Soil Organic Transformations in Urban Agricultural Systems: Application of a Neutrosophic Multicriteria Approach for Comprehensive Evaluation

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Abstract

This study highlights the importance of urban agriculture in ensuring food security and promoting sustainability in urban areas, using a neutrosophic multi-criteria approach to evaluate the impact of biostimulants and organic additives on soil quality, plant growth, and crop yields. The research demonstrates that biofertilizers such as Chromococcus and Azotobacter significantly improve nutrient availability and plant health, resulting in robust and high-quality harvests, while mineral additives like zeolites enhance soil fertility and moisture retention. Three scenarios were analyzed using neutrosophic logic to handle the inherent uncertainty in urban agricultural systems: the first scenario shows exceptional plant growth and yield with high sustainability (valued as "Very Very High" according to neutrosophic logic), the second scenario highlights challenges in vegetative growth and sustainability (valued as "Low"), and the third scenario combines good plant growth with high sustainability and significant contributions to climate change mitigation (valued as "Medium High"). In summary, integrating organic amendments and biofertilizers in urban agriculture, evaluated through neutrosophic methods, is essential for creating resilient and productive agricultural systems, benefiting soil health, biodiversity, resource conservation, and local economies.

Keywords: Biofertilizers; Neutrosophic Multicriteria Method; Aggregation Operators; OWA

1. Introduction

As the urban population grows, securing food supplies is increasingly important· According to the World Bank, more than 50% of the population lives in urban areas and this trend is expected to continue· It is predicted that by the end of the 21st century most people will live in cities [1]. Urban agriculture (UA) is a form of agriculture that originated in cities and aims to ensure access to high-quality food for all citizens· The UA is based on an organic urban management system that takes into account the risks of using chemicals in densely populated areas and emphasizes the use of organic soil amendments throughout the production process [2].

Urban agriculture has been around for a long time, but it was not until the 1970s, with the advent of organic farming, that it became popular around the world as an effective survival strategy [3]. Most studies agree on the benefits of universal adoption, such as access to healthy foods, greater social cohesion, revitalization of local economies, and support for disadvantaged communities.

In the Cuban context, urban agriculture emerged during a "special period" as a response to the economic crisis that followed the collapse of the Soviet Union. This change marks a paradigm shift in agriculture from mechanization to a subsistence approach, in which urban agriculture plays a key role. One of the most popular agricultural methods in Cuba is organic farming. It involves growing vegetables in a mixed substrate in underground stone holes. This approach allows fallow land to be used for agriculture, but the substrate continues to degrade and requires a continuous supply of nutrients to maintain productivity [4].

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To cover this need, the introduction of biofertilizers in urban agriculture, especially Chromococcus, has intensified· azotobacter, which can fix nitrogen in non-legumes and promote root growth and phosphorus solubilization · These biofertilizers have the benefits of promoting growth, improving soil quality, resisting pests and diseases, and increasing yields [5].

In addition to biofertilizers, organic farming also uses mineral additives such as zeolites, which are known to retain moisture and increase soil pH, thereby increasing crop yields. Although research has been conducted on the impact of different types of biofertilizers in urban agriculture, more research is needed to optimize alternative nutrient options and support Da Nang University. Da Nang is a truly efficient and sustainable city [6].

Therefore, the objective of this paper was to evaluate the effects of various biostimulants based on beneficial microorganisms and organic additives on the growth and yield of three crops under organic farming conditions.

2. Materials and Methods

This section describes how a multi-criteria neutrosophic approach can evaluate crop organic changes in urban agricultural systems. This method is based on neutrosophic logic and uses information aggregation operators to express uncertainty and indeterminacy [7].

This method is designed to guide the evaluation process of organic soil improvement indicators for crops in urban agriculture systems. We take a multi-criterion, multi-expert approach, using evaluation metrics to determine the basis for our conclusions. It has a processing stage that performs a mathematical analysis of the solution and finally provides the metric estimate as the output parameter of the method [8, 9, 10].

Activity 1 Framework Definition.

We follows a multi-criteria and interdisciplinary approach. Based on the opinions of the participating experts, the aim is to obtain evaluation indicators to analyze the organic changes of crops in urban agricultural systems. We recommend gathering between 5 and 7 experts to participate in this process.

In this step, we define the following finite sets [11]:

criteria $C = \{c_j, j = 1, \dots, n\}$.

Alternatives $X = \{x_k, k = 1, \dots, q\}$,

Experts E = {e_i, i = 1,…,m} are defined

Activity 2: Gathering and aggregation of the information

The aggregation of information is the main activity of this method [12]. It is a mechanism used for evaluation and decision making in decision support systems. It involves transforming a set of data (nto a single element [13,14].

Definition 1: T-norm operator [15]. The operator: [0,1] * [0,1] → [0,1] is a T-norm operator if it satisfies the following properties:

1. Commutative T(x , y) = T(y, x).
2. Associativity T(x, T(y , z))= T(T(x,y), Z).
3. Monotonicity: If $x \geq$ x' ∩ e ≥ y ' , then T(x, y) > T (x' , y') i.
4. Neutral Element: T(x, 1) = x.

Ordered Weighted Aggregation (OWA) operators allow to aggregate information along with predefined parameters to obtain representative values. Decision makers can add information based on their desired level of optimism or pessimism [16, 17].

Definition 2: OWA operator [18].

A Function: F: $\mathbb{R}^n \rightarrow \mathbb{R}$ is associated with an n-dimensional vector W and its components satisfy he following conditions [19], where it is an n-dimensional OWA operator if:

1. $w_i \in [0, 1]$ for all i.
2. $\sum_{i=1}^{n} w_i = 1$.

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3. $F(a_1, a_2, ,, a_n) = \sum_{j=1}^{n} w_j b_j$ where b_j is the j-th largest value of $\{ai\}$.

Aggregation operators can be expressed using vector notation, as shown in Equation 1.

$$F(a_1, a_2, ,, a_n) = W \cdot B \quad (1)$$

where:

W: is the OWA weight vector.

B is the ordered composite vector whose j-th largest component of B is equal to b_j

The neutrosophic number can be expressed according to Neutrosophic logic, such as [20, 21, 22]:

$$N = \langle T, I, F \rangle : T, I, F \subseteq [0,1]^n ,$$

The neutrosophic values are expressed proportionally in a series of equations from each set

p:

$$V^P = (T^P, I^P, F^P) \quad (2)$$

where:

T represents the dimension of truth.

I represent the dimension of indeterminacy.

F represents the dimension of falsity.

Mathematically, the OWA neutrosophic operator can be defined as a doublet (W,B), as shown in Equation 3.

$$F(a_1, a_2, ,, a_n) = W\ B(T, I, F) \quad (3)$$

where:

W: OWA weight vector.

B: Ordered composite vector. The largest component j of B is b_j and the largest component j of α coincides with the true, false, and unknown space (T, I, F).

The initial values for components can be represented by linguistic terms, as detailed in Table 1. These linguistic terms correspond to specific SVN [23] numbers, which help in quantifying and categorizing the elements within the neutrosophic framework.

Table 1. Linguistic terms

Linguistic term	**SVN number**
Extremely high (EH)	(1,0,0)
Very very high (VVH)	(0.9, 0.1, 0.1)
Very high (VH)	(0.8,0.15,0.20)
High (H)	(0.70, 0.25, 0.30)
Medium High (MH)	(0.60, 0.35, 0.40)
Medium(M)	(0.50, 0.50, 0.50)
Medium Low (ML)	(0.40, 0.65, 0.60)
Low (L)	(0.30, 0.75, 0.70)
Very low (VL)	(0.20, 0.85, 0.80)
Very very low (VVL)	(0.10, 0.90, 0.90)
Extremely low (EL)	(0,1,1)

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For calculating OWA, it is important to multiply by a scalar. Neutrosophic scalar multiplication is defined as follows [24]:

$$\lambda A = (1-(1-t)^{\lambda}, i^{\lambda}, f^{\lambda}), \quad (4)$$

where $\lambda \in \mathbb{R}$, and $\lambda > 0$.

Neutrosophic summation is defined as follows [24]:

$$A \oplus B = (t_1 + t_2 - t_1 t_2,\ i_1 i_2, f_1 f_2) \quad (5)$$

he Orness of a weight vector WW in an Ordered Weighted Averaging (OWA) operator is calculated using the formula[25]:

$$Orness(W) = \sum_1^n \left[W_i * \left(\frac{(n-i)}{(n-1)}\right)\right] \quad (6)$$

Here, W is a vector represented as W = [W1, W2, ..., Wn]. The weight vector $W = [W1, W2, \dots, Wn]$ indicates the weights assigned to each element or criterion being aggregated, where n is the total number of items or criteria. The Orness value is a numerical measure that falls within the range of 0 to 1. A value of 0 indicates a fully "and" (minimum) behavior, while a value of 1 indicates a fully "or" (maximum) behavior. This calculation evaluates the degree to which the OWA operator approximates a "or" or "and" operation, helping to comprehend how the weights impact the combination of multi-criteria data.

Activity 3: Information and result presentation.

Once the information is collected and aggregated and ranked. For the aggregation and ranking of the information and score function is used

Definition 3 [26]: Let A = (T, I, F) be a single-valued neutrosophic number. A score function S is derived from the truth-membership degree, indeterminacy-membership degree, and falsity-membership degree, is defined as follows:

$$S(A) = \frac{1 + T - 2I - F}{2} \quad (7)$$

where $S(A) \in [-1,1]$.

3. Results and discussion

In this section, the case study evaluates the ecological transition of crops in urban agricultural systems. A total of five criteria were identified as part of the information collection process to determine the evaluation indicators. Table 2 shows the final criteria.

Table 2: evaluation Criteria.

Criteria	Definition
C1	**Physical and chemical composition of the soil:** evaluate parameters such as pH, organic matter, electrical conductivity, the content of nutrients such as nitrogen, phosphorus and potassium and the presence of beneficial microorganisms in the soil.
C2	**Vegetative growth:** Observe plant growth height, stem diameter, number and size of leaves, and the appearance of nutritional deficiencies or disease symptoms.
C3	**Yield:** measure of the quantity and quality of the harvested product. Such as: B. Fresh or dry weight, size, color, flavor and nutritional value of the cultivated product.
C4	**Pest and disease resistance:** Observe the prevalence of pests and diseases in plants treated with organic additives compared to untreated plants and the ability of plants to resist or recover from these attacks.

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C5	**Sustainability of agricultural systems:** assessment of the long-term impacts of organic changes on soil health, biodiversity, water and energy conservation, and their contribution to climate change mitigation and greenhouse gas emissions reduction. carbon.

The process of collecting information to determine evaluation indicators in agriculture is a complex and multifaceted task· Identifying appropriate indicators not only requires a deep understanding of soil biology and ecology, but also meticulous consideration of agronomic and environmental factors· In this study, five critical indicators were identified, each with an essential role in the comprehensive evaluation of agricultural systems· Table 2 provides a detailed overview of these criteria, offering a solid basis for the assessment and improvement of agricultural practices·

The first criterion, C1, focuses on the physical and chemical composition of the soil· This indicator is essential because pH, organic matter, electrical conductivity, and the content of nutrients such as nitrogen, phosphorus, and potassium are key determinants of soil health· Furthermore, the presence of beneficial microorganisms plays a crucial role in soil fertility and the prevention of plant diseases· However, evaluating these parameters requires sophisticated analysis methods and careful interpretation of the data, since the interactions between these factors can be highly complex·

C2, vegetative growth, involves observing plant height, stem diameter, and the number and size of leaves· This indicator is visible and relatively easy to measure, making it a practical and useful criterion for farmers· However, it is important to consider that vegetative growth can be affected by numerous factors, including climate, water quality, and agronomic management practices· Therefore, this criterion must be evaluated in conjunction with other indicators to obtain a complete view of the state of the crop·

Yield, represented by C3, measures the quantity and quality of the harvested product, such as fresh or dry weight, size, color, flavor and nutritional value· This indicator is perhaps the most tangible and direct in terms of economic benefits for farmers· However, product quality can be influenced by many external factors and its evaluation may require advanced laboratory techniques· Furthermore, quality is a subjective attribute that can vary depending on market and consumer preferences·

Pest and disease resistance, C4, is crucial for agricultural sustainability· The ability of plants to resist or recover from pest and disease attacks can determine the long-term viability of an agricultural system· Observing the prevalence of pests and diseases in plants treated with organic additives versus untreated plants offers valuable insights into the effectiveness of various agricultural practices· However, this requires continuous and detailed monitoring, which can be laborious and expensive·

Finally, C5 assesses the sustainability of agricultural systems, considering long-term impacts on soil health, biodiversity, water and energy conservation, and their contribution to climate change mitigation· This criterion encompasses a holistic perspective, integrating ecological and social aspects· Sustainability assessment is complex and multidimensional, requiring interdisciplinary collaboration and a systemic approach to fully understand the long-term effects of agricultural practices·

In conclusion, the identification and evaluation of these five indicators provide a robust basis for the improvement and sustainability of agricultural systems· Each indicator contributes an essential piece to the puzzle, and together, they offer a comprehensive view that can guide informed decision-making and the implementation of sustainable agricultural practices· The complexity and dynamism of these criteria reflect the intricate nature of agricultural ecosystems and underline the importance of a multidisciplinary approach in their management and evaluation·

Three scenarios are identified

Alternative 1

Scenario 1 exhibits a soil with a remarkably elevated physical and chemical composition, creating an ideal habitat for plants to thrive due to abundant nutrients and the presence of advantageous microbes. The vegetative growth and output are exceptional, characterized by robust plants and bountiful, top-notch harvests. Plants that are treated with organic additives display a strong ability to resist pests and diseases. Additionally, agricultural systems that incorporate these additives are highly sustainable, resulting in substantial advantages for soil health, biodiversity, and resource conservation in the long run. This, in turn, effectively contributes to mitigating climate change.

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Alternative 2

Scenario 2 exhibits a soil with a moderately high physical and chemical composition. However, the vegetative growth is minimal, as plants display symptoms of lacking essential nutrients and being affected by illnesses. Although the output is satisfactory, it does not attain the desired values. Plants that have been treated with organic additives demonstrate remarkable resilience against pests and diseases. However, the sustainability of agricultural systems is compromised, as there are inadequate long-term effects on soil health and resource preservation, and only a small contribution to mitigating climate change.

Alternative 3

In Scenario 3, the soil exhibits a medium high physical and chemical composition, with metrics that are good but not optimal. The vegetative growth is exceptionally vigorous, with plants exhibiting strong and healthy development. The yield is exceptionally high, resulting in bountiful and superior-quality crops. Plants have strong resilience against pests and diseases, resulting in highly sustainable agricultural systems that offer long-term advantages for soil health, biodiversity, and resource preservation. Additionally, these systems make a considerable contribution to mitigating climate change.

A multi-expert approach was used to determine the weights assigned to the criteria. As part of this process, seven experts were consulted and provided their assessments. The result is a vector of preferences associated with each criterion. Table 3 summarizes the results provided by the experts. The weights vector W= [0.1818,0.2576,0.1212,0.1818,0.2576].

The Orness value of the weight vector W=[0.1818, 0.2576, 0.1212, 0.1818, 0.2576] is approximately 0.481, signifies a moderate inclination towards a "and" behavior in the Ordered Weighted Averaging (OWA) operator. The number is positioned approximately halfway between 0 and 1, indicating a balanced approach that combines both "and" and "or" actions.

Table 3: Weight vectors associated with the indicators.

Criteria	A_1 (T, I, F)	A_2 (T, I, F)	A3 (T, I, F)
C1	(1, 0.10, 0.15)	(0.60, 0.35, 0.40)	(0.60, 0.35, 0.40)
C2	(0,8,0,15,0,20)	(0.30, 0.75, 0.70)	(0,8,0,15,0,20)
C3	(1, 0.15, 0.10)	(0.70, 0.25, 0.30)	(0,8,0,15,0,20)
C4	(0,8,0,15,0,20)	(1, 0.10, 0.15)	(0.60, 0.35, 0.40)
C5	(1, 0.10, 0.15)	(0.30, 0.75, 0.70)	(1, 0.10, 0.15)

The information obtained in Table 3 is aggregated using the OWA operator. The evaluation is carried out through a comprehensive process. Table 4 shows the results of the values.

Table 4: Process Results.

Alternative	OWA	S(A)	Rank
A1	(1,0.0825,0.1340)	0.8505	1
A2	(1,0.2794,0.2892)	0.5760	3
A3	(1,0.2245,0.2358)	0.6576	2

These combined results provide us with a quantitative evaluation of each scenario. The ranking is as follows $A1 \succ A3 \succ A2$

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These aggregated findings offer us a numerical assessment of each situation. The order of ranking is as follows: A1 is strictly preferred to A3, and A3 is strictly preferred to A2. The ranking shows that Alternative A1 is deemed the most favorable, followed by A3, and finally A2, based on the aggregated scores S(A).
The OWA operator efficiently captures the preferences of decision-makers by integrating elements of both optimism and pessimism into the evaluation process. The weighted average of each alternative is determined using the OWA values, which consider both the best and worst possible outcomes within the decision-making framework. This approach guarantees a fair assessment by reducing the influence of extreme values, whether they are excessively optimistic or excessively pessimistic.

Upon examining the weights and subsequent scores, Alternative A1 attains the greatest score as a result of favorable conditions in all analyzed parameters, despite its relatively minor influence in the worst-case scenario component of the OWA vector. In contrast, Alternative A2, despite having greater weights in the pessimistic component (as indicated by its OWA vector), does not demonstrate strong overall performance, resulting in a lower ranking. This exemplifies the usefulness of the OWA operator in presenting a detailed representation of alternative outcomes, assisting stakeholders in making well-informed decisions that encompass a range of possible scenarios. This demonstrates the power of this method to integrate diverse and intricate data [26], resulting in practical insights that aid in making strategic decisions in uncertain circumstances.

4. Conclusion

The study emphasizes the crucial significance of urban agriculture in guaranteeing food security and advancing sustainable practices in highly populated regions. The research illustrates how the application of different biostimulants and organic additions can improve soil quality, promote plant growth, and enhance crop yields. The utilization of biofertilizers such as Chromococcus and Azotobacter has demonstrated encouraging outcomes in enhancing nutrient accessibility and plant well-being, therefore bolstering vigorous and superior harvests. In urban farming situations, the inclusion of mineral additions such zeolites enhance soil fertility and moisture retention, which are crucial for sustaining productivity.

The study effectively evaluates the long-term effects of organic changes in urban agriculture systems by using a multi-criteria neutrosophic approach. The results indicate that the use of organic additives and biofertilizers not only boosts plant resilience against pests and diseases but also improves the overall sustainability of agricultural methods. The assessed scenarios demonstrate that a soil with a substantial physical and chemical composition, along with the strategic application of organic amendments, can result in substantial advantages for soil health, biodiversity, and resource preservation. This comprehensive approach emphasizes the significance of incorporating ecological and agronomic elements to establish robust and efficient urban farming systems, ultimately aiding in the mitigation of climate change and the restoration of local economies. ·

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