Evaluation of the Economic Viability of Circular Models in Agriculture Based on Neutrosophic Cognitive Maps

Ketty Marilú Moscoso-Paucarchuco [1,*], Manuel Michael Beraún-Espíritu [2], Uriel Rigoberto Quispe-Quezada[3], Silvia Marina Alvarez-Bernuy [4], Miguel Angel Quispe Solano [5], Edson Hilmer Julca-Marcelo [5], Arturo Gamarra-Moreno [5], Wilfredo Ramirez-Salas [5]

[1]National Autonomous Highland University of Tarma, Peru.
[2]Continental University, Peru.
[3]National Autonomous University of Huanta, Peru.
[4]Technological University of Peru, Peru.
[5] National University of the Center of Peru, Peru.
Emails: kmoscoso@unaat.edu.pe; mberaun@continental.edu.pe; uquispe@unah.edu.pe; c26802@utp.edu.pe; mquispe@uncp.edu.pe; edsonjm@uncp.edu.pe; ahgamarra@uncp.edu.pe; wramirez@uncp.edu.pe

Abstract

The main purpose of this evaluation is to analyze the economic viability of the implementation of circular models in agriculture in Tarma, Peru. This involves examining the costs and benefits associated with the adoption of circular practices, as well as identifying possible barriers and opportunities for their implementation at the local level. By better understanding the economic landscape, it will be possible to inform decision-making both at the government level and at the level of individual farmers. For the analysis, we have a committee of 30 experts who will evaluate the relationship between variables that positively or negatively affect the implementation of these models in the town. The tool selected for the analysis is Neutrosophic Cognitive Maps, which includes an indeterminacy component within the calculations. This allows greater accuracy in the results since indeterminacy is an inherent part of prediction.

Keywords: Circular Agriculture; Sustainable Agriculture; Neutrosophic Cognitive Map; Neutrosophic Number; Neutrosophic Graph; Hidden Patterns.

1 Introduction

Tarma, which is located in the central region of Peru, is characterized by its climatic diversity and fertile soils, which makes it an area conducive to agriculture. The main crops include potatoes, corn, cereals, fruits and vegetables. However, conventional farming methods have raised concerns about soil degradation, water scarcity, and biodiversity loss, underscoring the need to adopt more sustainable approaches.
To achieve this, a proposal that can give encouraging results is the application of the circular economy in this area. The Circular Economy is a strategy that is becoming increasingly important in today's economy. It is essential to reduce input materials and also virgin waste. When production methods are aligned with this paradigm, sustainability is gained, since energy sources based on fossil fuels are usually replaced by renewable sources. In addition, environmental pollution due to the production of non-biodegradable industrial waste is considerably reduced. This paradigm is of increasing interest on the part of production companies worldwide. In the long run, natural resources are being depleted and environmental pollution is affecting production itself, especially in agriculture.

Circular models in agriculture seek to close the material and energy cycles, minimizing waste and maximizing resource efficiency. This is achieved through practices such as regenerative agriculture, agroecology, nutrient recycling, and the use of renewable energy. These approaches not only have the potential to improve the resilience of agricultural systems but also to generate economic benefits for farmers. Specifically in Tarma, a series of climatological characteristics are experienced that influence local agriculture, for example:

- Altitude: It is located at a considerable altitude, about 3,050 meters above sea level. This altitude influences

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local climatic conditions, as temperatures tend to be cooler than in the coastal or lowland jungle regions of Peru.

- Temperature: Due to its altitude, Tarma has a temperate climate with moderate temperatures throughout the year. However, temperatures can vary significantly between day and night, with warm days and cool nights, which can affect the growth of certain crops.
- Precipitation: Tarma experiences a rainy season from December to March, known as the Andean summer, and a drier season from May to September. During the rainy season, rainfall can be abundant, providing vital water for agriculture. However, water availability can be a challenge during the dry season.
- Climate variability: The region may experience significant climate variability due to phenomena such as *El Niño* and *La Niña*. These weather events can alter rainfall and temperature patterns, which can affect agricultural production and the availability of water for irrigation.
- Solar radiation: It receives a significant amount of solar radiation throughout the year due to its location in the equatorial zone. Solar radiation is crucial for crop growth and can influence agricultural production patterns.
- Winds: The presence of winds can affect local weather conditions in Tarma. Winds may be stronger in certain areas due to the mountainous topography of the region, which may influence the distribution of precipitation and temperature.

This paper aims to study the economic viability of applying a circular agriculture model in the Tarma region using Neutrosophic map analysis. To perform this work, we are based on the experience of a previous one where the analysis of the application of the circular economy is carried out in the context of the Peruvian economy [1]. The tool used in the analysis is Neutrosophic Cognitive Maps. This is a predictive tool to determine the influence over time of a group of variables on others.

Cognitive Maps and their generalization, Fuzzy Cognitive Maps are directed graphs that contain nodes representing concepts and edges representing the relationships between concepts [2-5]. Each edge has a weight associated with it, which is a numerical value that is used to measure the strength and type of relationship between the concepts joined by the edge. When the weight has a negative sign it means that when the presence of one concept increases (decreases), the presence of the other decreases (increases). On the contrary, when the value is positive, the increased (decreased) presence of one concept increases (decreases) the presence of the other.

In the case of the Neutrosophic Cognitive Maps, a value denoted by *I* of indeterminacy is added between the concepts, which generalizes the previous Cognitive Maps tools [6]. This allows greater accuracy in the analysis, since indeterminacy is an intrinsic part of decision-making, especially in prediction. That is why we consider it more valuable for our research to use this tool than its crisp or fuzzy predecessors.

This paper is includes a Materials and Methods section where the main concepts of the Neutrosophic Cognitive Map are explained. Then followed by other sections contain the details and results of this study. The last section is dedicated to conclusions.

2 Materials and Methods

This section contains the basic concepts of Neutrosophic Cognitive Maps and the algorithms associated with them.

Definition 1: ([1]) Let X be a universe of discourse. A *Neutrosophic Set* (NS) is characterized by three membership functions, $u_A(x), r_A(x), v_A(x) : X \rightarrow]^-0, 1^+[$, which satisfies the condition $^-0 \leq \inf u_A(x) + \inf r_A(x) + \inf v_A(x) \leq \sup u_A(x) + \sup r_A(x) + \sup v_A(x) \leq 3^+$ for all x∈X. $u_A(x), r_A(x)$ and $v_A(x)$ are the membership functions of truthfulness, indeterminacy, and falseness of x in A, respectively, and their images are standard or non-standard subsets of $]^-0, 1^+[$.

Definition 2: ([1]) Let X be a universe of discourse. A *Single-Valued Neutrosophic Set* (SVNS) A on X is a set of the form:

$$A = \{\langle x, u_A(x), r_A(x), v_A(x)\rangle : x \in X\} \quad (1)$$

Where $u_A, r_A, v_A : X \rightarrow [0,1]$, satisfy the condition $0 \leq u_A(x) + r_A(x) + v_A(x) \leq 3$ for all x∈X. $u_A(x), r_A(x)$ and $v_A(x)$ denote the membership functions of truthfulness, indeterminacy, and falseness of x in A, respectively. For convenience, a *Single-Valued Neutrosophic Number* (SVNN) will be expressed as $A = (a, b, c)$, where $a, b, c \in [0,1]$ and satisfy $0 \leq a + b + c \leq 3$.

Other important definitions are related to the graphs.

Definition 3: ([1, 7-8]) A *neutrosophic graph* is a graph containing at least one indeterminate edge, which is represented by dotted lines.

Definition 4: ([1, 7-8]) A *neutrosophic directed graph* is a directed graph containing at least one indeterminate edge, which is represented by dotted lines.

Definition 5: ([9-19]) A *Neutrosophic Cognitive Map* (NCM) is a neutrosophic directed graph, whose nodes represent concepts and whose edges represent causal relationships among the edges.

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If $C_1, C_2, \dots, C_k$ are k nodes, each of the C_i $(i = 1, 2, \dots, k)$ can be represented by a vector $(x_1, x_2, \dots, x_k)$ where $x_i \in \{0, 1, I\}$. $x_i = 0$ means that the node C_i is in an activated state, $x_i = 1$ means that the node C_i is in a deactivated state and $x_i = I$ means that the node C_i is in an indeterminate state, at a specific time, or in a specific situation.

If C_m and C_n are two nodes of the NCM, an edge directed from C_m to C_n is called a *connection* and represents the causality from C_m to C_n. Each node in the NCM is associated with a weight within the set $\{-1, 0, 1, I\}$. If α_{mn} denotes the weight of the edge C_mC_n, $\alpha_{mn} \in \{-1, 0, 1, I\}$ then we have the following:

$\alpha_{mn} = 0$ if C_m does not affect C_n,

$\alpha_{mn} = 1$ if an increase (decrease) in C_m produces an increase (decrease) in C_n,

$\alpha_{mn} = -1$ if an increase (decrease) in C_m produces a decrease (increase) in C_n,

$\alpha_{mn} = I$ if the effect of C_m on C_n is indeterminate.

Definition 6: ([1]) An NCM having edges with weights in $\{-1, 0, 1, I\}$ is called *a Simple Neutrosophic Cognitive Map*.

Definition 7: ([1]) If $C_1, C_2, \dots, C_k$ are the nodes of an NCM. The *neutrosophic matrix* N(E) is defined as $N(E) = (\alpha_{mn})$, where α_{mn} denotes the weight of the directed edge C_mC_n, such that $\alpha_{mn} \in \{-1, 0, 1, I\}$. N(E) is called the *neutrosophic adjacency matrix* of the NCM.

Definition 8: ([1]) Let $C_1, C_2, \dots, C_k$ be the nodes of an NCM. Let $A = (a_1, a_2, \dots, a_k)$, where $a_m \in \{-1, 0, 1, I\}$. A is called *an instantaneous state neutrosophic vector* and means a position of the on-off-indeterminate state of the node in a given instant.

$a_m = 0$ if C_m is deactivated (has no effect),

$a_m = 1$ if C_m is activated (has an effect),

$a_m = I$ if C_m is indeterminate (its effect cannot be determined).

Definition 9: ([1]) Let $C_1, C_2, \dots, C_k$ be the nodes of an NCM. Let $\overrightarrow{C_1C_2}$, $\overrightarrow{C_2C_3}$, $\overrightarrow{C_3C_4}$,…, $\overrightarrow{C_mC_n}$ be the edges of the NCM, then the edges constitute a *directed cycle*.
The NCM is called *cyclic* if it has a directed cycle. It is said *acyclic* if it does not have a directed cycle.
Definition 10: ([1]) An NCM containing cycles is said to have *feedback*. When there is feedback in the NCM, it is said that it is a *dynamic system*.
Definition 11: ([1]) Let $\overrightarrow{C_1C_2}$, $\overrightarrow{C_2C_3}$, $\overrightarrow{C_3C_4}$,…, $\overrightarrow{C_{k-1}C_k}$ be a cycle. When C_m is activated and its causality flows through the edges of the cycle and then it is the cause of C_m itself, then the dynamic system circulates. This is fulfilled for each node C_m with $m = 1, 2, \dots, k$. The equilibrium state for this dynamic system is called the *hidden pattern*.
Definition 12: ([1]) If the equilibrium state of a dynamic system is a single state, then it is called a *fixed point*. An example of a fixed point is when a dynamic system starts by being activated by C_l. If it is assumed that the NCM sits on C_l and C_k, i.e. the state remains as $(1, 0, \dots, 0, 1)$, then this vector of neutrosophic state is called a *fixed point*.
Definition 13: ([1]) If the NCM is established with a neutrosophic state-vector that repeats itself in the form:

$A_1 \to A_2 \to \cdots \to A_m \to A_1$, then the equilibrium is called a *limit cycle* of the NCM.

Method for Determining the Hidden Patterns

Let $C_1, C_2, \dots, C_k$ be the nodes of the NCM with feedback. Assume that E is the associated adjacency matrix. A hidden pattern is found when C_l is activated and a vector input $A_1 = (1, 0, 0, \dots, 0)$ is given. The data must pass through the neutrosophic matrix N(E), which is obtained by multiplying A_1 by the matrix N(E).

Let $A_1N(E) = (\alpha_1, \alpha_2, \dots, \alpha_k)$ with the threshold operation of replacing α_m by 1 if $\alpha_m > p$ and α_m by 0 if $\alpha_m < p$ (p is a suitable positive integer) and α_m is replaced by I if this is not an integer. The resulting concept is updated; vector C_1 is included in the updated vector by transforming the first coordinate of the resulting vector into 1.

If $A_1N(E) \to A_2$ is assumed then $A_2N(E)$ is considered and the same procedure is repeated. This procedure is repeated until a limit cycle or fixed point is reached.

Definition 14: ([20]) A *neutrosophic number* N is defined as a number as follows:

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$$N = d + I \quad (2)$$

Where d is called *the determined part* and I is called the *indeterminate part*.

Given $N_1 = a_1 + b_1 I$ and $N_2 = a_2 + b_2 I$ are two neutrosophic numbers, some operations between them are defined as follows[21-24]:

$N_1 + N_2 = a_1 + a_1 + (b_1 + b_2)I$ (Addition);

$N_1 - N_2 = a_1 - a_1 + (b_1 - b_2)I$ (Difference),

$N_1 \times N_2 = a_1 a_2 + (a_1 b_2 + b_1 a_2 + b_1 b_2)I$ (Product),

$\frac{N_1}{N_2} = \frac{a_1 + b_1 I}{a_2 + b_2 I} = \frac{a_1}{a_2} + \frac{a_2 b_1 - a_1 b_2}{a_2(a_2 + b_2)} I$ (Division).

3. Results

First, we specify the variables to take into account for the study, these are the following:
Historical crop yields (V_1): Analyzing historical data on crop yields in the Tarma region can provide valuable information on agricultural productivity and trends over time. This would include data on the production of conventional crops compared to those produced through circular practices.
Water consumption (V_2): Assessing water consumption in agriculture is crucial given the importance of water management in the Tarma region. Circular models often involve water conservation practices, such as drip irrigation or the use of rainwater harvesting systems. Data on water consumption in agriculture can provide insights into water use efficiency and potential savings associated with adopting circular practices.
Use of agricultural inputs (V_3): The use of fertilizers, pesticides, and other agricultural inputs can have a significant impact on production costs. Analyzing data on agricultural input use in the Tarma region can help estimate potential economic savings associated with reducing dependence on these inputs through circular practices, such as organic farming or crop rotation.
Market prices (V_4): Market prices of agricultural products can influence the economic viability of circular models. Analyzing historical and current data on crop prices in the Tarma region can help estimate potential income from the sale of agricultural products produced through circular practices.
Implementation costs (V_5): Assessing the costs associated with the implementation of circular practices in agriculture, such as investing in efficient irrigation technologies or training farmers in agroecological practices, is essential to determine the economic viability of these models. Analyzing data on implementation costs can help estimate the return on investment and payback period for associated costs.
In Tarma, Peru, some of the most important crops include:

- Potatoes: The potato is a fundamental crop in Peruvian agriculture and is probably one of the main crops in Tarma, due to the climatic and soil conditions conducive to its cultivation.
- Corn: Corn is another important crop in the Tarma region. It is grown in various varieties and is used for both human and animal consumption.
- Cereals: Crops such as wheat and barley are also grown in the region, although they may be less common than potatoes and corn.
- Fruits and vegetables: The Tarma region is also known for its production of fruits and vegetables, such as apples, peaches and carrots, among others.

From here we use the algorithm proposed in [1] to carry out the study we propose. This algorithm is the following:

Let be $E = \{e_1, e_2, \cdots, e_n\}$ the set of n experts. R_{ijk} symbolizes the relationship between the jth and kth criteria ($j, k \in \{1,2, \ldots, 5\}, j \neq k$) according to the expert e_i ($i = 1,2, \ldots, n$) such that $R_{ijk} \in \{-5, -4, \cdots, -1, 0, 1, \cdots, 4, 5, I\}$.

1. The numerical values of R_{ijk} are calculated, so $\hat{R}_{ijk} = R_{ijk}$, and if $R_{ijk} = I$ then it is maintained $\hat{R}_{ijk} = I$.
2. For each fixed pair $j, k \in \{1,2, \ldots, 5\}$, it is calculated $\bar{R}_{jk}$ as follows:
   - If the mode of $\hat{R}_{ijk}$ for $i = 1,2, \ldots$, n is unimodal, we take $\bar{R}_{jk} = mode_i(\hat{R}_{ijk})$ and $\bar{R}_{kj} = 0$.
   - If the mode of $\hat{R}_{ijk}$ for $i = 1,2, \ldots, n$ is not unimodal, it is defined as follows:
     - ✧ If $\hat{R}_{ikj}$ for $i = 1,2, \ldots$, n is unimodal, take $\bar{R}_{kj} = mode_i(\hat{R}_{ikj})$ and $\bar{R}_{jk} = 0$.

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✧ If $\hat{R}_{ikj}$ for $i = 1,2, \ldots,$ n is not unimodal, it is taken $\bar{R}_{jk} = \bar{R}_{kj} = I$.

3. In this way, the adjacency matrix is formed with the elements $\bar{R}_{jk}$ obtained from this algorithm.

To obtain the weights and form the NCM, 30 Peruvian specialists in circular agriculture were surveyed. Among them are scientists and academics with at least 10 years of experience. The Adjacency Matrix obtained is summarized in Table 1.

Table 1: The prediction adjacency matrix of the Circular Economy according to the 30 experts surveyed.

Variable	**V_1**	**V_2**	**V_3**	**V_4**	**V_5**
V_1	0	I	0	I	I
V_2	I	0	0	0	0
V_3	0	-1	0	1	1
V_4	I	1	0	0	1
V_5	I	-1	0	0	0

Figure 1 contains the NCM graph according to the adjacency matrix set out in Table 1.

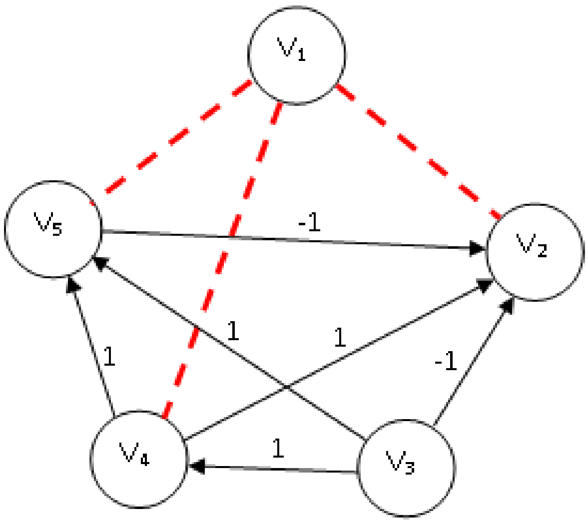

Figure 1: Neutrosophic Cognitive Map obtained from the experts.

All possible cases of convergence were studied when at least one of the variables was activated. This occurs in a total number of cases equal to $2^5 - 1 = 31$. Table 2 summarizes the results in absolute and relative frequencies for each of the three possible states of activated (1), deactivated (0), or indeterminate (I).

Table 2: Absolute frequency of convergence of the system at each of the possible values. The relative frequencies in percent appear in parentheses.

	Convergence to the value		
Variable	**0**	**1**	**I**
V_1	4 (12.9)	16 (51.6)	11 (35.5)
V_2	7 (22.6)	8 (25.8)	16 (51.6)
V_3	27 (87.1)	4 (12.9)	0 (0.0)
V_4	10 (32.3)	5 (16.1)	16 (51.6)
V_5	11 (35.5)	4 (12.9)	16 (51.6)

The results shown in Table 2 confirm the complexity of the work to be done to implement circular agriculture. This problem has different aspects, since on the one hand great ecological benefits are obtained, but on the other

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hand, the new technologies related to this paradigm can be more expensive because they are in an experimental phase. In addition, there is less knowledge about this new paradigm than what is known about the traditional ones.

Table 2 shows that the most robust variable is V_1 or "Historical crop yields" since it is activated in more than half of the possible initial conditions, while it is indeterminate in 35.5% of them. Therefore, it is logical that historical knowledge is the most solid to predict the future behavior of the region's crops.
The most certain variable is V_3 or "Use of agricultural inputs". This variable is fundamental for circular agriculture since it is part of the very concept of this paradigm. However, this will be activated in 19.2% of the possible initial conditions, which means that it is difficult for it to be activated from the other variables and there must be political and economic will for properly developing this variable, independently of the others.

The rest of the variables V_2 or "Water consumption", V_4 or "Market prices" and V_5 or "Implementation costs" show similar behaviors to each other, where there is indeterminacy for most of the possible initial conditions of states. This fact corroborates the complex and experimental nature of the project to be implemented. A more detailed study shows that the most efficient proposal is to activate (or implement) the variables V_3 and V_4 ($x_0 = (0, 0, 1, 1, 0)$) or V_3 and V_5 ($x_0 = (0, 0, 1, 0, 1)$). If the three V_3, V_4, and V_5 are activated ($x_0 = (0, 0, 1, 1, 1)$) the same results are obtained, however, this is not enough to activate the first two variables.
In the other cases of initial conditions, it can be seen that no other variable is activated from the others.

4. Conclusion

The study of the economic feasibility of implementing circular agriculture in the Peruvian town of Tarma is an aspiration of farmers and authorities in the area. Little by little, the use of traditional farming methods has become unsustainable. Agriculture is a fundamental source of food, work and cultural wealth for the inhabitants of this place. A change in the agricultural management model is required, due to the gradual loss of arable land, the increasing scarcity of water and soil erosion. It is clear to everyone that it is necessary to apply a circular model where little non-biodegradable waste is produced and where fewer resources are demanded for crop production. This paper contains the study of the economic viability of circular agriculture in Tarma. To do this, we have 30 experts on the subject who helped evaluate the relationship between five variables according to a Neutrosophic Cognitive Map. This type of Cognitive Map allows indeterminacy to be incorporated as part of the weights associated with the relationship between two concepts. NCMs tend to be more accurate than other Cognitive Maps because it takes into account the relations of indeterminacy that are not foreign to any predictive dynamic process such as the one carried out in this work. Specifically, we base our study on a previous one where the circular economy is studied. Among the conclusions we reached is that the five variables must be developed based on political and economic will because there is little influence of one on the other. So that by developing just one, the others will not be developed necessarily. The historical knowledge that exists about crops must be taken advantage of. The use of sustainable agricultural inputs is a key piece in this process and those inputs that are most appropriate at the lowest possible cost must be sought.

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