater value is better for performance", while a cost-oriented criterion means "smaller value is better for performance". The normalization is carried out with Equation (2) for benefit-oriented criteria and (3) for cost-oriented criteria [86,87].

$$r_{ij} = \frac{X_{ij}}{\text{mak } X_{ij}} \quad , i = 1,2,3\ldots m, \;\; j = 1,2,3\ldots n \tag{2}$$

$$r_{ij} = \frac{\min X_{ij}}{X_{ij}} \quad , \min X_{ij} \neq 0 \;\; i = 1,2,\ldots.m, \;\; j = 1,2,3\ldots.n \tag{3}$$

Step 3—Finding the entropy values (ej). The entropy values of the values normalized using the entropy coefficient are found by Equation (4) [86,92].

$$e_j = -k\sum\nolimits_{j=1}^{n} r_{ij} * \text{In}\left(r_{ij}\right) \; i = 1,2,3\ldots m, \qquad j = 1,2,3\ldots n \tag{4}$$

The term (k) in the equation (k = In (n) − 1) indicates the coefficient of entropy. In the Equation, In(rij) refers to the logarithm of the normalized value.

Step 4—Determining the degree of differentiation of knowledge (dj) or the distance from the ideal. Its value is calculated with the help of the following Equation [86].

$$d_j = 1 - e_j \quad , \quad i = 1,2,3\ldots m \qquad j = 1,2,3,\ldots n \tag{5}$$

Step 5—Finding the weights of the criteria. In this last step, the importance (effect) levels of the criteria (wj) in the performance of the alternatives are calculated with the following equation [86,92].

$$\mathrm{w_j} = \frac{\mathrm{d_j}}{\sum_{i=1}^{n}(d_j).} \quad , \quad \sum\nolimits_{j=1}^{n} \mathrm{w_j} = 1 \qquad j = 1,2,3,\ldots n \tag{6}$$

2.3. TOPSIS Method

The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method is also a method used to assess the performance ranking of alternatives in MCDM problems. TOPSIS was developed by Hwang and Yoon [86]. Its operational steps are described below:

Step 1—Creation of the matrix (X). In the columns of the decision matrix, there are criteria used in the decision-making process, and the alternatives are in the rows. This matrix is the initial one created by the decision maker as shown in the Equation below.

$$\mathrm{X} = \mathrm{X_{ij}} = \begin{bmatrix} \mathrm{X_{11}} & \cdots & \mathrm{X_{1n}} \\ \vdots & \ddots & \vdots \\ \mathrm{X_{m1}} & \cdots & \mathrm{X_{mn}} \end{bmatrix} \tag{7}$$

The variable (m) in the matrix Xij represents the number of alternatives and (n) represents the number of criteria [93,94].

Step 2—Creation of the standard decision matrix (rij). The square root of the sum of the squares of the values of each criterion in the decision matrix is taken. Then, these totals are divided by each criterion value in the relevant column in the decision matrix to create a normalized decision matrix. While creating this matrix, the elements in the X matrix are used and calculated with the following formula.

$$\mathrm{r_{ij}} = \frac{\mathrm{x_{ij}}}{\sqrt{\sum_{\mathrm{i=1}}^{\mathrm{m}} \mathrm{x_{ij}^2}}} \tag{8}$$

Step 3—Arrangement of the weighted standard matrix (V). The elements in the normalized decision matrix are multiplied by the criteria weight (wj) values [93,94].

$$\mathrm{V_j} = \sum_{\mathrm{i=1}}^{\mathrm{m}} \mathrm{r_{ij} w_j} \tag{9}$$

Step 4—Calculation of the ideal (A*) and negative ideal (A−) solutions. In the TOPSIS method, it is assumed that all the evaluation factors show either monotonous increasing or monotonous decreasing tendencies [93,94].

While creating the ideal solution set, the largest value (the smallest value if the evaluation criterion is cost-oriented) within the column values in the V matrix, that is, the weighted criteria, is selected. The ideal solution set is calculated with the following Equation [93,94].

$$A^* = \left\{ (\max_i v_{ij} \middle| j \in J), (\min_i v_{ij} | j \in J' \right\} \tag{10}$$

When creating the negative ideal solution set, the column values in the V matrix, that is, the smallest values within the weighted criteria (the largest value if the criterion is benefit-oriented), should be selected. The negative ideal solution set is calculated with the following equation [93,94].

$$A^{-} = \left\{ (\min_i v_{ij} \middle| j \in J), (\max_i v_{ij} | j \in J' \right\} \quad (11)$$

In the Equations above, J indicates the utility, i.e., maximization, and J′ indicates the loss, i.e., minimization, values. Both the ideal and negative ideal solution sets consist of (n) number of elements that indicate the criteria [86,93].

Step 5—Calculation of the separation measures. The TOPSIS method calculates the deviations of the criteria associated with the alternatives from the ideal solution set and the negative ideal solution set with the Euclidean distance. According to Euclidean theory, the distance between two points is the length of the line connecting these two points. The deviation values calculated in this way are indicated by the ideal discrimination measure (Si*) and the negative ideal discrimination measure (Si−). The calculation for the ideal discrimination measure is made with Equation (12), and the calculation for the negative ideal discrimination measure is made with Equation (13) [93,94]:

$$S_i^{*} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{*} \right)^2} \quad (12)$$

$$S_i^{-} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{-} \right)^2} \quad (13)$$

The numbers Si* and Si− must be equal to the number of alternatives expressed by (m) [93,94].

Step 6—Calculation of the relative affinity to the ideal solution. The ideal discrimination measures and the negative ideal discrimination measures are taken into account in the calculation of the relative affinity (Ci*) of the alternatives to the ideal solution. The ratio between the negative ideal discrimination measure and the total discrimination measure is calculated. The following Equation (14) is applied to calculate the relative proximity to the ideal solution [93,94]:

$$C_i^{*} = \frac{S_i^{-}}{S_i^{-} + S_i^{*}} \quad (14)$$

The relative proximity of the alternatives to the ideal solution (Ci*) takes a value between 0 and 1. The value of Ci* = 1 refers to the absolute closeness of the alternative to the ideal solution and the value of Ci* = 0 expresses the absolute closeness of the relevant alternative to the negative ideal solution [86].

In the first step of the ENTROPY method applied to determine the criterion weights, the initial matrix was arranged. The number of alternatives (m) such as (A1, A2,. . .) in the initial matrix (Table A1) is 21, and the number of criteria (n) such as (C1, C2,. . .) is 6. Therefore, the total number of elements in the matrix is 126 (21 × 6).

In the matrix, the criteria are divided into two as “benefit-oriented” or “cost-oriented”. The benefit-oriented criteria are shown as “Max.”, and the cost-oriented criteria are shown as “Min.”. The higher the numerical value of the criteria specified as Max., the higher the performance of the vermicompost will be. There is only one criterion determined as “Min.” This criterion is the C3 coded EC value, which indicates the salinity of the vermicompost. The smaller the numerical value in this criterion, the higher the performance.

In the second step of the method, the normalized matrix was created. The normalization was performed with Equation (2) for the benefit-oriented criteria and (3) for the cost-oriented criteria. The results of these operations are shown in the Table A2. In the third step of the method, the numerator matrix in the total, which shows the share of normalized values in the total on the basis of the criteria, was arranged. Table A3 shows the numerator matrix in total. In the next step, the ENTROPY values and weights were calculated with the help of Equations (4)–(6). The results of these operations are shown in Table A4.

After finding the criterion weights, the second part of the analysis, i.e., the comparison of the different vermicompost feedstocks with the TOPSIS method, was carried out. For this, a weighted normalized matrix was prepared based on the initial matrix in Table A1, and the criterion weights were found. The weighted normalized values were obtained with the help of Equations (8) and (9), and the ideal (A*) and negative ideal (A−) solutions were calculated with the help of Equations 10 and 11. The results of the procedure are shown in Table A5. In the next steps of the TOPSIS method, the discrimination measures (Si+ and Si−) and the relative affinities to the ideal solution (Ci) were calculated with the help of Equations (12)–(14). In the last stage, the performance ranking of the alternatives was carried out by taking into account the collected points.

The results of the other MCDM objective weight methods were also used to test the consistency and robustness of the results of the ENTROPY method, which reveals the effect weights of the quality performance criteria of the vermicompost species from different sources. Five of the objective weighting MCDM methods applied in the literature (WENSLO, MPSI, LODECI, IDOCRIW, and CRISUS) were selected for a comparative analysis with the other methods. These methods, rather than resorting to expert opinion, calculate weight coefficients objectively through mathematical relationships based only on the data, thus avoiding subjectivity based on personal conditioning. In this comparison, the Pearson correlation coefficient [r] was taken into account.

3. Results

3.1. Agronomic Performances

As a result of the application of the method, an agronomic performance weighting ranking was obtained as C5 > C3 > C6 > C2 > C4 > C1. Among the criteria affecting the agronomic performance of the different vermicompost substrates, the most effective was the C5 criterion, that is, the TP. The weight coefficient of this criterion in the total agronomic performance weighting is 21.6%. In other words, approximately one-fifth of the performance is determined according to this criterion. The second important performance criterion is C3, i.e., the EC factor, which indicates the salinity value of the vermicompost. In third place is the TK criterion. While the weight of the EC criterion in the performance is 20.7%, the weight of the TK is 18. 5%. The criterion that least affects vermicompost performance is the C1 coded OM criterion, which has a weight coefficient of 11.3% (Figure 1).

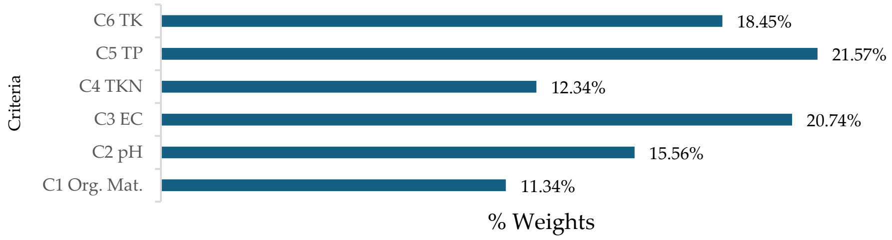

Figure 1. Weights of criteria affecting the agronomic performance of various vermicompost feedstocks. C1 Org. Mat: organic matter, C2 pH: potential of hydrogen, C3 EC: electrical conductivity, C4 TKN: total Kjeldahl nitrogen, C5 TP: total phosphorus, C6 TK: total potassium.

The results of the TOPIS method are presented in Table A6. According to Table A6, the highest performing vermicompost source was the brewer's spent grain type vermicompost with code A1. The second best was A3 coded cow manure plus rice straw, in a 50:50 ratio, while A7 coded olive pruning waste came third. In Figure 2, the total quality performance ranking of the vermicompost alternatives obtained from the different organic feedstocks indicates the agronomic performance ranking more effectively. According to the Figure below, the vermicompost obtained from the organic waste source brewer's spent grain ranked first in the performance assessment. The 2nd position was occupied by the vermicompost produced from cow manure plus rice straw, in a 50:50 ratio. At the end of the ranking list, with the worst performance, was the vermicompost obtained from paper waste (Figure 2).

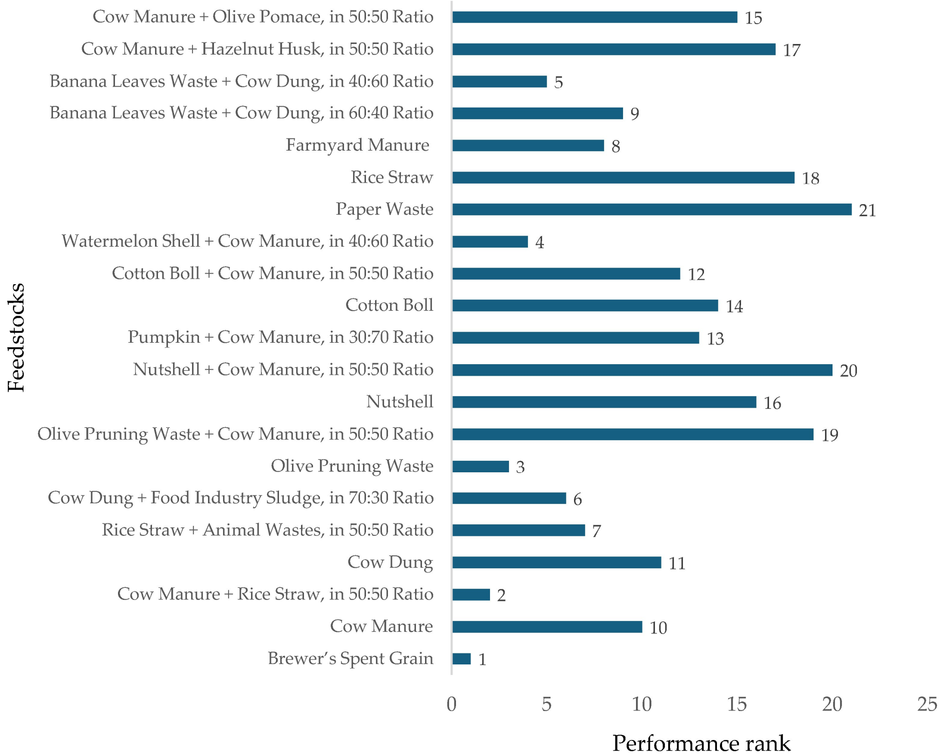

Figure 2. Agronomic performance ranking of different vermicompost feedstocks. Feedstocks indicate different vermicompost substrates compared in this study. Performance rank shows agronomic performance ranking of these feedstocks by the hybrid MCDM method.

3.2. Comparative Analysis

According to the findings of the comparative analysis, a significant and positive relationship ($r > 0.90$) was generally found between the criterion weights determined by the ENTROPY method and the criterion weights determined by the other methods. Of the five methods compared with ENTROPY, the correlation coefficients between the findings of three methods and the ENTROPY findings were calculated above 0.90. The highest correlation coefficients were found to be 0.94 by the WENSLO and the MPSI methods. Likewise, the correlation coefficient with the LODECI method is quite high at 0.93. While the correlation coefficient with the IDOCRIW method was at a high level of 0.82, the correlation coefficient with CRISUS was found to be at a slightly low level of 0.65. The main distinction among these six methods is as follows: ENTROPY, MPSI, and partly CRISUS are mainly dispersion/variation-based methods. WENSLO and LODECI are the methods that place a greater emphasis on the shape and stability of the data structure. IDOCRIW is a hybrid method, since it does not rely on a single perspective but combines different weighting logics. The main differences of the other methods can be seen in the Table below. These results of the comparative analysis indicate that the ENTROPY method applied in this study is a robust and reliable technique for determining the weights of the quality performance criteria among the different vermicompost types derived from different feedstocks (Table 3).

Table 3. Weight normalized matrix for the criterion assesment.

	ENTROPI	WENSLO	MPSI	LODECI	IDOCRIW	CRISUS
C1	0.11	0.09	0.14	0.16	0.12	0.13
C2	0.16	0.13	0.16	0.17	0.19	0.16
C3	0.21	0.22	0.20	0.17	0.16	0.14
C4	0.12	0.14	0.13	0.16	0.11	0.15
C5	0.22	0.24	0.18	0.17	0.23	0.22
C6	0.18	0.17	0.18	0.17	0.20	0.20
r	1.00 [1]	0.941	0.941	0.931	0.82	0.65

[1] The result is statistically significant at $p < 0.01$. C1: organic matter, C2: pH, C3: electrical conductivity, C4: total Kjeldahl nitrogen, C5: total phosphorus, C6: total potassium.

Table 4 indicates an overview of several multi-criteria decision-making (MCDM) weighting methods by highlighting their fundamental principles and distinguishing them from the ENTROPY method, which serves as the reference approach. The ENTROPY method determines the criterion weights based on the degree of information content, disorder, and variability within the dataset. In contrast, WENSLO extends this perspective by incorporating not only dispersion but also the geometric structure of the data through its envelope and slope characteristics, thereby capturing patterns of change more comprehensively. Similarly, MPSI diverges from entropy-based reasoning by focusing on oscillations around the mean and measuring variation through Euclidean distance, emphasizing deviation rather than uncertainty. LODECI introduces a logarithmic decomposition framework, which enhances stability and contrast sensitivity, particularly under complex or inconsistent data conditions. IDOCRIW adopts a hybrid approach by integrating ENTROPY with CILOS, thus accounting for both the information content and the relative loss associated with the criteria. Finally, CRISUS relies on the sum of squares and variance-related measures, prioritizing squared intensity and sensitivity to dispersion rather than entropy alone. Collectively, these methods illustrate diverse conceptualizations of variability and importance, offering alternative weighting mechanisms depending on the nature and structure of the data.

Table 4. Comparative analysis of different MCDM methods.

Method	Main Basis of Weighting	Main Difference from ENTROPY
ENTROPY [1]	Information content, disorder, and dispersion in the data	Reference method
WENSLO	Envelope and slope structure of the data distribution	It considers not only dispersion but also the geometric pattern of change
MPSI	Oscillation around the mean; Euclidean-distance-based variation	Instead of entropy, it relies on deviation/oscillation from the average
LODECI	Logarithmic decomposition and contrast intensity	Its logarithmic structure may provide more stable results under difficult data conditions
IDOCRIW	Combination of ENTROPY and CILOS	In addition to information content, it also incorporates the effect of relative loss
CRISUS	Sum of squares combined with standard deviation/variance	It is based on squared intensity and variance sensitivity rather than only entropy

[1] ENTROPY: Entropy Weighting Method. WENSLO: Weights by Envelope and Slope. MPSI: Modified Preference Selection Index. LODECI: Logarithmic Decomposition of Criteria Importance. IDOCRIW: Integrated Determination of Objective Criteria Weights. CRISUS: Criterion Importance Based on Sum of Squares.

4. Discussion

The findings of this study highlight the critical role of feedstock composition in determining the agronomic performance of different vermicompost substrates, since the feedstock type strongly affects soil nutrient availability and organic matter content, pH, salinity/electrical conductivity, as well as plant-growth responses [95–97]. The application of the ENTROPY method revealed that the TP was the most influential factor, underscoring the importance of P in soil fertility and plant growth. The electrical conductivity, ranked as the second most significant criterion, emphasizes the need to monitor salinity levels to ensure that the vermicompost remains beneficial rather than detrimental to crop production. The total potassium, positioned third, further emphasizes the relevance of nutrient balance in compost evaluation. The relatively low impact assigned to organic material content suggests that, in this dataset, nutrient-specific parameters may have provided more discriminative information than the bulk OM content.

This interpretation is consistent with the ENTROPY method, which assigns criterion weights objectively according to the information content and dispersion of values in the decision matrix rather than expert judgment [27,86,88]. Other objective MCDM weighting techniques similarly derive weights from the structure of the decision matrix, although they define "importance" differently: WENSLO uses envelope and slope information, MPSI is an objective modified preference-selection index, LODECI uses logarithmic decomposition and contrast intensity, IDOCRIW combines ENTROPY and CILOS, and CRISUS determines the criterion importance using a sum-of-squares framework [98–102].

The TOPSIS analysis provided a practical ranking of the vermicompost sources, with brewer's spent grain emerging as the most effective material. This result is consistent with previous research showing that brewer's spent grain, the major by-product of brewing, can be recycled through composting or vermicomposting to produce organic soil conditioners and horticultural biofertilizer substrates, supporting circular-economy and waste-valorization goals [31,32,103]. The strong performance of cow manure combined with rice straw highlights the potential synergy between animal waste and crop residues. Vermicomposting of cow dung and rice straw has been shown to produce stabilized vermicompost with an enhanced NPK content and a reduced C:N ratio compared with the original feedstocks [31]. Olive pruning waste also represents a valuable region-specific agricultural residue. Previous studies have shown that these residues, as well as the vermicompost or biochar derived from them, can enhance soil organic carbon, stimulate microbial activity, and improve crop yield [104,105]. Conversely, the low performance of paper waste confirms that not all organic residues are equally suitable for vermicomposting and that feedstock selection strongly affects the final vermicompost quality [22,95].

Within the TOPSIS framework, the superior ranking of brewer's spent grain can be attributed to its balanced performance across heavily weighted criteria, since TOPSIS ranks the alternatives according to their closeness to the positive ideal solution and their distance from the negative ideal solution [96,98].

From a practical perspective, these results provide guidance for farmers, waste managers, and policymakers in selecting suitable feedstocks for vermicomposting. By identifying the most influential criteria and the best-performing feedstock sources, this study supports more efficient resource utilization, reduces environmental burdens, and improves soil-health outcomes. The combined use of ENTROPY and TOPSIS provides a structured multi-criteria decision-making framework, in which the entropy weighting objectively determines the criterion importance from the decision matrix, while TOPSIS ranks the alternatives according to their closeness to the ideal solution. This integration has been widely applied in environmental management, agriculture, and waste-management decision problems, and it can provide a replicable model for evaluating compost or vermicompost alternatives in different contexts [60,61,96–98]. Looking ahead, further research should explore the long-term agronomic impacts of the identified vermicompost types under field conditions, as well as their economic feasibility at larger scales. Expanding future assessments to include additional criteria such as microbial activity, heavy metal content, and greenhouse gas emissions would provide a more holistic evaluation of the vermicompost quality, safety, and environmental performance. Moreover, integrating machine learning approaches with multi-criteria decision-making methods could improve the prediction, optimization, and real-time decision support in compost and organic-waste treatment systems. Overall, this study provides a basis for advancing sustainable agriculture through evidence-based vermicompost management strategies [95,97,106,107].

5. Conclusions

This study demonstrated that vermicompost feedstocks differ significantly in their physicochemical properties and agronomic performance. According to the ENTROPY analysis, the total phosphorus was identified as the most influential parameter, followed by the electrical conductivity and the total potassium, whereas the organic matter showed the least influence. The TOPSIS ranking revealed that brewer's spent grain had the highest agronomic performance among the evaluated feedstocks, followed by a cow manure–rice straw mixture (50:50) and olive pruning waste, while paper waste showed the lowest performance.

Overall, the integrated ENTROPY–TOPSIS approach was demonstrated to be effective in identifying the key evaluation criteria and ranking the vermicompost feedstocks. The results suggest that nutrient-related parameters, particularly the TP and the TK, together with the EC, are critical indicators for selecting high-performing vermicompost feedstocks.

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Appendix A

Table A1. Initial matrix.

	C1	C2	C3	C4	C5
	Max	Max	Min	Max	Max
A1	0.40	4.44	1.12	1.40	1.80
A2	0.56	3.39	8.40	2.14	0.77
A3	0.88	3.04	0.96	2.16	1.27
A4	0.34	5.75	2.81	2.37	0.64
A5	0.32	2.90	4.59	1.69	1.26
A6	0.53	3.96	1.80	2.60	0.98
A7	0.48	0.01	8.91	1.86	2.23

Table A1. *Cont.*

	C1	C2	C3	C4	C5
A8	0.48	2.24	12.64	1.62	0.44
A9	0.41	3.89	1.53	0.41	0.01
A10	0.37	3.40	8.35	0.76	0.38
A11	0.44	1.56	9.75	0.90	1.04
A12	0.76	2.60	16.53	2.93	0.26
A13	0.74	5.76	16.66	4.30	0.77
A14	0.03	4.44	0.74	3.26	0.61
A15	0.02	0.01	6.12	0.24	0.02
A16	0.02	0.16	2.98	0.07	0.01
A17	0.52	0.61	2.38	2.23	0.94
A18	0.34	5.76	1.87	1.38	0.83
A19	0.28	6.39	1.81	1.77	0.93
A20	0.81	1.10	4.06	0.75	0.08
A21	0.86	2.90	2.96	0.81	0.06
Mak	0.88	6.39	16.66	4.30	2.23
Min	0.02	0.01	0.74	0.07	0.01

Table A2. Normalized matrix.

	C1	C2	C8	C4	C5
	Max	Max	Min	Max	Max
A1	0.46	0.69	0.66	0.33	0.81
A2	0.64	0.53	0.09	0.50	0.34
A3	1.00	0.48	0.78	0.50	0.57
A4	0.39	0.90	0.26	0.55	0.29
A5	0.36	0.45	0.16	0.39	0.57
A6	0.60	0.62	0.41	0.60	0.44
A7	0.55	0.00	0.08	0.43	1.00
A8	0.55	0.35	0.06	0.38	0.20
A9	0.47	0.61	0.49	0.10	0.00
A10	0.43	0.53	0.09	0.18	0.17
A11	0.50	0.24	0.08	0.21	0.47
A12	0.87	0.41	0.05	0.68	0.12
A13	0.84	0.90	0.04	1.00	0.35
A14	0.04	0.69	1.00	0.76	0.27
A15	0.02	0.00	0.12	0.06	0.01
A16	0.02	0.02	0.25	0.02	0.00
A17	0.59	0.10	0.31	0.52	0.42
A18	0.39	0.90	0.40	0.32	0.37
A19	0.32	1.00	0.41	0.41	0.42
A20	0.92	0.17	0.18	0.17	0.04
A21	0.99	0.45	0.25	0.19	0.03
TOTAL	10.95	10.06	6.18	8.29	6.87

Table A3. Matrix of numerator in total.

	C1	C2	C8	C4	C5
	Max	Max	Min	Max	Max
A1	0.04	0.07	0.11	0.04	0.12
A2	0.06	0.05	0.01	0.06	0.05
A3	0.09	0.05	0.13	0.06	0.08
A4	0.04	0.09	0.04	0.07	0.04

Table A3. *Cont.*

	C1	C2	C8	C4	C5
A5	0.03	0.05	0.03	0.05	0.08
A6	0.05	0.06	0.07	0.07	0.06
A7	0.05	0.00	0.01	0.05	0.15
A8	0.05	0.03	0.01	0.05	0.03
A9	0.04	0.06	0.08	0.01	0.00
A10	0.04	0.05	0.01	0.02	0.02
A11	0.05	0.02	0.01	0.03	0.07
A12	0.08	0.04	0.01	0.08	0.02
A13	0.08	0.09	0.01	0.12	0.05
A14	0.00	0.07	0.16	0.09	0.04
A15	0.00	0.00	0.02	0.01	0.00
A16	0.00	0.00	0.04	0.00	0.00
A17	0.05	0.01	0.05	0.06	0.06
A18	0.04	0.09	0.06	0.04	0.05
A19	0.03	0.10	0.07	0.05	0.06
A20	0.08	0.02	0.03	0.02	0.01
A21	0.09	0.05	0.04	0.02	0.00
TOTAL	1.00	1.00	1.00	1.00	1.00

Table A4. Entropy values and weights.

	C1	C2	C8	C4	C5
	Max	Max	Min	Max	Max
A1	−0.1325	−0.1846	−0.2398	−0.1271	−0.2516
A2	−0.1660	−0.1550	−0.0609	−0.1690	−0.1498
A3	−0.2185	−0.1443	−0.2604	−0.1699	−0.2064
A4	−0.1181	−0.2159	−0.1349	−0.1803	−0.1323
A5	−0.1132	−0.1396	−0.0955	−0.1445	−0.2054
A6	−0.1590	−0.1717	−0.1809	−0.1909	−0.1758
A7	−0.1496	−0.0014	−0.0582	−0.1541	−0.2805
A8	−0.1506	−0.1168	−0.0443	−0.1405	−0.1019
A9	−0.1350	−0.1697	−0.2001	−0.0513	−0.0048
A10	−0.1261	−0.1554	−0.0611	−0.0820	−0.0917
A11	−0.1414	−0.0902	−0.0543	−0.0929	−0.1826
A12	−0.2008	−0.1299	−0.0359	−0.2053	−0.0692
A13	−0.1976	−0.2161	−0.0356	−0.2551	−0.1503
A14	−0.0193	−0.1846	−0.2947	−0.2187	−0.1283
A15	−0.0135	−0.0014	−0.0773	−0.0337	−0.0087
A16	−0.0129	−0.0149	−0.1297	−0.0122	−0.0048
A17	−0.1579	−0.0442	−0.1510	−0.1734	−0.1712
A18	−0.1179	−0.2161	−0.1766	−0.1259	−0.1579
A19	−0.1042	−0.2295	−0.1803	−0.1491	−0.1700
A20	−0.2086	−0.0696	−0.1043	−0.0812	−0.0274
A21	−0.2168	−0.1396	−0.1303	−0.0860	−0.0217
$\sum_{j=1}^{n} \text{rij} * \text{In}(\text{rij})$	−2.8595	−2.7905	−2.7060	−2.8431	−2.6924
−In (21)	−3.044522438				
$\sum_{j=1}^{n} \text{rij} * \text{In}(\text{rij}) / - \text{In}\ (21)$	0.9392	0.9166	0.8888	0.9338	0.8843
$1 - \sum_{j=1}^{n} \text{rij} * \text{In}(\text{rij}) / - \text{In}\ (21)$	0.0608	0.0834	0.1112	0.0662	0.1157
wj	0.11	0.16	0.21	0.12	0.22

Table A5. Weighted normalized matrix and ideal/negative ideal solutions.

	C1	C2	C8	C4	C5
	Max	Max	Min	Max	Max
A1	0.0190	0.0416	0.0069	0.0190	0.0908
A2	0.0266	0.0318	0.0514	0.0290	0.0387
A3	0.0416	0.0285	0.0059	0.0292	0.0641
A4	0.0161	0.0539	0.0172	0.0321	0.0322
A5	0.0152	0.0272	0.0281	0.0229	0.0636
A6	0.0249	0.0371	0.0110	0.0352	0.0495
A7	0.0227	0.0001	0.0545	0.0252	0.1125
A8	0.0230	0.0210	0.0774	0.0219	0.0222
A9	0.0195	0.0365	0.0094	0.0056	0.0005
A10	0.0177	0.0319	0.0512	0.0103	0.0192
A11	0.0209	0.0146	0.0597	0.0122	0.0525
A12	0.0361	0.0244	0.1012	0.0397	0.0131
A13	0.0351	0.0540	0.1020	0.0582	0.0389
A14	0.0015	0.0416	0.0046	0.0441	0.0308
A15	0.0010	0.0001	0.0375	0.0032	0.0010
A16	0.0010	0.0015	0.0183	0.0009	0.0005
A17	0.0247	0.0057	0.0146	0.0302	0.0474
A18	0.0161	0.0540	0.0115	0.0187	0.0419
A19	0.0135	0.0599	0.0111	0.0240	0.0469
A20	0.0385	0.0103	0.0249	0.0102	0.0040
A21	0.0411	0.0272	0.0181	0.0110	0.0030
MIN	0.0010	0.0001	0.0046	0.0009	0.0005
MAX	0.0416	0.0599	0.1020	0.0582	0.1125
A+	0.0416	0.0599	0.0046	0.0582	0.1125
A-	0.0010	0.0001	0.1020	0.0009	0.0005

Table A6. Discrimination measures, proximity to the ideal solution and performance ranking of alternatives.

Alternatives	Si+	Si−	Ci	Ci
A1	0.0639	0.1487	0.6995	0.700
A2	0.0988	0.1065	0.5189	0.519
A3	0.0897	0.1307	0.5930	0.593
A4	0.1069	0.1140	0.5160	0.516
A5	0.0951	0.1084	0.5328	0.533
A6	0.0998	0.1187	0.5432	0.543
A7	0.0979	0.1321	0.5742	0.574
A8	0.1366	0.0638	0.3184	0.318
A9	0.1521	0.1014	0.4000	0.400
A10	0.1427	0.0663	0.3172	0.317
A11	0.1084	0.0958	0.4693	0.469
A12	0.1445	0.1036	0.4178	0.418
A13	0.1233	0.1177	0.4884	0.488
A14	0.1028	0.1261	0.5508	0.551
A15	0.1689	0.0647	0.2768	0.277
A16	0.1684	0.0838	0.3323	0.332
A17	0.1026	0.1131	0.5244	0.524
A18	0.1081	0.1171	0.5200	0.520
A19	0.1019	0.1231	0.5471	0.547
A20	0.1508	0.0875	0.3671	0.367
A21	0.1458	0.0978	0.4015	0.402

References

1. Domínguez, J.; Edwards, C.A. Vermicomposting organic wastes: A review. In *Earthworm Ecology*; Edwards, C.A., Ed.; CRC Press: Boca Raton, FL, USA, 2004; pp. 401–424.
2. Poornima, S.; Dadi, M.; Subash, S.; Manikandan, S.; Karthik, V.; Deena, S.; Balachandar, R.; Kumaran, S.; Subbaiya, R. Review on advances in toxic pollutants remediation by solid waste composting and vermicomposting. *Sci. Afr.* **2024**, *23*, e02100. [CrossRef]
3. Arancon, N.Q.; Edwards, C.A.; Lee, S.; Byrne, R. Effects of humic acids from vermicomposts on plant growth. *Eur. J. Soil Biol.* **2006**, *42*, S65–S69. [CrossRef]
4. Hirzel, J.; Donnay, D.; Fernández, C.; Meier, S.; Lagos, O.; Mejias-Barrera, P.; Rodríguez, F. Controlled experiment to determine nitrogen availability for seven organic fertilisers in three contrasting soils. *Biol. Agric. Hortic.* **2019**, *35*, 197–213. [CrossRef]
5. Kong, A.Y.Y.; Rosenzweig, C.; Arky, J. Nitrogen dynamics associated with organic and inorganic inputs to substrate commonly used on rooftop farms. *HortScience* **2015**, *50*, 806–813. [CrossRef]
6. Chiba, A.; Vitow, N.; Baum, C.; Zacher, A.; Kahle, P.; Leinweber, P.; Schloter, M.; Schulz, S. Earthworm activities change phosphorus mobilization and uptake strategies in deep soil layers. *Appl. Soil Ecol.* **2024**, *193*, 105168. [CrossRef]
7. Le Bayon, R.C.; Binet, F. Earthworms change the distribution and availability of phosphorous in organic substrates. *Soil Biol. Biochem.* **2006**, *38*, 235–246. [CrossRef]
8. Chaoui, H.I.; Zibilske, L.M.; Ohno, T. Effects of earthworm casts and compost on soil microbial activity and plant nutrient availability. *Soil Biol. Biochem.* **2003**, *35*, 295–302. [CrossRef]
9. Ragel, P.; Raddatz, N.; Leidi, E.O.; Quintero, F.J.; Pardo, J.M. Regulation of K+ nutrition in plants. *Front. Plant Sci.* **2019**, *10*, 281. [CrossRef]
10. Arancon, N.Q.; Edwards, C.A.; Bierman, P.; Welch, C.; Metzger, J.D. Influences of vermicomposts on field crop production: Effects on growth and yields. *Bioresour. Technol.* **2004**, *93*, 145–153. [CrossRef]
11. Arancon, N.Q.; Edwards, C.A. The use of vermicomposts as soil amendments for production of field crops. In *Vermiculture Technology*; Edwards, C.A., Arancon, N.Q., Sherman, R., Eds.; CRC Press: Boca Raton, FL, USA; Taylor & Francis: Boca Raton, FL, USA, 2011; Chapter 10; pp. 129–151.
12. Arancon, N.Q.; Galvis, P.A.; Edwards, C.A. Suppression of insect pest populations and damage to plants by vermicomposts. *Bioresour. Technol.* **2008**, *99*, 834–844. [CrossRef]
13. Edwards, C.A.; Subler, S.; Arancon, N. Quality criteria for vermicomposts. In *Vermiculture Technology*; Edwards, C.A., Arancon, N.Q., Sherman, R., Eds.; CRC Press: Boca Raton, FL, USA; Taylor & Francis: Boca Raton, FL, USA, 2011; Chapter 18; pp. 287–301.
14. Ceritoğlu, M.; Şahin, S.; Erman, M. Effects of vermicompost on plant growth and soil structure. *Selcuk J. Agric. Food Sci.* **2018**, *32*, 607–615. [CrossRef]
15. Bhat, S.; Singh, J.; Vig, A. Earthworms as organic waste managers and biofertilizer producers. *Waste Biomass Valorization* **2018**, *9*, 1073–1086. [CrossRef]
16. Yang, Z.; Luo, Y.; Chen, H.; Zhang, Y.; Wu, S.; Jia, J.; Zhou, C.; Zhou, Y. Vermicompost addition improved soil aggregate stability, enzyme activity, and soil available nutrients. *J. Soil Sci. Plant Nutr.* **2024**, *24*, 6760–6774. [CrossRef]
17. Hajam, Y.; Kumar, R. Environmental waste management strategies and vermi transformation for sustainable development. *Environ. Chall.* **2023**, *13*, 100747. [CrossRef]
18. Yildiz, N.; Altunok, F.; Uncu, G.E.Y. Effect of vermicompost fertilizer application on soil properties: A review. *Int. J. Innov. Approaches Agric. Res.* **2025**, *9*, 142–151. [CrossRef]
19. Borthakur, M.; Kumari, S.; Khan, T.; Momin, P.G.; Borah, A.; Debbarma, R. Vermicompost: An efficacious alternative for reusing agricultural organic litter. *Vegetos* **2025**, 1–11. [CrossRef]
20. Joshi, R.; Singh, J.; Vig, A.P. Vermicompost as an effective organic fertilizer and biocontrol agent: Effect on growth, yield, and quality of plants. *Rev. Environ. Sci. Bio/Technol.* **2015**, *14*, 89–108. [CrossRef]
21. Biruntha, M.; Karmegam, N.; Archana, J.; Selvi, B.K.; John Paul, J.A.; Balamuralikrishnan, B.; Chang, S.W.; Ravindran, B. Vermiconversion of biowastes with low-to-high C/N ratio into value added vermicompost. *Bioresour. Technol.* **2020**, *297*, 122398. [CrossRef]
22. Sharma, K.; Garg, V.K. Comparative analysis of vermicompost quality produced from rice straw and paper waste employing earthworm *Eisenia fetida* (Sav.). *Bioresour. Technol.* **2018**, *250*, 708–715. [CrossRef]
23. Khalid, H.; Ikhlaq, A.; Pervaiz, U.; Wie, Y.; Lee, E.; Lee, K. Municipal waste degradation by vermicomposting using a combination of *Eisenia fetida* and *Lumbricus rubellus* species. *Agronomy* **2023**, *13*, 1370. [CrossRef]
24. Kashmiri, Z. Management of various types of waste using vermiculture. *Int. J. Curr. Microbiol. Appl. Sci.* **2020**, *9*, 1707–1712. [CrossRef]
25. Huntley, S.; Ansari, A.L.; Ori, L. Vermicomposting of different organic materials using the epigeic earthworm *Eisenia foetida*. *Int. J. Recycl. Org. Waste Agric.* **2018**, *8*, 23–36. [CrossRef]
26. Ducasse, V.; Capowiez, Y.; Peigné, J. Vermicomposting of municipal solid waste as a possible lever for the development of sustainable agriculture: A review. *Agron. Sustain. Dev.* **2022**, *42*, 89. [CrossRef]

https://doi.org/10.3390/horticulturae12050635

27. Shrestha, G.; Gwachha, S.; Shrestha, M. Comparison of vermicomposting quality using different food beds. *J. Environ. Sci.* **2024**, *10*, 1–9. [CrossRef]
28. Maharjan, K.; Noppradit, P.; Techato, K. Suitability of vermicomposting for different varieties of organic waste: A systematic literature review (2012–2021). *Org. Agric.* **2022**, *12*, 581–602. [CrossRef]
29. Ro, S.; Long, V.; Sor, R.; Pheap, S.; Nget, R.; William, J. Alternative feed sources for vermicompost production. *Environ. Nat. Resour. J.* **2022**, *20*, 393–399. [CrossRef]
30. Bai, X.; Lu, W.; Xu, J.; Li, Q.; Xue, Z.; Wang, X. Effects of cattle manure and sludge vermicompost on nutrient dynamics and yield in strawberry cultivation with distinct continuous cropping histories in a greenhouse. *Front. Plant Sci.* **2025**, *15*, 1514675. [CrossRef]
31. Gebrehana, Z.; Gebremikael, M.; Beyene, S.; Sleutel, S.; Wesemael, W.; De Neve, S. Organic residue valorization for Ethiopian agriculture through vermicomposting with native (*Eudrilus eugeniae*) and exotic (*Eisenia fetida* and *Eisenia andrei*) earthworms. *Eur. J. Soil Biol.* **2023**, *116*, 103488. [CrossRef]
32. Torun Kayabaşı, H.; Yılmaz, H. The importance of vermicompost in agricultural production and economy. *J. Agric. Econ. Policy* **2021**, *7*, 123–135.
33. Niento-Cantero, N.; Garcia-Lopez, A.M.; Recena, R.; Quintero, J.M.; Delgado, A. Recycling manure as vermicompost: Assessing phosphorus fertilizer efficiency and effects on soil health under different soil management. *J. Soil Sci. Plant Nutr.* **2025**, *25*, 5046–5061. [CrossRef]
34. Dugassa, M.; Worku, W. Evaluation of selected physical, chemical properties and nutrient quality of vermicompost from different feedstocks. *Environ. Res. Commun.* **2025**, *7*, 045001. [CrossRef]
35. Avramova, T.; Peneva, T.; Ivanov, A. Overview of existing multi-criteria decision-making (MCDM) methods used in industrial environments. *Technologies* **2025**, *13*, 444. [CrossRef]
36. Sitorus, F.; Cilliers, J.; Brito-Parada, P. Multi-criteria decision making for the choice problem in mining and mineral processing: Applications and trends. *Expert Syst. Appl.* **2019**, *121*, 393–417. [CrossRef]
37. Chow, C.S.M.; Manaf, L.A. Making a decision using analytical hierarchy process (AHP) in selecting suitable food waste management method: A conceptual framework. *Proc. World Conf. Waste Manag.* **2022**, *3*, 72–82. [CrossRef]
38. Sohail, S.S.; Javed, Z.; Nadeem, M.; Anwer, F.; Farhat, F.; Hussain, A.; Himeur, Y.; Madsen, D.Ø. Multi-criteria decision making-based waste management: A bibliometric analysis. *Heliyon* **2023**, *9*, e21261. [CrossRef]
39. García-García, G. Using multi-criteria decision-making to optimise solid waste management. *Curr. Opin. Green. Sustain Chem.* **2022**, *37*, 100650. [CrossRef]
40. Torkayesh, A.E.; Rajaeifar, M.A.; Rostom, M.; Malmir, B.; Yazdani, M.; Suh, S.; Heidrich, O. Integrating life cycle assessment and multi criteria decision making for sustainable waste management: Key issues and recommendations for future studies. *Renew. Sustain. Energy Rev.* **2022**, *168*, 112819. [CrossRef]
41. Kaur, T. Vermicomposting: An effective option for recycling organic wastes. In *Organic Agriculture*; IntechOpen: London, UK, 2020. [CrossRef]
42. Agbejule, A.; Panula-Ontto, J.; Rapo, J.; Naumanen, M. Application of multi-criteria decision-making process to select waste-to-energy technology in developing countries: The case of Accra, Ghana. *Sustainability* **2021**, *13*, 12863. [CrossRef]
43. Babalola, M.A. A multi-criteria decision analysis of waste treatment options for food and biodegradable waste management in Japan. *Environments* **2015**, *2*, 471–488. [CrossRef]
44. Çoban, A.; Ertis, I.F.; Çavdaroğlu, N.A. Municipal solid waste management via multi-criteria decision making methods: A case study in Istanbul, Turkey. *J. Clean. Prod.* **2018**, *180*, 159–167. [CrossRef]
45. Shahnazari, A.; Rafiee, M.; Rohani, A.; Bhushan Nagar, B.; Ebrahiminik, M.A.; Aghkhani, M.H. Ranking of organic fertilizer production from solid municipal waste systems using analytic hierarchy process and VIKOR models. *Biocatal. Agric. Biotechnol.* **2021**, *32*, 101946. [CrossRef]
46. Katiyar, R.B.; Sundaramurthy, S.; Sharma, A.K.; Arisutha, S.; Khan, M.A.; Sillanpää, M. Optimization of engineering and process parameters for vermicomposting. *Sustainability* **2023**, *15*, 8090. [CrossRef]
47. Romero-Perdomo, F.; González-Curbelo, M. Integrating multi-criteria techniques in life-cycle tools for the circular bioeconomy transition of agri-food waste biomass: A systematic review. *Sustainability* **2023**, *6*, 5026. [CrossRef]
48. Balasbaneh, A.; Aldrovandi, S.; Sher, W. A systematic review of implementing multi-criteria decision-making (MCDM) approaches for the circular economy and cost assessment. *Sustainability* **2025**, *17*, 5007. [CrossRef]
49. Ikram, S.; Huang, L.; Zhang, H.; Wang, J.; Yin, M. Composition and nutrient value proposition of brewers spent grain. *J. Food Sci.* **2017**, *82*, 2232–2242. [CrossRef]
50. Bianco, A.; Fancello, F.; Garau, M.; Deroma, M.; Atzori, S.A.; Castaldi, P.; Zara, G.; Budroni, M. Microbial and chemical dynamics of brewers' spent grain during a low-input pre-vermicomposting treatment. *Sci. Total Environ.* **2022**, *802*, 149792. [CrossRef]
51. Bianco, A.; Budroni, M.; Zara, S.; Mannazzu, I.; Fancello, F.; Zara, G. The role of microorganisms on biotransformation of brewers' spent grain. *Appl. Microbiol. Biotechnol.* **2020**, *104*, 8661–8678. [CrossRef]

52. Budroni, M.; Mannazzu, I.; Zara, S.; Saba, S.; Pais, A.; Zara, G. Composition and functional profiling of the microbiota in the casts of *Eisenia fetida* during vermicomposting of brewers' spent grain. *Biotechnol. Rep.* **2020**, *25*, e00439. [CrossRef] [PubMed]
53. Assandri, D.; Pampuro, N.; Zara, G.; Cavallo, E.; Budroni, M. Suitability of composting process for the disposal and valorization of brewers' spent grain. *Agriculture* **2021**, *11*, 2. [CrossRef]
54. Assandri, D.; Pampuro, N.; Zara, G.; Bianco, A.; Cavallo, E.; Budroni, M. Cocomposting of brewers' spent grain with animal manures and wheat straw: Influence of two composting strategies on compost quality. *Agronomy* **2021**, *11*, 1349. [CrossRef]
55. Saba, S.; Zara, G.; Bianco, A.; Garau, M.; Bononi, M.; Deroma, M.; Pais, A.; Budroni, M. Comparative analysis of vermicompost quality produced from brewers' spent grain and cow manure by the red earthworm *Eisenia fetida*. *Bioresour. Technol.* **2019**, *293*, 122019. [CrossRef]
56. Ghadimi, M.; Sirousmehr, A.; Ansari, M.H.; Ghanbari, A. Organic soil amendments using vermicomposts under inoculation of N2-fixing bacteria for sustainable rice production. *PeerJ* **2021**, *9*, e10833. [CrossRef]
57. Belliturk, K.; Görres, J.H.; Turan, H.S.; Göçmez, S.; Bağdatlı, M.C.; Eker, M.; Aslan, S. Environmental quality of compost: Can composting earthworms (*Eisenia fetida*) help manage compost nutrient ratios? In Proceedings of the International Conference on Civil and Environmental Engineering (ICOCEE), Cappadocia, Turkey, 20–23 May 2015; pp. 159–162.
58. Bellitürk, K.; Görres, J.H.; Bağdatlı, M.C.; Göçmez, S.; Turan, H.S.; Eker, M.; Aslan, S. The evaluation of olive pruning waste as a vermicompost: Micro elements. *J. Agric. Vis.* **2015**, *1*, 7–12.
59. Bellitürk, K.; Soytürk, Ö. Can vermicompost obtained from *Eisenia foetida* fed by nutshell and cow manure mix be an organic fertilizer? *Fresenius Environ. Bull.* **2020**, *29*, 11273–11284.
60. Günsen, M.; Erkan, B.C.; Bellitürk, K.; Çelik, A. Obtaining vermicomposting from mixture of snack sunflower waste and cow manure for zero waste aim. In Proceedings of the VI International Conference on Global Practice of Multidisciplinary Scientific Studies, Lisbon, Portugal, 9–16 April 2024; pp. 326–358.
61. Göçmez, S.; Bellitürk, K.; Görres, J.H.; Turan, H.S.; Üstündağ, Ö.; Solmaz, Y.; Adiloğlu, A. The effects of the use of vermicompost in olive tree farming on microbiological and biochemical characteristics of the production material. *Erwerbs-Obstbau* **2019**, *61*, 337–344. [CrossRef]
62. Özbucak, T.; Özbucak, S.; Özbucak, İ.; Arısoy, A. The effect of two different vermiculture treatments on lettuce (*Lactuca sativa* L.) plant growth. *Black Sea J. Sci.* **2023**, *13*, 1552–1569.
63. Gadde, B.; Bonnet, S.; Menke, C.; Garivait, S. Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines. *Environ. Pollut.* **2009**, *157*, 1554–1558. [CrossRef]
64. Garai, T.K.; Datta, J.K.; Mondal, N.K. Evaluation of integrated nutrient management on boro rice in alluvial soil and its impacts upon growth, yield attributes, yield and soil nutrient status. *Arch. Agron. Soil Sci.* **2014**, *60*, 1–14. [CrossRef]
65. Aechra, S.; Yadav, B.L.; Doodhwal, K.; Bhinda, R.; Jat, L. Yield and total nutrient uptake influenced by soil salinity, phosphorus sources and biofertilizers in cowpea (*Vigna unguiculata* L.). *J. Exp. Agric. Int.* **2021**, *43*, 56–63. [CrossRef]
66. Özyazici, G.; Turan, N. Effect of vermicompost application on mineral nutrient composition of grains of buckwheat (*Fagopyrum esculentum* M.). *Sustainability* **2021**, *13*, 6004. [CrossRef]
67. Yadav, A.; Garg, V.K. Recycling of organic wastes by employing *Eisenia fetida*. *Bioresour. Technol.* **2011**, *102*, 2874–2880. [CrossRef]
68. Aslam, Z.; Bashir, S.; Hassan, W.; Bellitürk, K.; Ahmad, N.; Niazi, N.K.; Khan, A.; Khan, M.I.; Chen, Z.; Maitah, M. Unveiling the efficiency of vermicompost derived from different biowastes on wheat (*Triticum aestivum* L.) plant growth and soil health. *Agronomy* **2019**, *9*, 791. [CrossRef]
69. Mago, M.; Yadav, A.; Gupta, R.; Garg, V.K. Management of banana crop waste biomass using vermicomposting technology. *Bioresour. Technol.* **2021**, *326*, 124742. [CrossRef]
70. Deepthi, M.P.; Kathireswari, P.; Rini, J.; Saminathan, K.; Karmegam, N. Vermitransformation of monogastric Elephas maximus and ruminant Bos taurus excrements into vermicompost using *Eudrilus eugeniae*. *Bioresour. Technol.* **2021**, *320*, 124302. [CrossRef]
71. Bellitürk, K.; Şahin, M.; Günsen, M.; Korucuoğlu, H. Can vermicompost be produced from grape litter waste? In *TUBITAK 2209—A Research Project Support Programme for Undergraduate Students*; Project No. 1919B012211426; TÜBİTAK: Ankara, Turkey, 2023.
72. Hoque, T.S.; Hasan, A.K.; Hasan, M.A.; Nahar, N.; Dey, D.K.; Mia, S.; Solaiman, Z.M.; Kader, M.A. Nutrient release from vermicompost under anaerobic conditions in two contrasting soils of Bangladesh and its effect on wetland rice crop. *Agriculture* **2022**, *12*, 376. [CrossRef]
73. Sangwan, P.; Kaushik, C.P.; Garg, V.K. Vermiconversion of industrial sludge for recycling the nutrients. *Bioresour. Technol.* **2008**, *99*, 8699–8704. [CrossRef]
74. Umut, H. Comparison of Some Nutrients in Solid Vermicompost Obtained from Native and Red California Worms Fed with Cattle Manure and Domestic Food Waste. Master's Thesis, Recep Tayyip Erdoğan University, Institute of Natural and Applied Sciences, Rize, Turkey, 2019.
75. Khalifa, T.H.; Mariey, S.A.; Ghareeb, Z.E.; Khatab, I.A.; Alyamani, A. Effect of organic amendments and nano-zinc foliar application on alleviation of water stress in some soil properties and water productivity of barley yield. *Agronomy* **2022**, *12*, 585. [CrossRef]

76. Zarea, M.J.; Karimi, N. Vermicomposting of cow dung amended with eggshell powder: Possible roles of eggshell powder on the growth models of Serendipita indica, wheat growth and performances and soil enzymes activity. *Int. J. Recycl. Org. Waste Agric.* **2022**, *11*, 463–480. [CrossRef]
77. Ghoneim, A.M.; Elbassir, O.I.; Modahish, A.S.; Mahjoub, M.O. Compost production from olive tree pruning wastes enriched with phosphate rock. *Compost Sci. Util.* **2016**, *25*, 13–21. [CrossRef]
78. Coşkun, A.N.; Sümer, A. The effect of the increasing doses of vermicompost applications to soil on some nutrient concentrations in olive (*Olea europaea* L.) leaves. *Canakkale Onsekiz Mart Univ. J. Adv. Res. Nat. Appl. Sci.* **2023**, *9*, 990–1004. [CrossRef]
79. Dayan, A. Impact of vermicompost and different plant activators on yield and some quality parameters in pumpkin (*Cucurbita pepo* L.). *Yuz. Yil Univ. J. Agric. Sci.* **2024**, *34*, 539–548. [CrossRef]
80. Singh, V.; Wyatt, J.; Zoungrana, A.; Yuan, Q. Evaluation of vermicompost produced by using post-consumer cotton textile as carbon source. *Recycling* **2022**, *7*, 10. [CrossRef]
81. Serif, E. Investigation of the Usability of Organic Wastes as Vermicompost. Master's Thesis, Tekirdağ Namık Kemal University, Tekirdağ, Turkey, 2025.
82. Patel, D.D.; Patel, T.U.; Patel, S.N.; Patel, H.H.; Patel, S.G.; Patel, H.M.; Malek, F.M. Macro and micro nutrient profiling of vermicompost derived from cotton-based substrate. *Int. J. Res. Agron.* **2026**, *9*, 116–118. [CrossRef]
83. Bayram, C.A.; Büyük, G.; Kaya, A. Effects of farm manure, vermicompost and plant growth regulators on yield and fruit quality in watermelon. *KSU J. Agric. Nat.* **2021**, *24*, 64–69. [CrossRef]
84. Sozubek, B.; Belliturk, K.; Kocabas, A. Impact of paper waste and earthworm on nutrient and heavy metal content of rice straw compost in the absence of manure. *ISPEC J. Agric. Sci.* **2023**, *7*, 451–460. [CrossRef]
85. Ahmad, A.; Aslam, Z.; Hussain, S.; Bibi, A.; Khaliq, A.; Javed, T.; Hussain, S.; Alotaibi, S.S.; Kalaji, H.M.; Telesiński, A.; et al. Rice straw vermicompost enriched with cellulolytic microbes ameliorate the negative effect of drought in wheat through modulating the morpho-physiological attributes. *Front. Environ. Sci.* **2022**, *10*, 902999. [CrossRef]
86. Hwang, C.L.; Yoon, K.M. *Multiple Attribute Decision Making: Methods and Applications*; Springer: New York, NY, USA, 1981. [CrossRef]
87. Roszkowska, E.; Wachowicz, T.; Kacprzak, D. Impact of normalization on entropy-based weights in MCDM. *Entropy* **2024**, *26*, 405. [CrossRef]
88. Shannon, C.E. A mathematical theory of communication. *Bell Syst. Tech. J.* **1948**, *27*, 379–423. [CrossRef]
89. Zhang, H.; Gu, C.; Gu, L.; Zhang, Y. The evaluation of tourism destination competitiveness by TOPSIS and information entropy—A case in the Yangtze River delta of China. *Tour. Manag.* **2011**, *32*, 443–451. [CrossRef]
90. Karami, A.; Johansson, R. Multi-criteria decision making: A review. *J. Inf. Sci. Eng.* **2014**, *30*, 519–534.
91. Ömürbek, N.; Delibaş, D.; Altın, F.G. Entropi temelli MAUT yöntemine göre devlet üniversiteleri kütüphanelerinin değerlendirilmesi. *Selcuk Univ. J. Soc. Tech. Res.* **2017**, *13*, 72–89.
92. Zavadskas, E.K.; Podvezko, V. Integrated determination of objective criteria weights in MCDM. *Int. J. Inf. Technol. Decis. Mak.* **2016**, *15*, 267–283. [CrossRef]
93. Behzadian, M.; Otaghsara, S.K.; Yazdani, M.; Ignatius, J. A state-of-the-art survey of TOPSIS applications. *Expert Syst. Appl.* **2012**, *39*, 13051–13069. [CrossRef]
94. Zavadskas, E.K.; Mardani, A.; Turskis, Z.; Jusoh, A.; Nor, K.M. Development of TOPSIS method to solve complicated decision-making problems: An overview on developments from 2000 to 2015. *Int. J. Inf. Technol. Decis. Mak.* **2016**, *15*, 645–682. [CrossRef]
95. Lazcano, C.; Domínguez, J. The use of vermicompost in sustainable agriculture: Impact on plant growth and soil fertility. *Soil Nutr.* **2011**, *10*, 187.
96. Blouin, M.; Barrere, J.; Meyer, N.; Lartigue, S.; Barot, S.; Mathieu, J. Vermicompost significantly affects plant growth: A meta-analysis. *Agron. Sustain. Dev.* **2019**, *39*, 34. [CrossRef]
97. Oyege, I.; Bhaskar, M.S.B. Effects of vermicompost on soil and plant health and promoting sustainable agriculture. *Soil Syst.* **2023**, *7*, 101. [CrossRef]
98. Gligorić, M.; Gligorić, Z.; Lutovac, S.; Negovanović, M. Novel hybrid MPSI-MARA decision-making model for support system selection in an underground mine. *Systems* **2022**, *10*, 248. [CrossRef]
99. Ayan, B.; Abacıoğlu, S.; Basilio, M.P. A comprehensive review of the novel weighting methods for multi-criteria decision-making. *Information* **2023**, *14*, 285. [CrossRef]
100. Pala, O. Assessment of the social progress of European Union countries by logarithmic decomposition of criteria importance. *Expert Syst. Appl.* **2024**, *238*, 121846. [CrossRef]
101. Podvezko, V.; Zavadskas, E.K.; Podviezko, A. An extension of the new objective weight assessment methods CILOS and IDOCRIW to fuzzy MCDM. *Econ. Comput Econ. Cybern. Stud. Res.* **2020**, *54*, 59–75. [CrossRef]
102. Adalar, İ.; Işık, Ö. CRiterion Importance Based on SUm of Squares (CRISUS): A new objective weighting method. *Econ. Comput. Econ. Cybern. Stud. Res.* **2025**, *59*, 1–17.

103. Assandri, D.; Pampuro, N.; Zara, G.; Budroni, M.; Zara, S.; Cavallo, E.; Zara, G.; Bardi, L.; Coronas, R.; Budroni, M. Enhancing fertilizer effect of bioprocessed brewers' spent grain for sustainable horticulture. *Agronomy* **2023**, *13*, 2654. [CrossRef]
104. Repullo, M.A.; Carbonell, R.; Hidalgo, J.; Rodríguez-Lizana, A.; Ordóñez, R. Using olive pruning residues to cover soil and improve fertility. *Soil Tillage Res.* **2012**, *124*, 36–46. [CrossRef]
105. Namaki, M.H.; Ansari, M.H.; Akhgari, H. Effect of vermicompost and biochar of pruning waste on soil properties and faba bean (*Vicia faba* L.) yield under calcareous soil. *Turk. J. Field Crops* **2025**, *30*, 55–66. [CrossRef]
106. Raza, S.T.; Zhu, B.; Tang, J.; Ali, M.A. Effects of vermicompost preparation and application on ammonia and nitrous oxide emissions: A review. *Environ. Technol. Innov.* **2024**, *35*, 103691. [CrossRef]
107. Temel, F.A.; Kuleyin, A.; Tüfekci, N. Artificial intelligence and machine learning approaches in composting: A review. *Chemosphere* **2023**, *336*, 139208.

https://doi.org/10.3390/horticulturae12050635